Identifying potential areas for *Bambusa balcooa* Roxb. using Ecological Niche Modelling tools

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Abstract: *Bambusa balcooa* Roxb. is an extremely sturdy bamboo species which finds diverse applications. It also has great potential for carbon sequestration, which along with its other usage potential makes it an ideal candidate for large scale cultivation in farm forestry. In this paper we assess potential areas for good growth of the bamboo species using Ecological Niche Modelling (ENM) as a tool. In this study, a distribution map was first prepared using secondary data points of natural bamboo growth from various sources. Subsequently the model was run using Maximum Entropy (Max. Ent) Species Distribution Modelling software to create a map of potential suitable habitats of growth on a spatial scale. The model was next validated by comparing results in select predicted habitats with empirical field work, where, primary growth data like basal culm diameter, culm height and total number of culms in humid, sub humid and semiarid regions of Peninsular and Western India was collected. The modelling results, also supported by primary growth data, indicate that *Bambusa balcooa* Roxb. grows best in humid tropics in comparison to the semiarid regions. These results can help to prioritize potential areas for growth of this bamboo in farm forestry.

Keywords: bamboos, *Bambusa balcooa* Roxb., ecological niche model, farm forestry, potential growth areas

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Introduction

Bambusa balcooa Roxb., belongs to subfamily Bambusoideae, tribe Bambuseae and is an important multipurpose species in India and surrounding regions. The culms of *B. balcooa* are 12-23 m tall with 18-25cm circumference. This species is originated from north-eastern part of India from whereon it spread to other locations due to its multiple uses (Rao *et al*., 1998 and Banik, 2000) and also found in certain parts of Bihar, Jharkhand, Uttarakhand and West Bengal (Stapleton, 1994; Ohrberger, 1999). Today, it has spread to almost all parts of India with the exception of Jammu of Kashmir, Himachal Pradesh and Haryana for its use in construction purposes and for energy generation. It is also used as raw material for paper making by the paper and pulp industry, making agarbathi sticks (Tewari, 1992; Ohrnberger, 1999; Sarangthem and Singh, 2003). The young shoots of *B. balcooa* are in addition edible in nature (Viswanath and Chadramouli, 2015; Rao and Rao, 1986).

B. balcooa has multiple uses and it is because of this multifaceted nature of the bamboo, that this species of bamboo has been identified by the National Mission on Bamboo (NBM) India as one of the species for large scale cultivation. *B. balcooa* typically occurs at altitudes of upto 600m, with a preference towards soil having good drainage and heavy texture. It is an extremely sturdy bamboo and is a preferred bamboo species for scaffolding. *B. balcooa* grows to a height of 15-25 m in North East, while it is limited to approximately 15 feet in the semi arid conditions. In addition new shoot emergence is merely 3-4 numbers annually in semi arid conditions as opposed to 6-7 new shoots in tropical humid regions (Chandramouli and Viswanath, 2015).

In this study, we have tried to understand the natural distribution of *Bambusa balcooa* Roxb. which is one of the bamboo species that has recently gained attention as a high calorific value species with low ash content ideal for electricity generation through gasification process (Kumar and Chandrasekher, 2014). Bamboos, in general, because of its fast growing nature, is considered an ideal species for afforestation (Zhou *et al*., 2005). In addition, Nair *et al*., (2010), have recognised afforestation as one of the best approaches to different environmental problems, with specific mention of afforestation in non-forest areas. Traditionally, the common practice to identify prospective areas of cultivating a particular species has been to conduct multilocational trials. With technological advances along with availability of extensive data, modern tools like Ecological Niche Modelling (ENM) is taking a forefront to identify potential areas of cultivation (Raxworthy *et al*., 2003; Phillips *et al*., 2006). There are many ENM tools available, in this paper, we however try to create a map of potential suitable areas of growth for the species with the use of Maximum Entropy (MaxEnt) Species Distribution Modelling software.

Ecological sciences broadly subscribe to the theory that there are "strong patterns (that) exist with respect to body size, geographical distributions, abundances, species diversity and community structure at coarse spatio-temporal scales" (Brown, 1995). These patterns thus put forth the theory that there may be certain laws that need to be studied in greater detail which has the potential to form the foundation for a prediction based ecological science (O'Connor, 2000). Ecological Niche Modelling is one of the more recent progressive step in that direction.

Ecological Niche Modelling (ENM) basically identifies the ecological niche of a particular species (Sillero, 2011; Warren, 2012). ENMs work by providing simple mathematical representations that are limited by local environment that are endemic to it and then expanding it to finding similar such environments where the particular species can live and flourish (Guisan and Zimmermann, 2000). Early approaches to modelling species distribution using GIS as a tool involved simple use of geographical mapping in combination with environmental matching. This has today emerged as a useful tool to understand species distribution, and make effective conservation plans for the species under threat.

Methodology

A three step methodology was adopted for the study wherein first its natural distribution was identified, followed by modelling potential areas to grow the species and finally validation of model.

Secondary data collection and Preparation of Distribution Map: Secondary data was collected from different sources, including published journal articles, archives, and forest records. In addition, Global Biodiversity Information Facility (GBIF) was also scanned for records of occurrences of *Bambusa balcooa* Roxb. (GBIF, 2020). The complete data (53 locations) was collated into a tabular form along with information on location of occurrences in latitude and longitude. These were used to create a distribution map of the bamboo species using ArcGIS 10.1.

Modelling potential suitable areas using Max.Ent Software: Nineteen bioclimatic parameters known as bioclim variables were used along with data on altitude to model potential areas. These nineteen parameters are listed in Table 1. Pearsons correlation coefficient was calculated for the bioclimatic parameters, and highly correlated bioclimatic parameters (>0.8) were discarded. The final list of bioclimatic parameters selected for the modelling have been represented in bold in Table 1. Maxent software 3.4.1 was used to conduct ENM output map of prospective favourable locations to grow *B. balcooa*. The software works on the principle of Maximum Entropy (MaxEnt), which basically assumes that the bioclimatic parameters of regions where the species is endemically found is favourable for its growth. Based on the information of secondary climatic data and distribution data, an output map classifying high, medium and low potential suitable areas of growth was generated.

Model authentication: The generated model needs to be authenticated and was the third and last stage of methodology adopted. Empirical field visits were conducted across different zones in western and peninsular India to collect biometric data like basal diameter and height along with number of culms in each clump. This data was then compared to the habitat suitability index (HSI) generated from the model output.

Study Area

To validate the model, empirical field study was conducted across Peninsular India and in particular at three states in India –Maharashtra, Karnataka and Tamil Nadu in different agroclimatic zones viz. Semiarid, sub humid and tropical humid. The semiarid region has been classified as the stretch of land in the Indian subcontinent located south of Tropic of Cancer and having at least one long dry spell annually and mean annual rainfall ranging less than 750mm. This also makes the region extremely prone to droughts. Tropical humid region includes the Western Ghats and the western coastal plains where the rainfall is seasonal but heavy (>1250mm/year). Subhumid is the transition zone geographically from humid to the dry regions (Peel *et al*., 2007 and Nair, 1993). The intention to select these regions was to encompass contrasting agroclimatic zones and compare niche model results across different climatic zones.

Table 1. List of Bioclimatic parameters from GBIF

BIO1	Annual mean Temperature
BIO2	**Mean Diurnal Range (Mean of monthly (max temp - min temp))**
BIO3	**Isothermality (BIO2/BIO7) (* 100)**
BIO4	**Temperature Seasonality (standard deviation *100)**
BIO5	**Max Temperature of Warmest Month**
BIO6	**Min Temperature of Coldest Month**
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	**Mean Temperature of Wettest Quarter**
BIO9	**Mean Temperature of Driest Quarter**
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	**Annual Precipitation**
BIO13	Precipitation of Wettest Month
BIO14	**Precipitation of Driest Month**
BIO15	**Precipitation Seasonality (Coefficient of Variation)**
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	**Precipitation of Warmest Quarter**
BIO19	**Precipitation of Coldest Quarter**

Table 2. Details of sampling locations for *B. balcooa* in different agroclimatic zones (ACZ)

Sl. No	Village Name	Taluk	District & State	Latitude	Longitude	Minimum Temp	Maximum Temp	Elevation	RF
1.	Kanur	Chandgad	Kolhapur, Maharashtra	16.0001	74.1211	41.5	12.3	564	2742
2.	Khamdale	Chandgad		15.4644	75.3301	41.5	12.3	580	2742
4.	Kaneri	Armori	Gaddchiroli, Maharashtra	20.1307	79.9445	45.6	10.5	207	1326.1
5.	Hingna	Savner	Nagpur, Maharashtra	21.1148	78.9785	45.1	10.2	324	1095.8
7.	Nuggi	Koppa	Chikmagalur, Karnataka	13.4868	75.3919	32	12	950	2729
9.	Gottipura	Hosakote	Bangalore Rural, Karnataka	12.9724	77.5806	34.2	14.8	890	690
15.	Tumbipadi	Omlur	Salem, Tamil Nadu	11.0491	78.3443	39.1	19.7	147	860.2
16.	Sembedu	Vellore	Vellore, Tamil Nadu	12.9165	79.1325	40.2	14.6	136	814.8

* Rainfall data collected from census, India and Temperature data from Indian Meteorological Department.

Fig 1. Distribution map of *Bambusa balcooa* Roxb.

Results and discussion

Species Distribution: The species distribution map was prepared using secondary data from different sources mentioned in the methodology. This bamboo species is originated from north-eastern part of India from where it spread to other locations by virtue of its multifarious uses (Rao *et al*., 1998 and Banik, 2000) and the distribution map also reinforces this aspect. In addition to north-eastern India, occurrences were also observed in Bangladesh and Nepal. Some parts of Eastern India like Bengal also showed the presence of the species. Fig 1 depicts the world map with natural distribution occurrences of *B. balcooa*. It also highlights the Indian subcontinent wherein maximum occurrences of *B. balcooa* was observed.

Ecological Niche Modelling: The distribution map along with the bioclimatic parameters was used to create the ENM prediction map (Fig 2). When compared to the natural distribution of the species, it was found to show high potential in the regions where it is naturally found. The coastal areas were found more favourable to the species as compared to inner land areas. Select central location in the Indian subcontinent (fig 3A), South America and Africa (fig 3B) also showed potential to grow the bamboo species. In South America, primarily location in Brazil were found to show favourable climatic conditions to growth of the species. In Africa, the south west and south east coastal regions were found to be favourable. Interestingly Madagascar too was found favourable for growth of the bamboo species. Overall, the southern hemisphere was found slightly more favourable to the species as compared to the northern hemisphere. In India and the Indian subcontinent, it was observed that the species is more favourable towards the North-Eastern region and the Western Ghats. Nepal, Bangladesh and some provinces of China also showed considerable growth potential for the bamboo species. Additionally, a large part of central India also showed potential for growing *B. balcooa.*

In addition to model building, a separate set of occurrence points were used to evaluate the model

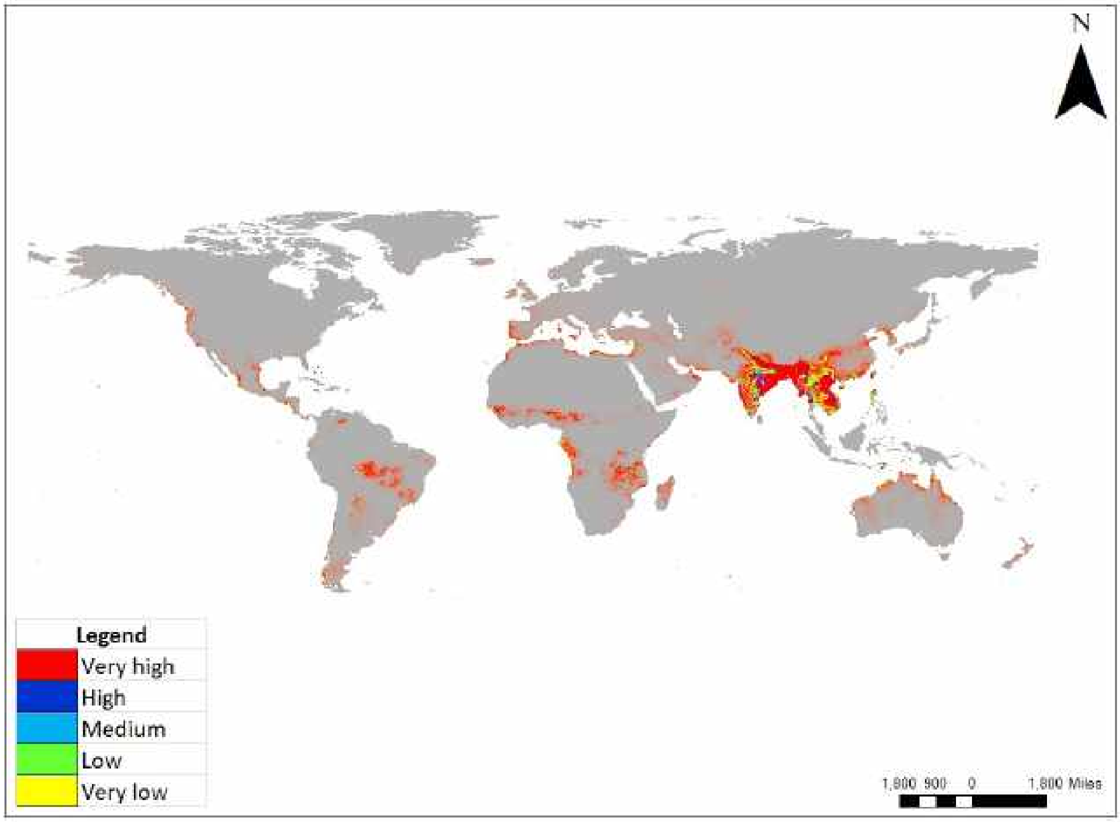

Fig 2. World map depicting habitat suitability prediction for *B. balcooa*

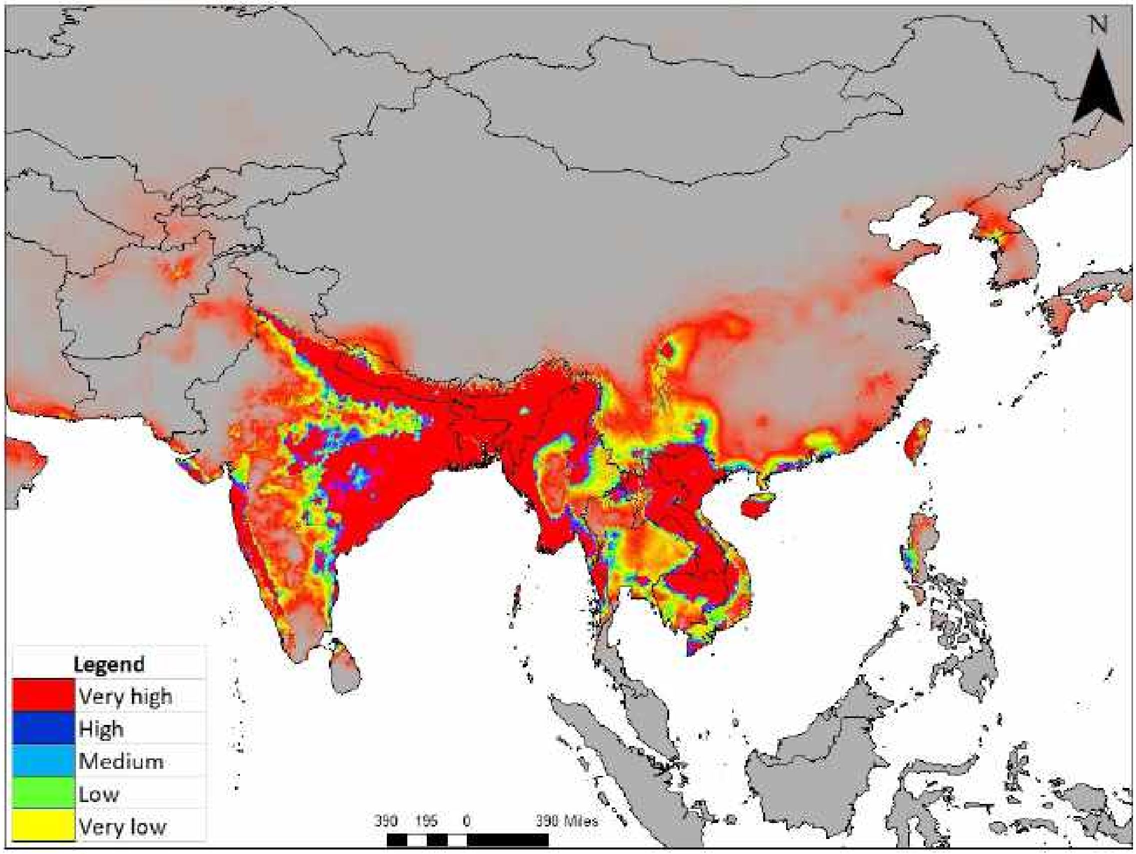

Fig 3A. Ecological Niche Model predictions for India and surrounding regions

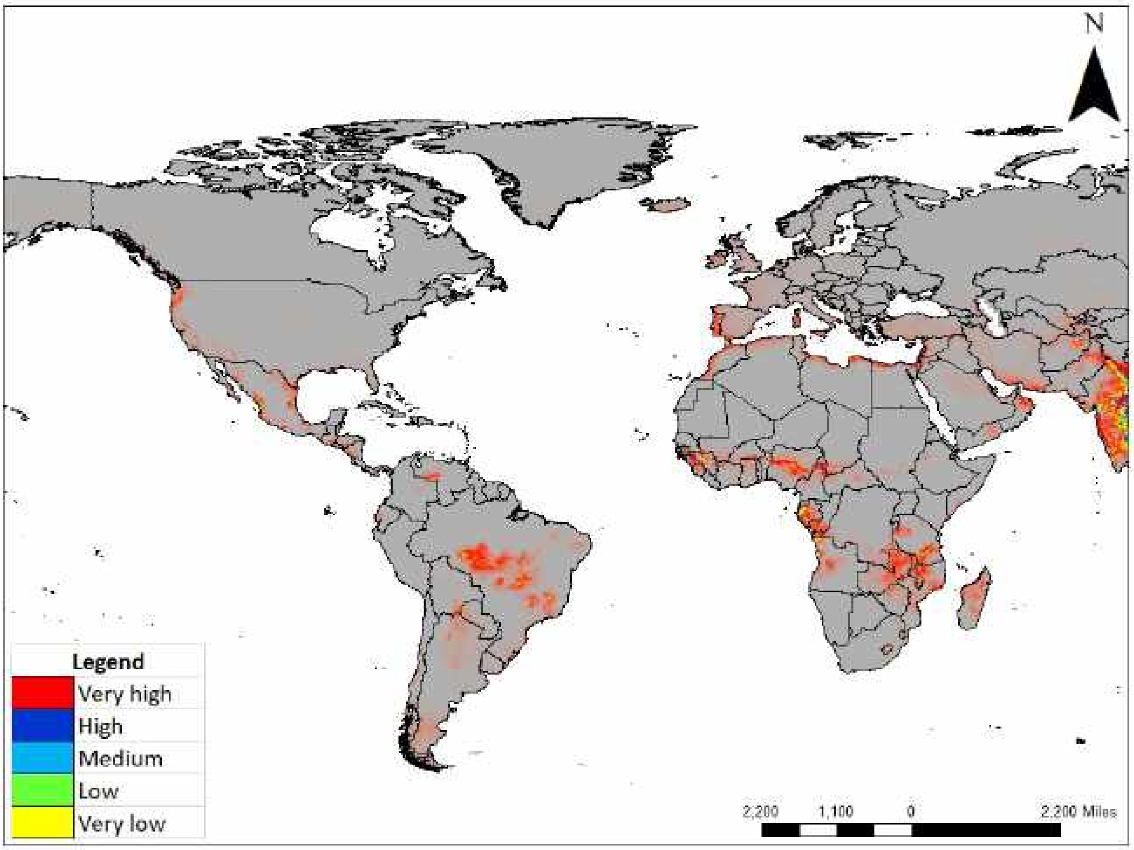

Fig 3B. Ecological Niche Model predictions for Continents of South America and Africa performance. This was done on the basis of Area Under Curve (AUC)-Receiver Operating Characteristic (ROC) curve, which gives equal weight to commission and omission error (Peterson *et al*., 2008). This does not have great significance in scenarios such as ours wherein we use 'presence-only data'. Hence, ROC curve for the same data, again averaged over the replicate runs. The average test AUC for the replicate runs was 0.992 with a standard deviation of 0.004.

Model Validation: The model output was validated by simple correlation and regression models of habitat suitability index along with certain biometric and other parameters. Earlier studies have used population genetic variability and fecundity in plants for model evaluation (Saccheri *et al.* 1998, Slate *et al.,* 2000, Wisely *et al*., 2002). A few others have also used plant functional traits such as specific leaf area and weight for model evaluation (Kozlov *et al*., 1996, Nagamitsu *et al*., 2004, Nagaraju *et al*., 2013, Valkama and Kozlov 2001, Wilsey *et al*., 1998). The factors used for model evaluation or fitness assessment of the model vary based on the species being modelled and parameters evaluated. In this study, we have collected data on the basal diameter of culm, height of culm and number of culms per clump for fitness assessment of the ENM Map. (fig 4, 5 and 6). Jagadish *et al*., (2015) conducted a similar modelling study on *Guadua angustifolia* wherein they used the parameters used in the study for fitness assessment. In addition they also used percent survival of the species since multi-location trials (MLTs) were also part of that study. In the present study, only primary data has been collected from already existing plantations, and since MLTs were not available percent survival could be assessed. The results reveal that there is a positive correlation between these parameters and Habitat Suitability Index (HSI). Field data collected from Salem and Ranipet in Tamil Nadu Karnataka show below average growth performance of *B.balcooa.* The results of ENM model also predict that these regions are not suitable for growth. Similarly, regions like Koppa in Karnataka and Chandgad in Maharashtra located in the Western Ghats show extremely good growth. The results of ENM modelling indicate that probably the Western Ghats landscape may be a suitable habitat for favourable growth of *B. balcooa* Roxb. The primary data collected in the study shows a significant relation to the ENM modelled map. The significance was observed greater for height and total number of culms in a

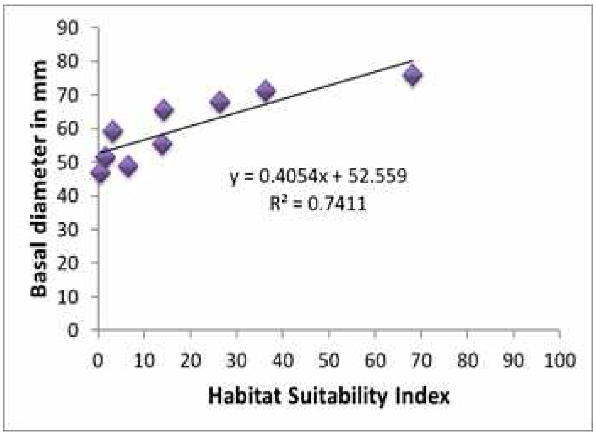

Fig 4. Graph depicting basal diameter in relation to Habitat Suitability Index

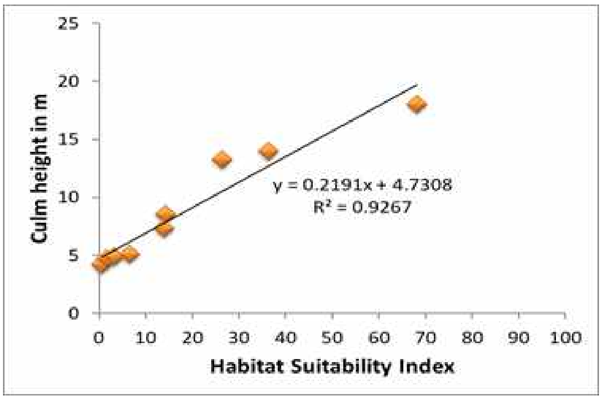

Fig 5. Graph depicting culm height in relation to Habitat Suitability Index

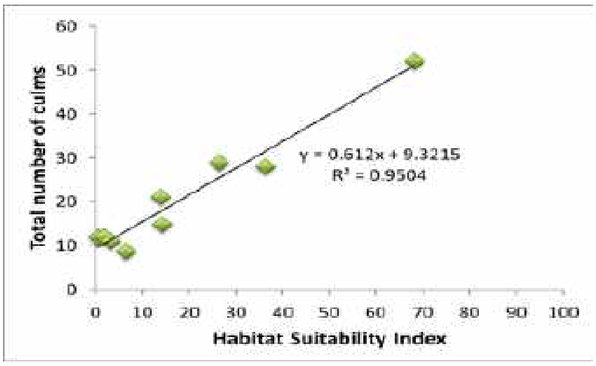

Fig 6. Graph depicting total number of culms in relation to Habitat Suitability Index

clump at R^2 values of 0.9267 and 0.9504 respectively as can be seen in fig 5 and fig 6 respectively. For basal culm diameter, the niche model results were significant with R^2 value of 0.7411 as depicted in fig 4.

Conclusion

Bambusa balcooa is an extremely sturdy bamboo species which finds its use in diverse applications, and has hence has gained prominence. Distribution map based on occurrence data suggested that this bamboo species is naturally distributed in north-east India, Bangladesh and Nepal. The convergence of field based ecological studies, secondary database and advances in GIS and spatial data technologies in the current study has resulted in producing a world map depicting potential areas of growth of *Bambusa balcooa.* Overall, the southern hemisphere was found more favourable to the species as compared to the northern hemisphere. MaxEnt Model was used to map out prospective areas of *Bambusa balcooa* cultivation in India. It was observed that the species had a more favourable inclination towards the north-eastern region and the Western Ghats in India. Nepal, Bangladesh and some provinces of China also showed growth potential for this bamboo species. The primary data collected in the study shows a significant relation to the ENM modelled map. It was observed that humid regions were more favourable for growth of *Bambusa balcooa* as compared to the semi-arid regions. This has major implication for cultivation of this species in India especially its integration in existing agroforestry practices.

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