Ecological niche modelling for prioritizing areas for domestication of introduced bamboo species in India

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Abstract

Identifying potential areas for domestication of a species or reintroduction in the wild is an important step in conservation and utilization. The traditional method of conducting multi-locational species trials and evaluating growth performance to match species with site is rather time consuming and not very cost effective. An innovative approach to overcome this issue is through ecological niche modeling (ENM) which is considered to be a robust tool for predicting suitable sites for domestication. In the present study, potential geographic distributions of industrially important bamboo *Guadua angustifolia* Kunth.were projected onto a spatial scale to predict suitable habitats in India. Also the species fitness was evaluated in the predicted habitats based on the primary growth data in distinct locations in humid tropics, sub humid and semi-arid regions of southern India and compared with the secondary growth data in the native range of Columbia, South America. The growth parameters such as survival percent, clump height, culm numbers and culm diameter had positive correlation with the predicted habitat. The results indicate that the growth performance was significantly higher in humid tropics compared to semiarid locations. Also the secondary growth data in native range was on par with the growth performance in humid tropics, which was predicted to be highly suitable habitat. Based on the niche modeling predictions and the comparison of growth data in the present study, it may be surmised that the fitness with respect to the growth performance was higher in habitats predicted to be highly suitable compared to habitats that were less suitable. These results have significant relevance in prioritizing potential areas for large scale domestication or afforestation programmes.

Keywords: *Guaduaangustifolia*, ecological niche modeling, fitness, growth performance, multi-locational species trial, domestication

Introduction

Afforestation in non forest areas is one of the grassroots resilient approach to mitigate global level environmental issues arising due to increased population growth (Nair et al. 2010). The major focus of contemporary plantation programmes is to meet the immediate needs of wood based industries as well as to alleviate livelihood problems especially for agrarian communities. Bamboo is known to be one of the promising fastest growing flora and its biology makes it a perfect solution for the environmental and social consequences of tropical deforestation (Zhou et al.2005), hence it is commonly referred to as'green gold' or 'poor man's timber' due to its multifarious benefits (Tewari 1992). International trade of bamboo at global scale and the total demand of various bamboo consuming sectors in India is skewed on the demand side and supply is less than half of its total requirement due to depletion of these versatile resources(Planning Commission 2003; Singh et al.2009). The demand for bamboo for industrial use is met from state owned forests, for non-industrial purposes private and to a lesser extent state owned resources come into play (Singh et al. 2009). Considering the versatility of bamboo uses and its potential in upliftment of rural economy, Government of India has launched initiatives like NMBA (National Mission on Bamboo Application) and NBM (National Bamboo Mission) to popularize the bamboo as the best substitute of wood. The mission has taken major initiatives for development, promotion and commercialization of technologies for bamboo based products and application in different areas and to improve the Indian representation in global market. One of the critical areas for focus and action is the standardization of cultivation and management practices of certain promising bamboo species in degraded lands and abandoned farmlands. This involves selection of site-specific bamboo species primarily for domestication at a larger scale.

The common practice of selecting a suitable species for any targeted areas is through conducting a multilocational species trial at distinct geographic locations and evaluating their performance to identify site-specific species. These conventional methods have several practical constraints i.e., laborand time consuming and involving considerable financial investments. With the advent of modern cultivation practices, the traditional methods (species trials) have vanished, and the recent focus is to employ modeling tools to resolve these drawbacks. In this scenario, Ecological Niche Modeling (ENM) is considered to be a robust innovative tool for providing information on potential species niche, where a species can survive and perform better by combining geographic locations of a given species with spatial environmental data to identify suitable parameters of the given species and then map this information to predict the species geographic distribution (Peterson 2003; Peterson and Robins 2003; Phillips et al. 2006; Nagarajuet al. 2013). It is a recognized fact that in the process of evolution species would undergo selection pressure to acclimatize to a set of ecological niches. Thus, the species fitness would be maximized at its ideal ecological niche than outside of it. This is the underlying assumption of ecological niche of a given species (Holt and Gaines 1992; Zizhen and Hong 1997; Maguire 1973). Hence the potential ecological niche of a given species should be a clear indicator of its fitness. There are many ecological niche modeling tools (e.g. BIOCLIM-Busby 1991; GARP-Stockwell and Noble 1992; Maxent-Phillips et al. 2006) that have been developed in recent years to identify specific habitat where a species can thrive best. This ENM provides a prediction map at spatial scale from poor to highly suitable habitat by combining known geographic positions of a given species corresponding to its environmental data (Peterson 2003; Peterson and Robins 2003; Hirzel and Le Lay 2008; Pearmanet al. 2008).

In the recent times ENM has been extensively used for various purposes in the forestry sector such as in assessing species richness (Jetz and Rahbeck 2002), centres of endemism (Johnsonet al. 1998), occurrence of particular species assemblages (Neave 1996), occurrence of individual species (Gibson et al. 2004), location of unknown populations (Raxworthyet al. 2003), location of suitable breeding habitat (Osborneet al. 2001), breeding success (Paradiset al. 2000), abundance (Jarvis and Robertson 1997),genetic variability of species (Scribner et al. 2001), predicting the spread of invasive species (Peterson 2003), predicting the spread of crop pests (Ganeshaiah 2003) and in estimating the response of species to global climate change (Barve 2012). However, there are hardly any studies that have tested the robustness of the predictions with respect to the species fitness in that habitat.
The fundamental hypothesis of this paper is that the habitat suitability of a species as predicted by the ecological niche model may imitate the adaptive landscape of the species. Consequently, the fitness with respect to species growth performance would be higherin habitats predicted to be highly suitable compared to habitats that are less suitable. The principal focus of this paper is to test the present hypothesis using ENM prediction map for one of the promising exotic bamboo species *Guadua angustifolia* (referred to as Guadua). The study also aims to validate the predictions with respect to the species field performance across the gradient of habitat suitability in India using primary growth performance data and also in native range using secondary growth data and in the conclusion section to identify excellent niche or habitat for Guaduadomestication by using ENM predictions.

Materials and Methods

Study system

Belonging to the sub-family Bambusoideae of sub-tribeGuaduainae genus, *Guadua* consists of 29 species (Grosser and Liese 1773). *Guadua angustifolia*is one of the most important species of South America and endemic to Latin America, where it is well stretching for miles together. It occurs in moist and hot valleys and at moderate altitude (Bennet and Gaur 1990). It also grows on rich to medium soils, especially along rivers and on hilly ground, and has ability to tolerate the temperature of -2°C. It is large spectacular, sympodial bamboo and its culms attain about 30m in height and 20cm in diameter. The species has high economic and conservation potential, has been studied intensively over the past years in Colombia. It is considered as an alternative product for the farmers in the central region of Colombia, dominated traditionally by coffee-production. Guadua “forests” are found along rivers and creeks and also in patches away from waters. Most of the Guadua stands in Colombia grow naturally. However, commercial cultivation has been increasing over the past few decades (Morales and Kleinn 2004). It is also being cultivated in Philippines and other tropical countries in south Asia.

The species can be used for multifarious benefits especially for rural livelihood. It is one of the large, strong, superior quality t valuable multipurpose bamboos used for scaffolding, building material for low cost housing or even for big buildings. This is the most popular bamboo in Central American countries. Several houses and large buildings built of this bamboo have withstood the earthquakes of varying intensity. It is also used as a source of pulp for industry, furniture making and also have supported local farming community wherever, it is grown. It is outstanding in stature, mechanical properties and durability. Its diameter is consistent for the first 15 meters and then at the top it becomes elegantly tapered. Hence it has attracted the attention of civil engineers, architects, academics, designers and artists. Environmentally it has several advantages; it is effective at removing carbon dioxide from the atmosphere than most of the other tropical forests. The species is found to be valuable on sloping lands and for soil conservation. It is one of the fast growing bamboo and its young shoots are edible (McClure 1966). It is considered outstanding in stature, with superior mechanical properties and durability of culms, hence plays an important role in rural economics and house or building construction.

Despite its excellent mechanical properties and versatility, present research efforts on this species are limited to studies on culm preservation and determining the physical properties. However, further research is needed on domestication and sustainable management and there are still pitfalls and bottlenecks to address especially regarding social and environmental issues (Cleuren and Henkemans 2003; Raoet al. 1998). Both INBAR (at global level) and NMBA (at national level) have identified a few industrially important bamboo species, out of which, *Guadua angustifolia* is also considered as a key species, which is having enormous potential for alleviating many environmental and social problems facing the world today.

Ecological niche modeling

In the present modeling approach, species occurrence data was collected from secondary source such as published literature, herbarium records etc. also mainly from Global Biodiversity Information Facility (GBIF) http://www.gbif.org/.(Elith 2006).These secondary occurrence data was used to develop species distribution map using a software called DIVA-GIS (version 7.1.7.2; http://www.divagis. org). The algorithms used to predict the potential occurrence and generating the suitability surfaces was Maxent, (Maximum entropy) - this tool uses species occurrence points and using Maxent software (version 3.3.2).

We used 19 bioclimatic variables generated (Table 1) which were downloaded from http://www.worldclim.org/ with 30 seconds (~1km) spatial resolution(Hijmanset al. 2005). These variables represent combinations of temperature and precipitation, which are fundamental to species survival. The native occurrence points of144were divided into 2 sets of 50% each, one set for calibration of model and the other set for evaluation of model performance. The buffer of 100 km was applied to India map to generate the calibration area for the model. Barve et al. (2011), discusses the effect of calibration area in training the model. While training, the default setting was used for the Maxent software model and also Least Training Presence Threshold method was applied for converting the prediction into habitat suitable indices (Pearson et al. 2006). In this method, the probability of presence was assigned to each occurrence point and considered lowest suitability score as the least score where species could be present. The calibrated model was used to evaluate the model performance using the set of occurrence points that was not used in building the model. As the classic area under curve (AUC)-Receiver operating curve (ROC) gives equal weight to commission and omission error (Peterson et al. 2008), it is not greatly applicable to the modeling algorithm where presence only data is used for training the model. Partial ROC method was used for testing performance of the model against null expectation of random model. The model calibration was better than random with p-value < 0.05.

Study area

Based on the model predictions, seven contrastinglocations were randomly selected representing different habitat suitability indices to conduct field trials and to evaluate their fitness. These locations were spread over in three different states (Karnataka, Kerala and Andhra Pradesh) in Peninsular India (Table 2). The sites selected at each of these locations were abandoned forest land and the major vegetation was few scattered trees of native species. Three month old hardened planting stock produced through vegetative multiplication (macro-proliferation) was planted separately in the field in one m^3 pits under Randomized Block Design in 5x5m spacing with four replication, with 16 plants for each replicate and each block totalling 64 plants. Planting was completed during August to September 2005 in each of these locations and the recommended silvicultural practices of irrigation; weeding, protection and maintenance of the experimental site were carried out as and when required. In order validate the predictions, four growth parameters were selected as fitness measures such as survival, height of the clump (m), number of shoots/culms produced and culm diameter (mm) at 5th internode (NMBA). These parameters were recorded yearly during December for a period of six years (2005 to 2010).

Statistical analysis

Using Maxentprediction map, the sites were categorized into highly suitable (sites with habitat suitability index >50), medium suitable (sites with habitat suitability index 10 to 50) and poorly suitable (sites with habitat suitability index <10). In addition to primary growth data of the present experiment, the secondary growth data in the native range of both cultivated and natural plantation at Columbia, South America (Londono, 1998) was also used to compare the fitness.The growth parameters as fitness measures such as survival percentage, clump height, number of culms and culm diameter with habitat suitability index was evaluated using simple linear regression models.

Results and Discussion

Distribution of the species

The secondary occurrence points downloaded from GBIF as well as from published literatures were used to develop a distribution map of Guadua using DIVA-GIS software. The map clearly illustrates the species distribution points which were clustered in South America (Figure 1). The maximum occurrence points in the native rage were in Colombia and Ecuador, also some parts of Peru, Panama and Costa Rica. The initial exploration of Grosser and Liese (1773) and also subsequent field survey of Bennet and Gaur (1990) clearly indicated that Guadua is an endemic species of Latin America. The growth of the species is luxuriant especially along the riparian habitats. In addition, the species thrive best in hot valleys to sub-zero temperature in the winter season.

Niche Modeling Predictions

The ENM prediction map was developed using Maxent software by considering secondary occurrence data which was used to develop distribution map. The model uses both lat-long points and the set of 19 bio-climatic layers and then prediction map was projected to spatial scale for the globe and also for Indian scenario to get habitat suitability. The model prediction map was identical with that of its native range distribution in South America. The predicted worldwide map shows clear area for highly suitable habitat (dark red regions), medium suitable habitat (mix of both yellow and dark red), poor suitable habitat (light green). Worldwide, medium to highly suitable habitats were found in tropical belt and the temperate areas predicted to be poor suitable habitats (Figure 2). The prediction map of India showed distinct patches from poor to high suitable niche (Figure 3). The Western Ghats and North-Eastern Himalayan in India was predicted to be low to medium suitable areas, however some parts in these two regions were predicted to be highly suitable habitats. Other than these two regions rest of all the areas were predicted to be unsuitable areas. The high suitable areas in both Western Ghats and the North-East regions could be due to high precipitation receives during monsoon season also high relative humidity in these mountain stretch. Thus, the mountains chains of Western Ghats and North-Eastern Himalayas are considered as global biodiversity hotspots in India, which supports different types of vegetation and considered has treasure trove of biodiversity (Myers 2003; Mittermeier et al. 2004).

Fitness assessment

In order to evaluate the robustness of the prediction map for selecting the areas for domestication in the present paper, plantation of Guadua was established in seven sites (Figure 4) in India and growth parameters such as survival percent, clump height, culm numbers and culm diameter was monitored for the period of six years (Figure 6). However, for the present paper the cumulative growth data at the age of fourth year was considered to compare between the native range at South America and the introduced sites in India. For each of these experimental sites habitat suitability index was obtained from the prediction map and the sites were categorized into high, medium and poor suitable habitats (Table 3). The results showed secondary data of the native range sites of Quindio (cultivated) and Bolivar, South America (natural) were predicted to be high suitable area with more suitability index. However, the experimental sites in India were predicted to be medium (Thithimathi, Koppa and Alwaye) and poor suitable habitats (Hosakote, Yelawala, Palakkad and FRC).

The fitness was validated by using growth parameters data with habitat suitability index using simple correlation and linear regression models. The results revealed, there was a significant positive relationship between growth parameters and habitat suitability index based on Maxent models (Figure 5 and Table 4). Habitats that were predicted to be highly suitable had on an average significantly greater survival percent, clump height, culm number and culm diameter. For example, the experimental sites such as Bangalore, Mysore, Palakkad and Hyderabad were predicted to be poor suitable habitat by the model had least survival percent compared to site such as Kodagu, Chikmagalur and Alwayewhich had significantly better survival. The significant growth parameters in these predicted to be medium suitable habitats could be due to the patches that are in humid tropics and which receives sufficient rains during monsoon to sustain growth of the plantation compared to poorly suitable habitats which are falls under semiarid locations with a long dry spell. Since the species native range is in humid tropics, luxuriant growth was observed in moist hot valleys and at moderate altitude in South America (Bennet and Gaur 1990). Thus, the species in the present study in humid tropics in India exhibited better performance as in its native range compared to semiarid sites. The commonly used measures to evaluate population fitness are by measuring population genetic variability and fecundity in plants (Saccheri et al. 1998; Wisely et al. 2002; Slate et al. 2000). However in some studies, plant functional traits such as fluctuating asymmetry, specific leaf area and weight, also few physiological parameters were considered to evaluate the population fitness and the results were significant enough to validate the niche predictions (Nagarajuet al. 2013; Wilsey et al. 1998; Nagamitsu et al. 2004; Kozlov et al.1996 ;Valkama and Kozlov 2001; Jurik et al. 1977). The number of experimental sites were less in the present study due to practical and financial constraints, thus the sites were limited to seven locations in southern Peninsular India compared to North-Eastern regions of India. But the results growth parameters showed significant relationship with niche predictions.

Conclusion

The growth parameters of Guadua such as survival percent, clump height, culm numbers and culm diameter had significant relation with predicted habitat by ENM. Growth performance was significantly higher in humid tropics compared to semiarid locations. Also the primary growth data of the humid tropics in the present study were more or less on par with the secondary growth data in its native range in Latin america. Based on the niche modeling predictions and growth data, we can conclude that the fitness with respect to the growth performance was higher in habitats predicted to be highly suitable compared to habitats that are less suitable. The results suggest that, not all regions in India are uniformly suitable for domestication with particular reference to *Guaduaangustifolia*. The performance is likely to be better if the cultivation was restricted to Western Ghats and North-Eastern Himalayan region where the species performed better compared to other unsuitable areas in semiarid tropics. The study has significant relevance to resolve conventional drawbacks of Multilocational species trials. Since NBM (National Bamboo Mission) and NMBA (National Mission on Bamboo Application) missions under Planning Commission, Government of India has launched initiatives to popularize the bamboo cultivation, the study provides scientific base line information for these agencies in selecting sites for large scale afforestation or domestication programmes of this species.

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Table 1.19 bioclimatic variables used for Maxent ENM.

Bioclimatic Variables
BIO1 = Annual Mean Temperature
BIO2 = Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3 = Isothermality (P2/P7) (* 100)
BIO4 = Temperature Seasonality (standard deviation *100)
BIO5 = Max Temperature of Warmest Month
BIO6 = Min Temperature of Coldest Month
BIO7 = Temperature Annual Range (P5-P6)
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. Geographical points of the experimental sites in Peninsular India.

Place	Lat	Long
Hosakote_Karnataka	13.10	77.85
Yelawala_Karnataka	12.34	76.53
Thithimathi_Karnataka	12.23	76.01
Chickmagalur_Karnataka	13.48	75.38
Desam_Alwaye_Kerala	10.12	76.37
Palakkad_Kerala	10.69	76.62
FRC_Hyderabad	17.56	78.45
Quindio_South America (cultivated)	-4.34	-75.47
Bolivar_South America (natural)	-7.08	-73.54

Table 3.Habitat suitability index and category of the experimental sites.

Place	Suitability value	Suitability category
Bangalore_Karnataka, India	2.472	Poor
Mysore_Karnataka, India	4.6	Poor
Kodagu_Karnataka, India	68.63	Medium
Chickmagalur_Karnataka, India	54.3	Medium
Alwaye_Kerala, India	62.66	Medium
Palakkad_Kerala, India	15.88	Poor
Hyderabad_Telangana, India	0.477	Poor
Quindio_South America (cultivated)	99.24	High
Bolivar_South America (natural)	99.45	High

Theme: Propagation, Plantations & Management

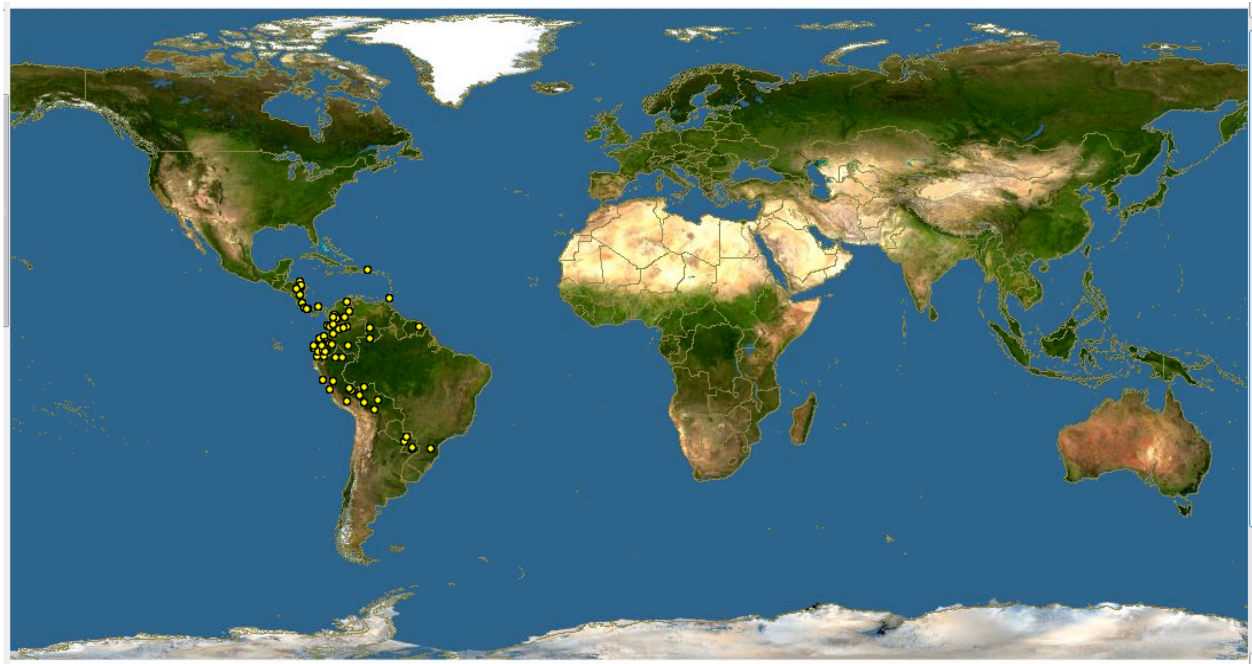

Figure 1. Distribution map *G. angustifolia* in native range of South America

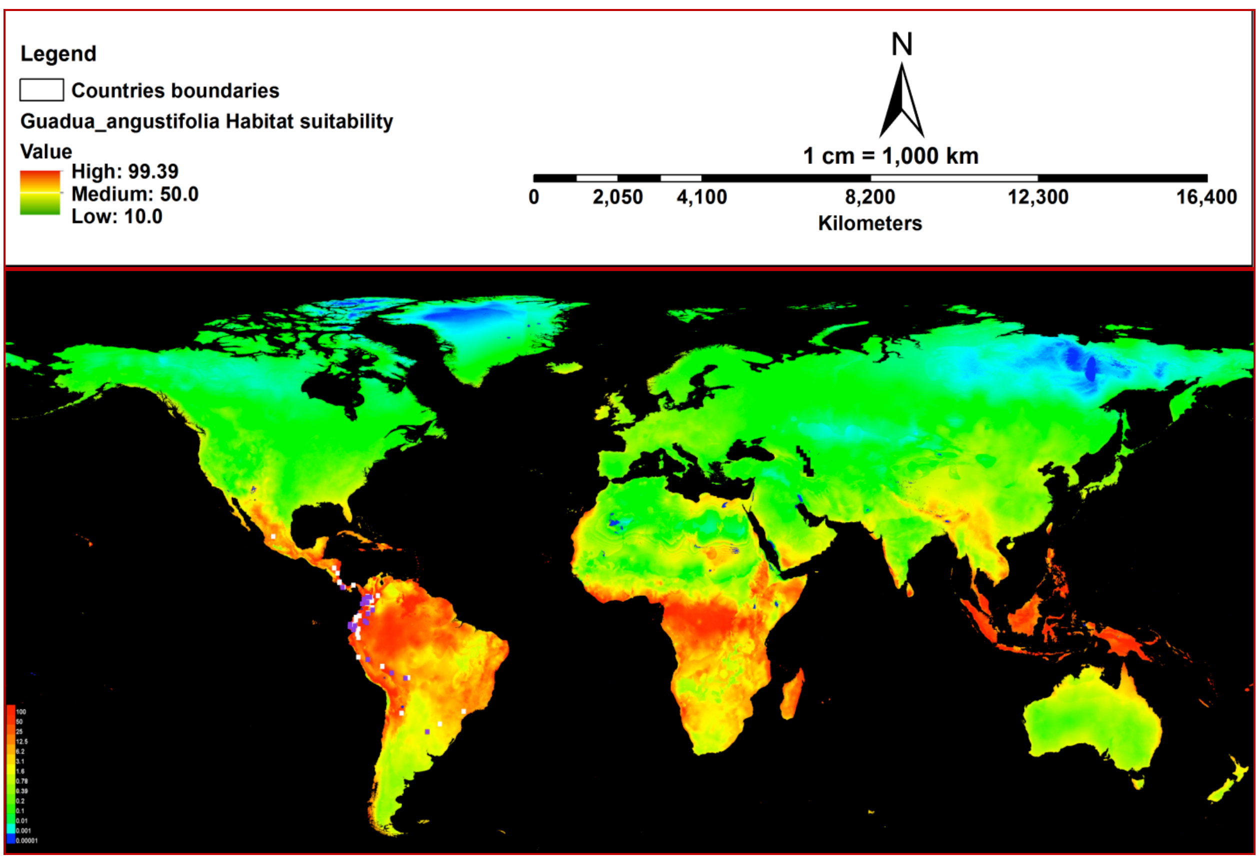

Figure 2.Ecological niche prediction map of *G. angustifolia* forglobe.

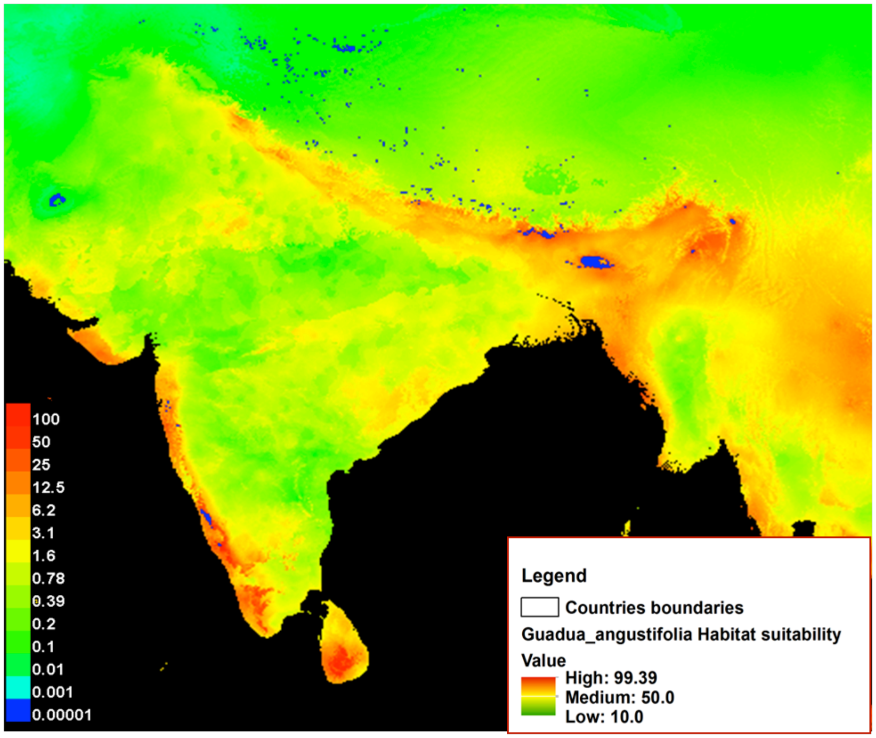

Figure 3.Ecological niche prediction map of *G. angustifolia* for India.

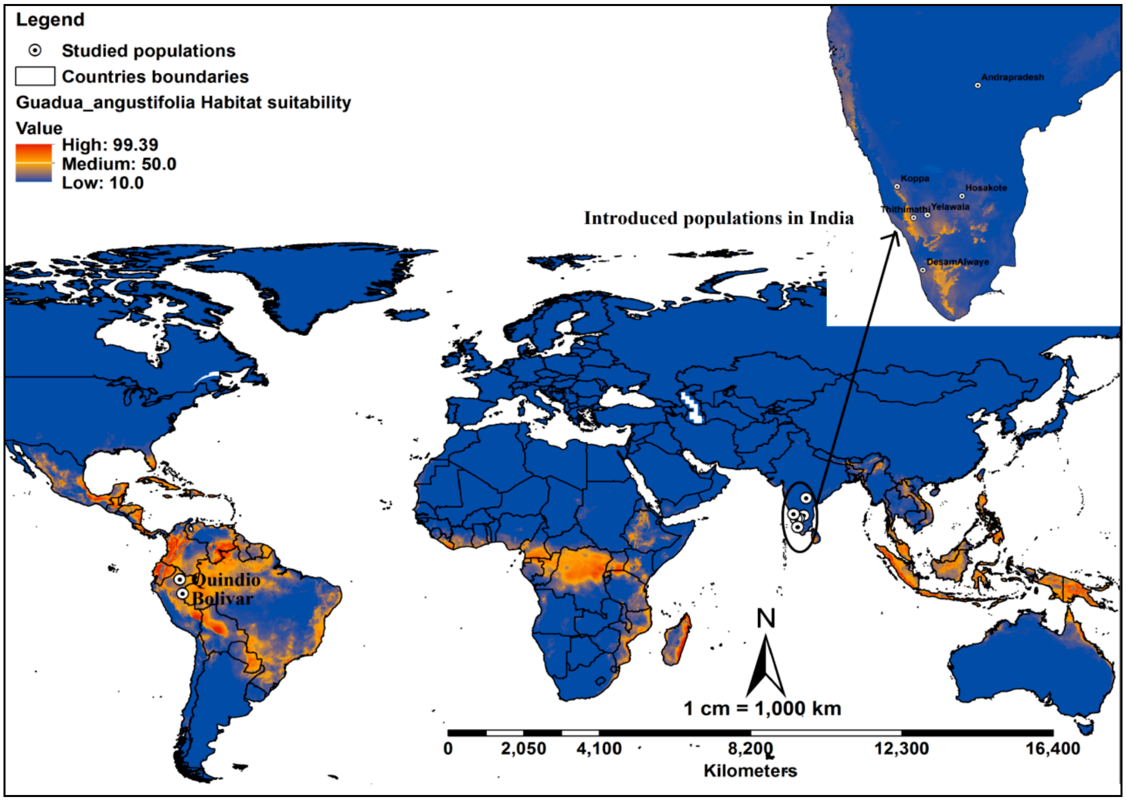

Figure 4. Ecological niche prediction map along with the points of introduced sitesin India.

Table 4.Relationship between Guadua growth traits and habitat suitability index

Fitness traits	F-value	*p*- value
Survival percent	41.82	0.00034
Clump height (m)	97.82	2.3×10^{-5}
Culm numbers/ha	44.18	0.00029
Culm diameter (cm)	33.81	0.00065

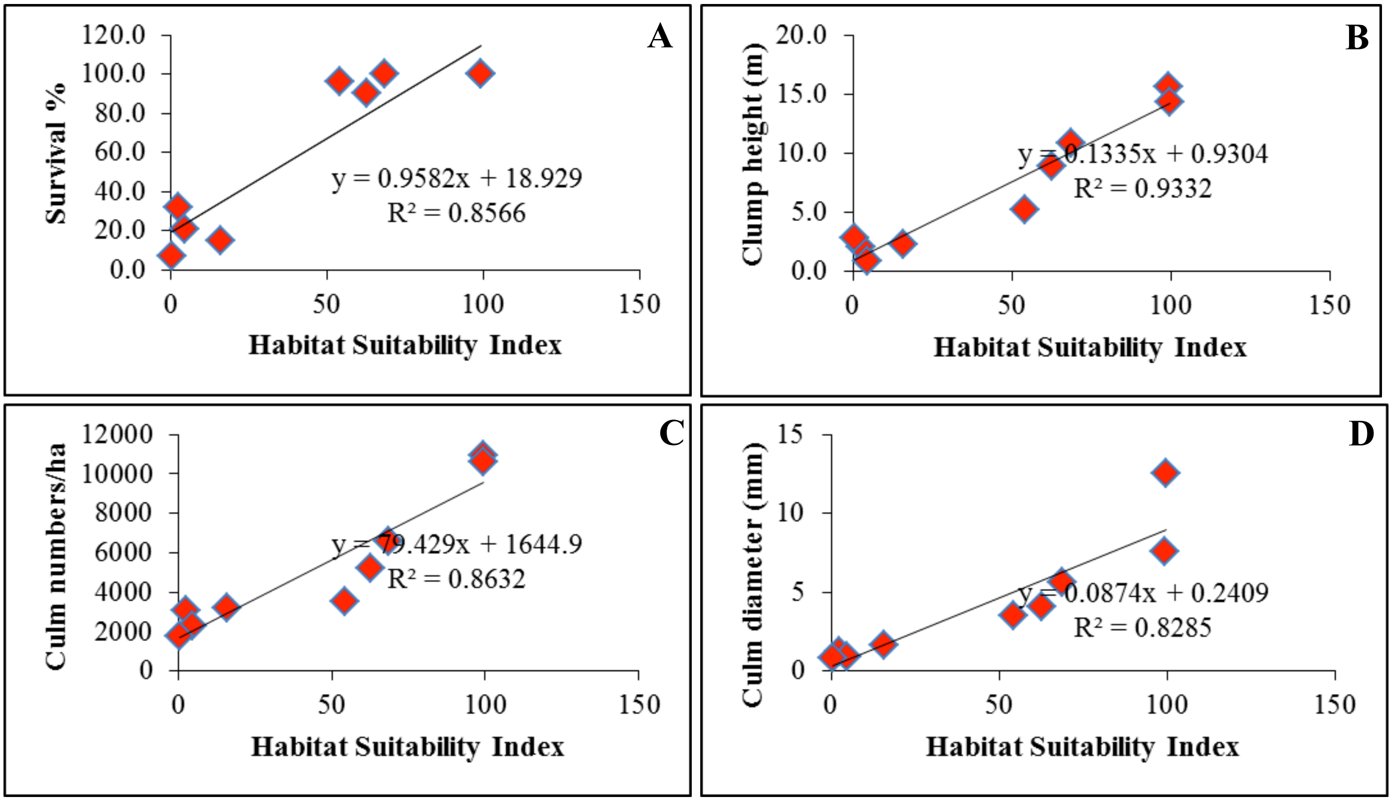

Figure 5. Fitness parameters (A. Survival percent; B. Clump height; C. Culm number; D. Culm diameter) in relation to habitat suitability index.

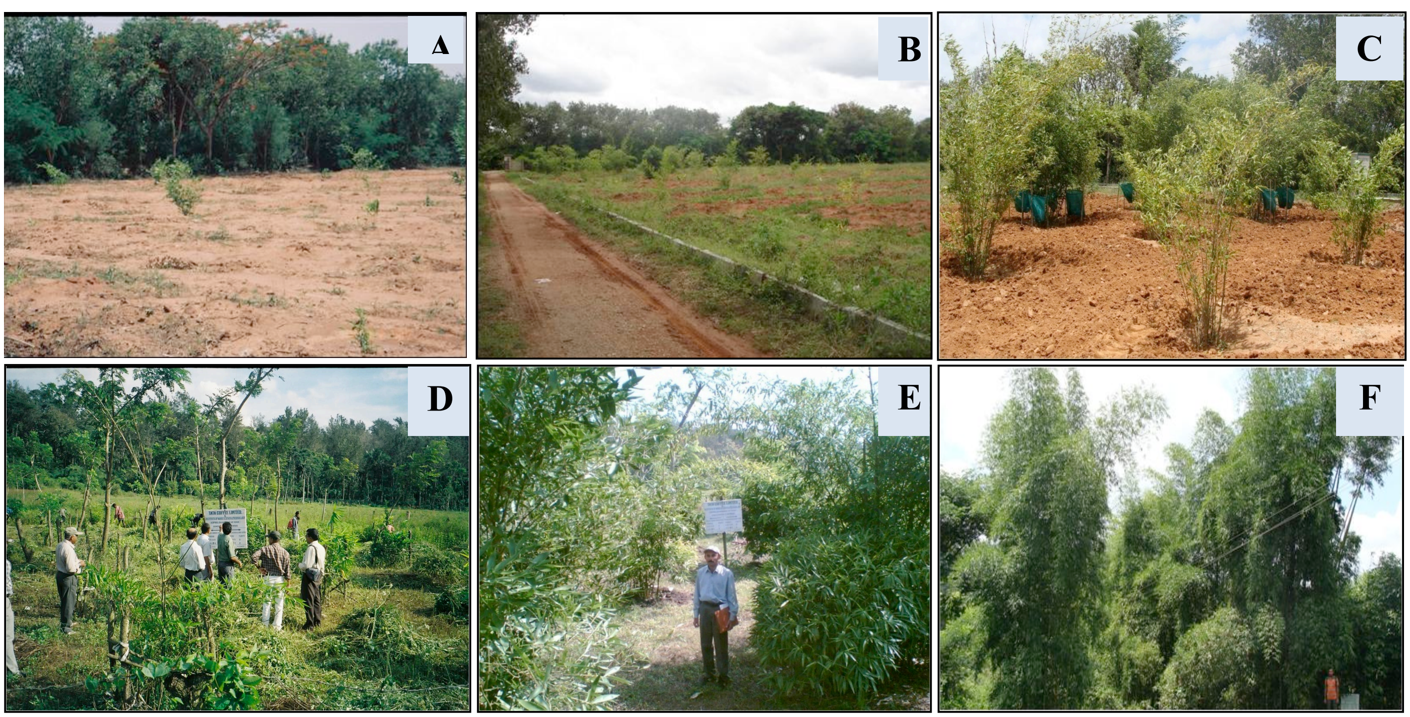

Figure 6.Overview of the experimental trials of Guadua at Semiarid location in Bangalore, Karnataka (A to C) and at Humid tropics in Kodagu, Karnataka (D to F) during 2006, 2008 and 2010.

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