Distribution Potential of *Simarouba Glauca* under Climate Change - Strategizing Rural Livelihood Adaptation

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Abstract
The impacts of climate change are global concerns, but in India, where large parts of the population are chronically vulnerable to natural hazards, climate change impacts are particularly critical. Agriculture (largest sector of Indian economy), accounts for some 17.2% of the GDP and 52% of labor force, is already under pressure and impacts of climate variability cause an additional risk. Livelihood diversification is one means of adapting to climate change. It is being realized through development of a robust low cost input technology that gives maximum returns within a short gestation period. In the present study, current and future distribution model of Simarouba glauca is developed. The results indicate that many Indian states and districts are suitable for its introduction/cultivation and hold a great potential under climate change projections. The species cultivation is an example of a low input cost technology that would give assured returns and focus on rural livelihood improvement.

1. Introduction

The scientific basis of climate change has now been well established (IPCC, 2007). The causes of present and future climate changes, the rate of change, their possible implications on humans and ecosystems are however notably different from past. Evidences of global warming have manifested themselves in global rise of sea-levels (2mm rise per year in 1993-2003) (IPCC, 2007), lengthened growing season of agricultural crops (Deschenes and Greenstone, 2006), and changed intensity of extreme weather events (Timmermann et al., 1999 and Pachauri and Reisinger, 2007). This has resulted in the incidences of vector borne diseases (Sutherst, 2004). Human societies and ecosystems have evolved strategies to cope with some degree of intrinsic climate variability but what can be dealt differs greatly between societies and ecosystems. Developing countries are more vulnerable to these changes than developed nations (Adger et al., 2003 and Morton, 2007). Vulnerability has different forms, but ability to withstand shocks and stresses are more important (IPCC, 2012). Social vulnerabilities to the risks associated with changing climate are particularly crucial in context of rural communities that are dependent on resources sensitive to climate change (Adger et al., 2003). In developing nations, even within rural communities, impacts would be more severe on populations that are predominantly referred as subsistence or small holder farmers. Adaptation refers to adjustments in social and or economic systems in response to actual or expected climatic stimuli and their effects or impacts (Parry et al., 1999 and IPCC, 2007). For climate change adaptation to be mainstreamed in the development process, the impacts of climate change need to be identified and analyzed in terms of broader national level economic impacts (Thomas and Twyman, 2005 and Rahman and Manprasert, 2006) and policies need to be formulated along these guidelines. Altered precipitation and temperature conditions in a climate change scenario are likely to have critical impacts on both land and water resources. India being a tropical country where the vagaries of monsoon have often created conditions of simultaneous floods and droughts are bound to have drastic effects (Roy and Venema, 2002). The requirement of a preferably low cost input technology in rural areas that would give assured economic returns can be met by modifying or renewing existing agriculture practices. Native crop species are adaptive to climate stress and would continue to evolve additional mechanisms.

However, hardy perennial species that can withstand the vagaries of climate are desirable. These species need not necessarily replace food crops or cash crops but they can be integrated into agro-forestry systems supplementing the farmer's income (Altieri, 2002). Given the average size of agricultural land holdings in India and a huge population of marginal workers, climate change adaptation of these communities should be a matter of prime importance to the government.

2. Ecological Niche Modeling

Ecological niche modeling (ENM) refers to reconstruction of the ecological requirements of the species (Peterson, 2001). The outputs of ENM framework have the potential to be incorporated into decision making like conservation planning (Peterson and Kluza, 2003 and Peterson and Martinez-Meyer, 2007), reserve system designing (Roura-Pascual et al., 2006), identifying sites for species introductions and translocations (Skov and Swenning, 2004), and impacts of climate change on biodiversity like spread of invasive species (Beaumont et al., 2009). Openmodeller (http://www.openmodeller.com) is a fundamental niche modeling library that provides a medium for running ecological niche modeling experiments by using a variety of modeling algorithms. Genetic Algorithm for Rule Prediction (GARP) is one such algorithm that works in an iterative process of rule selection, evaluation, testing, incorporation and rejection. Best rule-set are kept while other developed rule-sets are recombined on the principles of genetic recombination to generate different rule-sets (Peterson, 2001). This process is repeated till iteration or user specified convergence limit is reached. Maximum entropy modeling (Maxent) for species distribution is a general purpose machine learning algorithm for predicting species distribution that uses presence only data. The concept behind Maxent is to estimate target distribution of species by finding the distribution of maximum entropy (i.e. closest to uniform) subject to the constraint that the expected value of each feature under this estimated distribution matches its empirical average (Philips et al., 2006 and Kumar and Stohlgren, 2009). For the present study, two niche modeling approaches were used in the study: OpenModeller's desktop GARP with best subsets and Maxent to approximate the distribution potential of *Simarouba glauca* under current and future climate projections. Outputs from these models has been used to locate suitable sites of a multi-purpose tree species *Simarouba glauca*in India for introduction under current and future climate conditions that is believed to improve rural livelihoods and aid in poverty alleviation.

3. *Simarouba Glauca*

Simarouba glauca or paradise tree is a native of forests of Central America and is distributed in low to medium elevations of Mexico, Panama, Southern Florida to West Indies, Islands of Caribbean, The Bahamas, Jamaica, Cuba, Hispaniola and Puerto Rico (Figure 1). The oil tree is essentially a crop of the tropics and has acclimatized to a wide range of climatic and soil conditions. In India, it was first introduced in the 1960s in a research station at Amravati, Maharashtra and in 1986 was brought to the University of Agricultural sciences, Bangalore where systematic research and development activities began. It has been introduced selectively in different parts of India and is reported to grow well in the marginal lands and wastelands of Karnataka, Andhra Pradesh, Tamil Nadu, Maharashtra, Orissa, Chhattisgarh, Bihar and Gujarat (Joshi and Hiremath, 2000). The species begins fetching returns from the tenth year of its planting although income from leaf litter is available from the sixth year itself. Some economic aspects to a farmer employing family labor from a single tree of *Simarouba glauca* are given in the Table 1. Thus, farmers subsisting on small land holdings and marginal farmers can benefit from cultivation of this tree species on government allocated wastelands/common lands and can start getting some income after 5 years of planting (Joshi and Joshi, 2008). They would get a regular income of Rs. 65,000 ha/year or Rs. 26,000/acre/year from a 10 year old plantation regardless of vagaries of climate. Addition of biomass at 10-15 tonnes/ha can be useful in generating CDM based benefits from agro forestry systems (Joshi and Joshi, 2008). The success of this tree has been a point of interest for most agro forestry attempts and has intrigued scientist and farmers alike. The present study therefore has also made an attempt at understanding the ecological preferences of species based on its native range distribution to predict suitable regions in India under current and future climate projections. This research would help respective private, public and government agencies in planning a systematic introduction of this species in suitable regions in India and achieve the desired benefits as encompassed in the objectives of such an introduction/cultivation.

Figure 1: *Simarouba glauca*: a) leaves b) flower and c) fruits

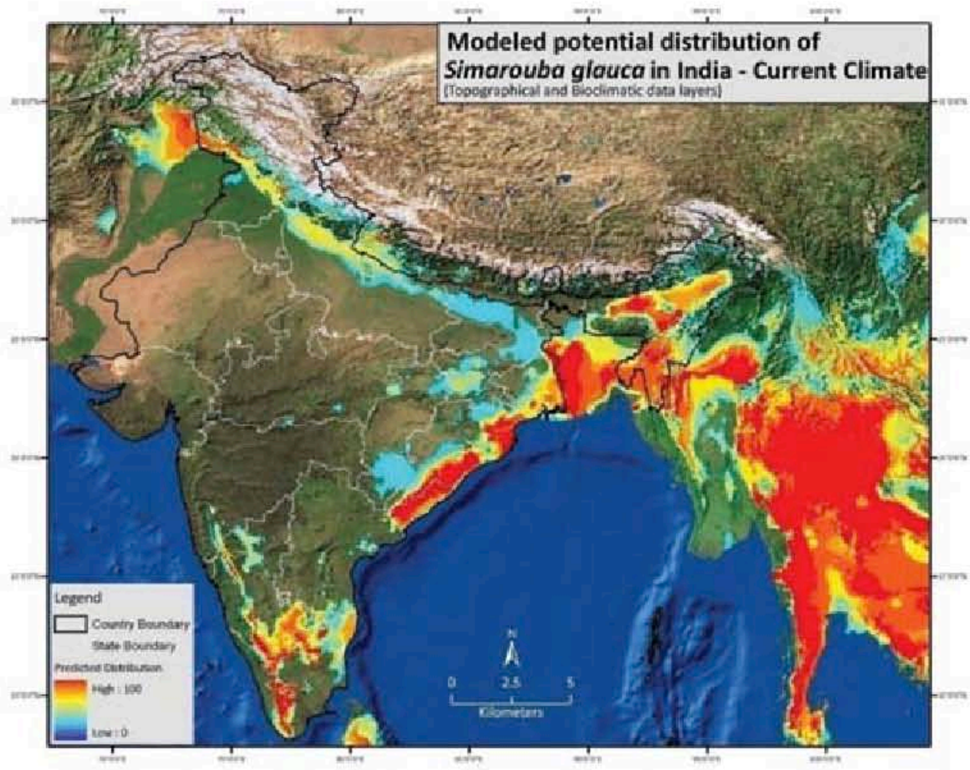

Figure 2: Potential distribution of *Simarouba glauca* in India under current climate projections

Table 1: Economic aspects of farmers employing family labor

Economic aspects (for a single Paradise tree)		Amount (in INR)
Cost	Amount needed to raise to establish one cluster of plants (2-3)/pit)	1.00
Benefit	Amount fetched by cutting and selling 1-2 low yielding trees / pit, after 5/6 years	100.00
	Annual income by selling the produce (nutlets, vermicompost etc.) / tree	100.00
	Income by felling a 10 year old tree(for quality timber) for fuel	100.00 to 500.00
	Income from a 10 year old tree for timber	1000.00 to 5000.00

Table 2: List of bioclimatic parameters used in niche modeling

Bioclimatic parameter	Description
BIO 1: Annual mean temperature	The mean of all the weekly mean temperatures. Each weekly mean temperature is the mean of that week's maximum and minimum temperature
BIO 2: Mean Diurnal Range (Mean of monthly (max temp - min temp))	The mean of all the weekly diurnal temperature ranges. Each weekly diurnal range is the difference between that week's maximum and minimum temperature.
BIO 3: Isothermality (P2/P7) (× 100)	The mean diurnal range (parameter 2) divided by the Annual Temperature Range (parameter 7)
BIO 4: Temperature Seasonality (standard deviation ×100)	The temperature Coefficient of Variation (C of V) is the standard deviation of the weekly mean temperatures expressed as a percentage of the mean of those temperatures (i.e. the annual mean). For this calculation, the mean in degrees Kelvin is used. This avoids the possibility of having to divide by zero, but does mean that the values are usually quite small
BIO 7: Temperature Annual Range (BIO5 –BIO6)	The difference between the Max Temperature of Warmest Period and the Min Temperature of Coldest Period
BIO 10: Mean Temperature of Warmest Quarter	The warmest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.
BIO 11: Mean Temperature of Coldest Quarter	The coldest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated
BIO 12: Annual Precipitation	The sum of all the monthly precipitation estimates
BIO 15: Precipitation Seasonality (Coefficient of Variation)	The Coefficient of Variation (C of V) is the standard deviation of the weekly precipitation estimates expressed as a percentage of the mean of those estimates (i.e. the annual mean)
BIO 16: Precipitation of Wettest Quarter	The wettest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated
BIO17: Precipitation of Driest Quarter	The driest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated
BIO 18: Precipitation of Warmest Quarter	The warmest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated
BIO 19: Precipitation of Coldest Quarter	The coldest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated

4. Materials and Methods

Two modeling approaches were used in the study: OpenModeller's desktop GARP with best subsets and Maxent to approximate the distribution potential of *Simarouba glauca* under current and future climate projections using 78 native occurrence locations obtained from the Global Biodiversity information facility (GBIF). Environmental data used as input in ecological niche modeling are geospatial grid of bioclimatic parameters. A total of 12 amongst 35 bioclimatic variables derived from the globally interpolated datasets of precipitation, temperature and altitude (Hijmans et al., 2005) were used at a resolution of 2.5′ (~5 km) resolution (Table 2). Future climate scenario of 2 × CO_2 climate conditions for the year 2100 derived from CCM3 climate model was used (Hijmans and Graham, 2006) for developing future distribution models.

5. Results and Discussion

Both Maxent and OpenModeller's implementation of GARP gave similar potential distributions of *Simarouba glauca* under current and future climatic conditions showing potential suitability for *Simarouba glauca* ranging between 0-100%, where 0 indicated no suitability and 100% indicates best suitability as picked by the modeling algorithms. The correspondence between both current and future climate was 99%. The regions of lowest suitability falling in the 0-20% range were eliminated and the remaining (20-100%) was divided into three equal interval classes of suitability viz. low, moderate and high. For India, potential distribution both at state and district level was mapped and the outputs were analyzed at the district level to achieve better understanding of the dynamics of the decision making process by policy makers.

5.1 Global Potential Distribution of Simarouba Glauca

The current distribution expands from its native range in Central America, Mexico, Costa Rica to Central Africa, Australia and India, China, Indonesia in Asia. In Africa it has been reportedly found present in the states of Kenya and Burundi. In Australia, the presence of subspecies of the paradise tree has been recorded. Largest areas under high suitability region have been predicted in Brazil, Bolivia, Argentina, Mexico, Thailand and China. Under the future estimated climatic conditions by the 2× CO_2 CCM3 scenario for the year 2100, the potential distribution of the species has both expanded and contracted. Slight contractions in area of high suitability in parts of China can be seen while there has been major expansion in the potential distribution in Africa. There is possibility of minor change in distributional area in Australia as well.

5.2 Potential Distribution of Simarouba Glauca in India

5.2.1 Current climate projections

In India, potential distribution under current climatic conditions lies in peninsular India and North East, as well as northern states of Jammu and Kashmir, Uttaranchal, Punjab and Uttar Pradesh. Major areas of high suitability lie in the states of Tamil Nadu, Orissa, Assam, Mizoram and Andhra Pradesh (Figure 2).

5.2.2 Future climate projections

Under climate change scenario (Figure 3), the distribution of *Simarouba glauca* is predicted to expand towards the western coasts of Maharashtra, parts of Gujarat, occupying major states of north east and completely in Tamil Nadu, major parts of Andhra Pradesh and Karnataka.

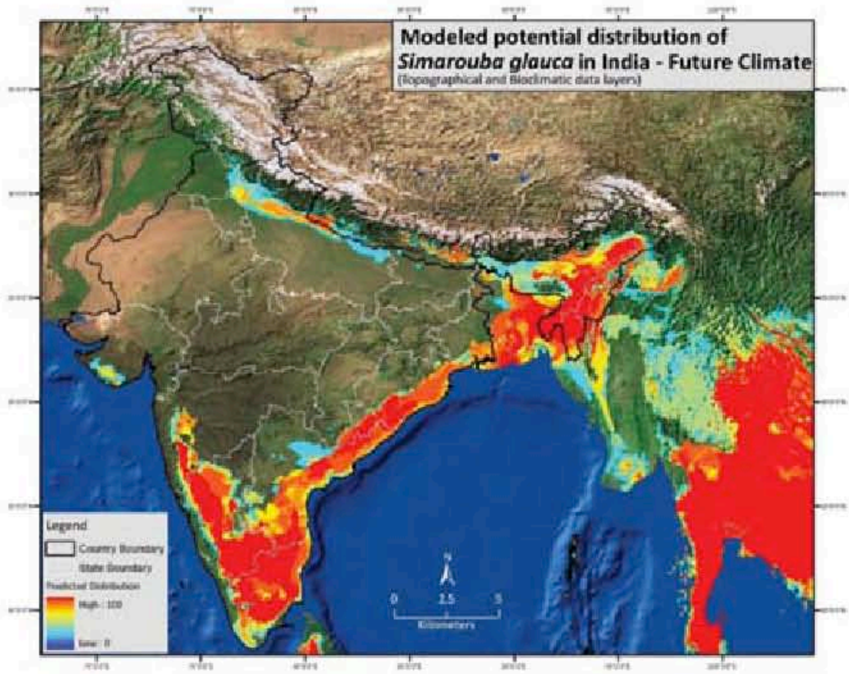

Figure 3: Potential distribution of *Simarouba glauca* in India under future climate projections

Table 3: Ecologically most suitable states under current climate projections

State	Low suitability area (sq. km)	Moderate suitability area (sq. km)	High suitability area (sq. km)	Normalized predicted area (sq. km)
Tamil Nadu	18418	55485	26058	143279
Karnataka	33089	45609	19220	123624
Assam	6853	48261	8806	115566
Orissa	27705	24763	12852	72197
Uttaranchal	17070	20162	1019	65810
Kerala	1978	9682	9336	27300
Mizoram	1816	8850	9702	21140
Andhra Pradesh	13786	21694	0	20424
West Bengal	8735	18115	10	20033
Manipur	6951	8772	4804	18224

Table 4: Ecologically most suitable states under future climate projections

State	Low suitability area (sq. km)	Moderate suitability area (sq. km)	High suitability area (sq. km)	Normalized predicted area (sq. km)
Andhra Pradesh	27712	10263	131220	143279
Karnataka	11540	7696	116891	123624
Tamil Nadu	4527	7351	110758	115566
Orissa	3037	2925	69975	72197
Assam	8403	11333	58042	65810
Maharashtra	5689	7735	22011	27300
Uttar Pradesh	22583	93	15448	21140
Mizoram	20	1249	19794	20424
Manipur	758	1164	19261	20033
West Bengal	9798	4146	13702	18224

5.2.3 Prediction estimates

The predicted area falling under the three classes of high suitability, moderate suitability and low suitability were estimated for both current and future climate conditions at both state and district level. Under current climate projections it was found that at national level, ten states showed high potential for cultivation of *Simarouba glauca* (Table 3). Amongst these, Tamil Nadu has the highest potential distribution area (1,43,279 sq. km). At the district level, Dharmapuri in Tamil Nadu has the highest predicted distributional area while Vishakhapatnam has the highest area under high suitability. Under future climate change projections, the potential distribution of the species is predicted to change. Andhra Pradesh is predicted to have highest suitable area (1,43,279 sq. km) fulfilling *Simarouba glauca*'s ecological requirements (Table 4). At the district level, districts in Andhra Pradesh like Prakasam, Cuddapah, Nellore, Vishakhapatnam, Anantpur, and East Godavari feature in the ten most suitable districts for future distribution of the species. Cuddapah and Anantpur are NREGA districts and Prakasam, Cuddapah, Anantpur, and Belgaum are drought prone districts and also known for incidences of farmer suicides. Around 105 districts have been predicted common between both current and future climate scenarios. Some of these districts are Kancheepuram, Kodagu, Mayurbhanj and Vishakhapatnam. This information is useful for future planning and decision making in terms of directing cultivation of the tree species. Maximum priority should be given to districts that have been predicted suitable under both current and future climatic conditions; next priority should be given to districts that have been deemed suitable in the future but not at present e.g. Satara, Junagarh. Probably least important or low priority districts are those districts that are suitable only at present e.g. Bastar and Gumla.

6. Conclusion

The present study was an attempt at conceptualizing a methodology for crop introductions/cultivation on the basis of an ecological niche modeling approach. Climate change is expected to alter the distribution of native plant species and can lead to range expansions or contractions. Under such conditions, dependence or reliance on native crops for livelihoods is a matter of concern. Rural livelihoods in developing countries are expected to be the worst affected by climate change and even within the rural communities, it is the small landholders and marginal workers that would be severely affected. Livelihood diversification is one means of adapting to climatic changes. *Simarouba glauca* is a generalist species that can benefit huge populations of rural poor both at present and in the future. The results indicate that many Indian states and districts are suitable for the introduction/cultivation of this species. It is truly a paradise tree with its multipurpose properties and has the potential for supporting rural livelihoods at present as well as in future especially in regions where rainfall is erratic; landholdings are small and farmers are landless (Joshi and Joshi, 2008).

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