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RESEARCH ARTICLE

Habitat distribution modeling for reintroduction of *Flacourtia jangomas* (Lour.) Raeusch. (Salicaceae): an indigenous fruit tree of Terai region

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Abstract

Flacourtia jangomas (Lour.) Raeusch., commonly known as paniala, is an important underutilized fruit tree of Terai region. Due to the wide spectrum of pharmacological, cytotoxic and nutraceutical properties, the fruits of *F. jangomas* has been in high demand. In the present study, an extensive survey has been conducted to observe the distribution pattern of male and female tree populations of *F. jangomas* from 2020 to 2024 in Gorakhpur district of Uttar Pradesh. A decline in male and female population have been also reported during the study. During a population survey (2020-2022) 68 places were marked in Gorakhpur district and adjoining regions with 1,340 trees (161 male and 1,179 female) of *F. jangomas*. In a recent survey (2023-2024), the same locations gave the decreased number of tree population which is 1,051 trees (144 male and 907 female). The decrease in population is due to over exploitation, increased urbanization, change in environment and infection caused by insects in the leaves, flowers, and fruits which is alarming. Therefore, the present study was carried out to predict the current suitable habitat of *F. jangomas* in India using MaxEnt species distribution model. Output of MaxEnt model reveal that the suitable habitat for distribution is Uttar Pradesh and Kerala with an area of 50,734 km^2 of highest suitability. Future prediction model for 2050 showed loss of habitat area with an optimal geographic distribution of 25,050 km^2 for this important plant which is alarming and measures should be taken timely.

Keywords: *Flacourtia jangomas, Gorakhpur, Indigenous fruit tree, MaxEnt species distribution model, Terai region*

Introduction

Flacourtia jangomas (Lour.) Raeusch., a member of family Salicaceae (earlier Flacourtiaceae), is commonly known as coffee plum, Indian plum, Indian cherry or Paniala. The native range of this species is Nepal to China (Southern Yunnan, Western Guangxi) and Northern Myanmar (POWO, 2024). Several studies have mentioned it as a native to the North-Eastern Terai region of Uttar Pradesh, Assam, Bihar, Maharashtra, Bengal, Orissa, and some areas of South India (Chandra and Bhanja 2012, Dutta and Borah 2017, Hossain *et al.* 2011, Jogad and Ducharme 2002, Zhang *et al.* 2019). It is a very important and popular indigenous fruit tree with Geographical Indication tag of Gorakhpur region. The fruit only ripens while being attached to the branch and once harvested, they stop the ripening process thus the postharvest life is very critical (Abdullah *et al.* 2020, Anushruti and Maurya 2023, Pai and Shenoy 2021). The major active components have antimicrobial, analgesic, antidiabetic, antidiarrheal, antioxidant and cytotoxic activities (Sasi *et al.* 2018). Nutraceutical properties of *F. jangomas* have also been well recognized and the fruits contain most of the bioactive compounds which are vital for good health (Dutta and Borah 2017). Though *F. jangomas* is a common indigenous fruit tree of Terai region, it may become threatened in near future due to over exploitation and habitat destruction (Ansari and Singh 1979, Mishra and Rai 2020).

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Figure 1a: (A-H). Population survey of *Flacourtia jangomas* (Lour.) Raeusch. A. Habit and Habitat, B. Female flowers, C. Male flowers, D. Fruits, E. Many trees were cut down during the population survey (2020-2024), F.&H. Showing insect infection, G. Survey and questionnaire session of local villagers

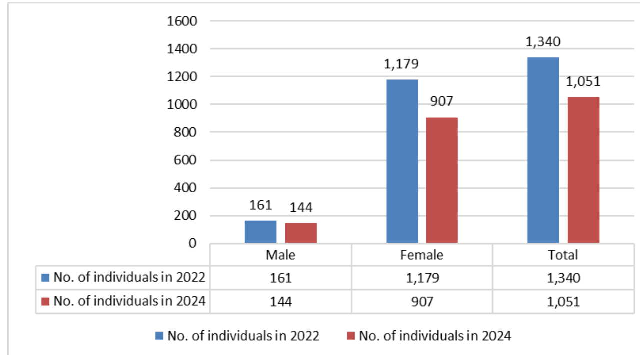

Figure 1b: Decline in male and female population as observed in the study area

During the study (2020-2024) there have been very few new plantations observed in the past and recent surveyed areas. Local orchard owners and fruit sellers were interviewed through questionnaire for finding the reasons behind the increased price of fruit/kg and the declining tree populations. It was found that due to indiscriminate development, increased urbanization, change in rainfall pattern of Gorakhpur and adjoining regions and the infection caused by insects and pest in the leaves, flowers and fruits has affected its flowering pattern which resulted into low fruit set (Figure 1a, 1b.). Thus, the present study has been carried out to predict the suitable habitat distribution for *F. jangomas*. The data may also be utilized for the reintroduction of the plant in its natural habitats. This would further help in protecting and conserving the species and mass production of quality fruits.

Methodology

Occurrence data collection

Primary occurrence data for model building and evaluation were collected through field surveys in Terai region. The location of natural populations was identified and explored with the help of published literature and Floras (Gaur 1999, Singh *et al.* 2016, Srivastava 1976). The occurrence records were also obtained from the web resource of Global Biodiversity Information Facility (http://www.gbif.org). Different herbaria including Central National Herbarium (CNH) Kolkata, Botanical Survey of India Northern Circle (BSD) Dehra Dun, Forest Research Institute (DD) Dehra Dun, National Botanical Research Institute (LWG), Botanical Survey of India, Central Regional Centre (BSA) Allahabad was consulted. Additional information about vernacular names, habitat, life form, attitudinal range and occurrence had been collected during the primary field visits. The coordinates of all the occurrence points obtained through field surveys were recorded to an accuracy of ≤ 10 m using a GPS (Garmin). These coordinates were then converted to decimal degrees for use in modeling the distribution of habitats of the species. To avoid spatial autocorrelations, only one location per grid (1 km × 1 km) was used in modeling. Finally, a total of 68 occurrence points of *Flacourtia jangomas* were compiled and included in this study to model current and future potential distribution of the species.

Climatic data

Bioclimatic variables (Booth *et al.* 2014) with 30 seconds spatial resolution, downloaded from World Clim dataset (www.worldclim.org) were used in the present study. The World Clim data (for the period from 1950 to 2000) are compiled from measurements of temperature and precipitation collected from weather stations worldwide. These data are often used in species distribution modeling (Adhikari *et al.* 2015, Booth *et al.* 2014, Khanum *et al.* 2013, Sanchez *et al.* 2011). The 19 bioclimatic variables from the WorldClim dataset were used to assess current climatic conditions. These variables are frequently used in modeling species distributions (Booth *et al.* 2014, Evangelista *et al.* 2008, Sanchez *et al.* 2011) and capture annual ranges, seasonality, and limiting factors such as monthly and quarterly temperature and precipitation extremes. Future climate scenario data for 2050 (A2a emission scenario) were obtained from Consultative Group on International Agricultural Research (CGIAR)'s Research Program on Climate Change, Agriculture and Food Security (CCAFS) climate data archive (http://ccafsclimate.org). These future climate projections are based on IPCC 4th assessment data and were calibrated and statistically downscaled using the data for 'current' conditions.

Predictive modeling

The habitat model was constructed using the Maximum Entropy Distribution software, MaxEnt version 3.3.3 (http://www.cs.princeton.edu/wschapire) (Phillips *et al.* 2006). This software generates a likelihood estimation for the presence of species, providing a range from 0 to 1, where 0 signifies the lowest probability and 1 indicates the highest probability. Of the 68 records, seventy-five percent were used for model training and twenty five percent for testing. To validate the model robustness, 10 replicated models run for the species with a threshold rule of 10 percentile training presence was executed. In the replicated runs, cross validation technique was employed, where samples were divided into replicate folds and each fold was used for test data. Other parameters were set to default as the program is already calibrated on a wide range of species datasets (Phillips and Dudik 2008). From the replicated runs average, maximum, minimum, median and standard deviation were generated. Jackknife procedure and percent variable contributions were used to estimate the relative influence of different predictor variables. Receiver operating characteristics (ROC) analyses the performance of a model at all possible threshold by a single number called, the area under the curve (AUC). AUC is a measure of model performance and varies from 0 to 1 (Fielding and Bell 1997). Higher AUC values correspond to better model quality and accuracy. The Area under the ROC curve was used to evaluate model performance.

Results

An AUC value of 0.50 indicates that model did not perform better than random whereas a value of 1.0 indicates

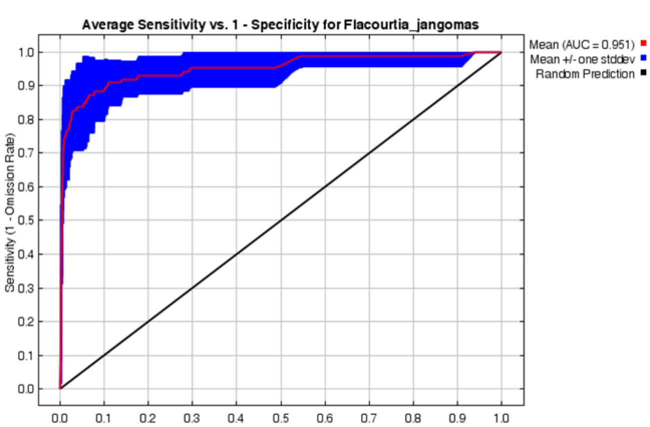

Figure 2: Result of AUC in developing habitat suitability model for *F. jangomas*

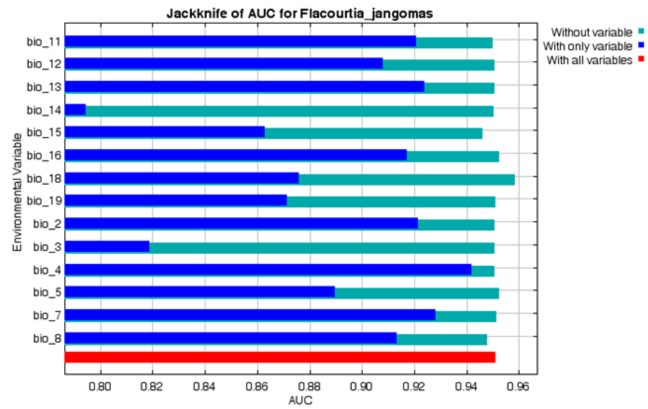

Figure 3: Relative predictive power of different bioclimatic variables based on the jackknife of regularized training gain in MaxEnt model for *F. jangomas*

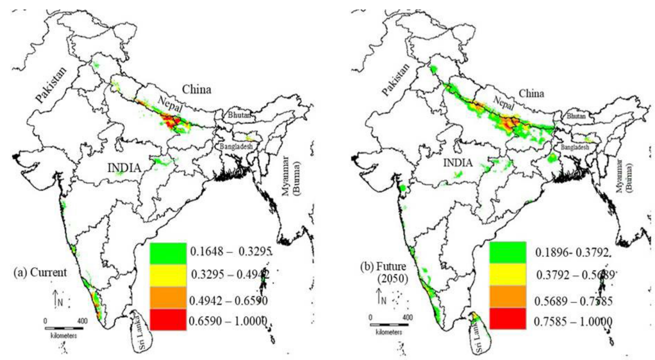

Figure 4: Predicted current (a) and future (b) potential suitable habitat of *F. jangomas* (Shapefile republished from DIVA-GIS database (https:// www.diva-gis.org/) under a CC BY license, with permission from Global Administrative Areas (GADM), original copyright 2018.)

Table 1: Selected environmental variables and their percent contribution in MaxEnt model for *Flacourtia jangomas*

Environment Variables	*Percent Contribution*
Precipitation of Wettest Quarter (Bio 16)	28.8
Mean Temperature of Wettest Quarter (Bio 8)	16.7
Precipitation Seasonality (Bio 15)	15
Precipitation of Wettest Month (Bio 13)	12.8
Max Temperature of Warmest Month (Bio 5)	11.4
Precipitation of Coldest Quarter (Bio 19)	3.3
Precipitation of Warmest Quarter (Bio 18)	2.9
Annual Precipitation (Bio 12)	2.5
Temperature Annual range (Bio 7)	1.6
Temperature Seasonality ((Bio 4)	1.6
Mean Temperature of Coldest Quarter (Bio 11)	1.6
Precipitation of Driest Month (Bio 14)	1.5
Mean Diurnal Change (Mean of monthly (max temp-min temp)) (Bio 2)	0.2
Isothermality (Bio 3)	0.1

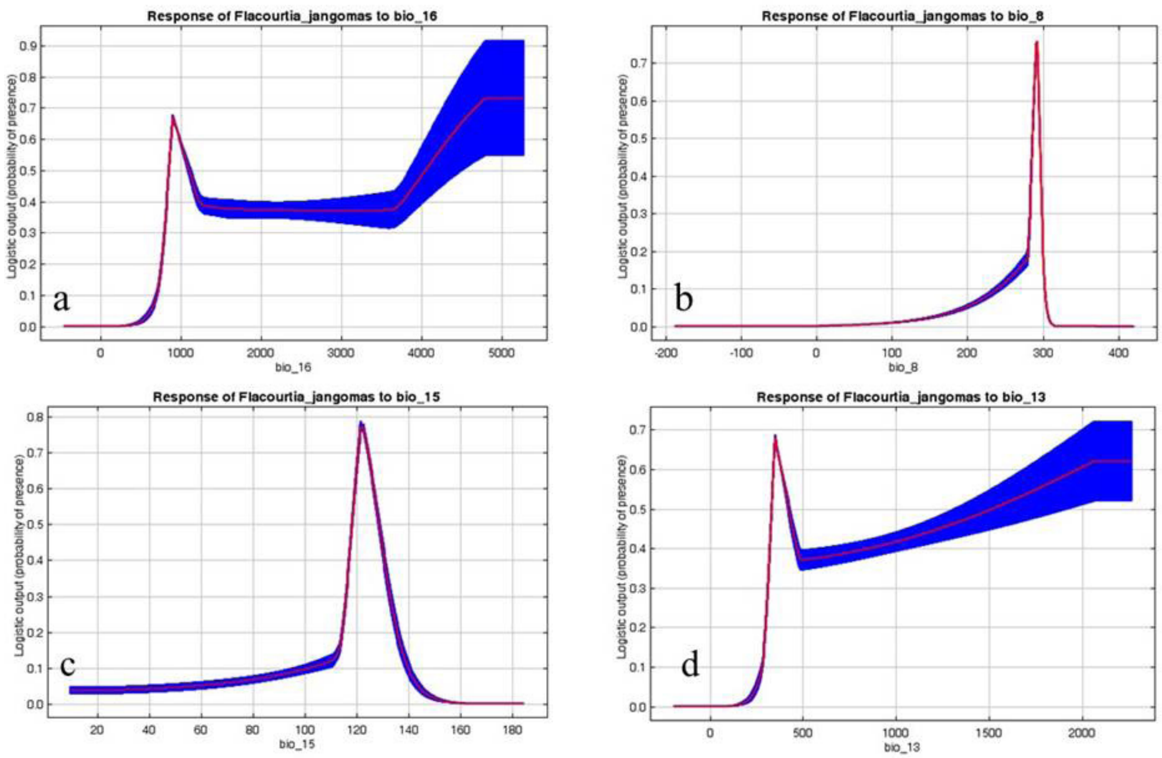

Figure 5: Response curves showing relationships between probability of presence of a species and top bioclimatic predictor of *F. jangomas* (a) Precipitation of Wettest Quarter (Bio 16); (b) Mean Temperature of Wettest Quarter (Bio 8); (c) Precipitation Seasonality (Bio 15); (d) Precipitation of Wettest Month (Bio 13)

perfect discrimination (Swets 1988). The MaxEnt model for *Flacourtia jangomas* performed well with an average AUC value of 0.951 (Figure 2). Relative importance of different environmental variables based on results of jackknife tests in MaxEnt are shown in Figure 3. To minimize the possible errors in species occurrence data, duplicate records were eliminated. The model suggests some parts of Uttar Pradesh and Kerala to be the most suitable habitat with a significant area of 50,734 km^2 of highest suitability (Figure 4). The relative contributions of the predictor variables in MaxEnt for distribution of *Flacourtia jangomas* is given in Table 1.

To minimize the possible errors in species occurrence data, duplicate records were eliminated. Most suitable habitat is predicted in Uttar Pradesh (Figure 3) with an area of 50,734 km^2 of high suitability. Table 1 shows the relative contributions of the predictor variables in MaxEnt for distribution of *F. jangomas*. Precipitation of Wettest Quarter (Bio 16), Mean Temperature of Wettest Quarter (Bio 8), Precipitation Seasonality (Bio 15), Precipitation of Wettest Month (Bio 13) were the strongest predictors for the distribution *F. jangomas* with 28.6%, 16.7%, 15% and 12.8% contributions, respectively (Figure 5).

When compared to the currently predicted most suitable habitat area of 50,734 km^2, the future prediction model for 2050 (under the A2a emission scenario) indicates a reduction in habitat, as illustrated in Figure 4, with an optimal geographic distribution measuring 25,050 km^2. While the prospective distribution of *Flacourtia jangomas* closely mirrors the existing potential distribution, the model's findings suggest a decrease in highly suitable habitat by 50.62% in terms of area.

Discussion

Precipitation of Wettest Quarter plays an important role in the potential habitat distribution of *F. jangomas*. Output of the MaxEnt model shows that most suitable natural habitat for *F. jangomas* is some parts of Uttar Pradesh and Kerala. Regarding future prediction of the species, MaxEnt modeling shows loss of habitat in 2050 in the current predicted areas.

The current study describes the application of ecological niche modeling to identify the areas that support *F. jangomas* populations using occurrence points and environmental variables. The areas located through current distribution modeling can be very helpful in identifying suitable habitats for reintroducing *F. jangomas*. Under future climatic scenarios (A2a emission scenario), this species shows a decrease in the habitat suitability (25,050 km^2) as compared to the current prediction where the suitable habitats range across 50,734 km^2. Based on habitat contraction prediction, in the near future, potential suitable areas must be prioritized and maintained at an utmost importance.

As during the study, total 1,340 trees of *F. jangomas* were observed with 161 male population and 1,179 female population. In a recent survey (2024) of the same locations, a decline in number (1,051 trees) with 144 male and 907 female trees has been observed. Thus, the current study indicates that habitat distribution modeling can be highly beneficial in identifying suitable habitats for *F. jangomas*. The predicted areas in this research may aid in the species' rehabilitation and enhancement of its conservation status. Employing various integrative in-situ conservation approaches, along with captive propagation in controlled settings like natural habitats, botanical gardens, and other conservation facilities, could boost species recovery rate and promote germplasm conservation. The MaxEnt model, used for predicting the appropriate habitat of a species, can be applied to forecast the potential suitable habitats of other economically important plants, thereby assisting in conservation planning for these species.

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