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Modelling the potential habitat of *Taxus baccata* Linn. in Shi-Yomi District of Arunachal Pradesh, India

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ABSTRACT
Taxus baccata Linn., commonly known as *Yew* is a temperate conifer tree usually small to medium in size. The barks, leaves, and twigs have traditional medicinal uses. It is also processed to make taxol which is used in the preparation of anti-cancer drugs (breast and ovarian cancer). The plant is rare, endangered, and listed in Appendix II of CITES. In this study, we used the maximum entropy (MaxEnt) model to predict the potential distribution of the species. The results show an area of 2444.01 km^2 (88.77%) as least suitable, followed by 237.06 km^2 (8.61%) as moderately suitable and only 72.01 km^2 (2.62%) as highly suitable category. The model performance was reasonably good and reliable with a mean Area under curve (AUC) of 0.934 and a standard deviation of 0.018. Isothermality, precipitation seasonality, and mean diurnal range of temperature significantly contributed to predicting the suitable habitat of *T. baccata*. An examination of the model results shows the northern part of the district is the potential area of occurrence for *T. baccata* in the natural stand and suitable for regeneration. Thus, the model outcomes could be used to explore the natural population status of the plant.

Key words: Cancer; Medicinal plants; Taxol; Species distribution model; *Yew*.

INTRODUCTION

The application of the species distribution model (SDM) in defining the potential habitats of economically and medicinally important plants has been gaining popularity in recent decades. These models use environmental factors and occurrence records vital for species conservation (Graham and Hijmans 2006, Glor and Warren 2011). SDMs are known by diverse names such as climate envelope modelling, habitat modelling, and environmental or ecological niche modelling (Elith and Leathwick 2009, Guisan et al. 2017). SDMs predict where the species may be present but unrecorded or where they might be found if not removed by anthropogenic activities (Anderson et al. 2009). It also predicts where species may be in the coming years (Parmesan and Yohe 2003). Such forecasts are beneficial in categorizing priority areas for conservation (Vaughan and Ormerod 2003, Kremen et al. 2008) and evaluating risks from climate change (Julliard et al. 2004, Huntley et al. 2008). According to Skov (2000), the application of modelling techniques in the distribution of plants is a powerful tool that combines occurrence records, modelling software, and geographic information systems (GIS). Maximum entropy (MaxEnt) is a widely used technique for species distribution modelling (Graham and Hijmans 2006, Baldwin 2009, Ramírez-Villegas and Bueno Cabrera 2009). It uses concise mathematical algorithms and quantitative assessment of variable contribution to generate spatially explicit habitat suitability maps (Phillips et al. 2006, Elith et al. 2010, Yi et al. 2016).

Taxus baccata Linn. (family: Taxaceae) commonly known as *Yew* is a temperate conifer tree usually small to medium in size. The barks, leaves, and twigs have traditional medicinal uses and are also processed for taxol (Phillips et al. 1999). Taxol is used in the preparation of anti-cancer drugs (breast and ovarian cancer). According to Schippmann (2001), the plant is rare, endangered, and listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). It is valuable for taxol or paclitaxel extraction used in the preparation of anti-cancer drugs, in addition to the other medicinal uses in Ayurveda and Tibetan medicine (Saqib et al. 2006). The non-cancer uses are for coating stents (anti-angiogenesis), Alzheimer's, multiple sclerosis, and polycystic kidney disease (Cameron and Smith 2002). It has been used by the native population for treating common colds, coughs, fever, and pain. The bark paste is applied to the forehead for relief from headaches and the leaves and bark extracts are also used for the treatment of bronchitis, asthma, poisonous insect bites, and also as aphrodisiac (Beckstrom-Sternberg and Duke 1993). This tree is found in the temperate and least disturbed forests due to inaccessibility for other land use. The tree has spreading branches and leaves arranged in whorls which are 2.5 to 3.5 cm long and linear. They are glossy green and pale beneath. *T. baccata* flowers from March to May and seeds are produced from October to November. It is ideal for cultivation in high-altitude regions as mixed plantations and propagation is through seeds. It is easier to multiply through stem cuttings and has high demand in the market.

Arunachal Pradesh falls under the Eastern Himalayan Biodiversity Hotspot with more than 500 species of plants of medicinal and pharmacological significance (Haridasan et al. 1995). The reconnaissance survey of *Taxus* in the state reveals a wide distribution and many more possible areas of occurrence (Shukla et al. 1994). The ideal altitudinal zone where the tree occurs is between 2000 to 2500 m amsl throughout the state in the temperate forest of Bomdila, Shergaon, Eagle Nest Wildlife Sanctuary, Dirang, Thungri, Tawang, Mago and Zemithang in West Kameng and Tawang districts, Talley (few trees only) in Lower Subansiri, Anini, Mayodiya in Dibang Valley district, Mechuka in West Siang district (now Shi-Yomi) and hot spring areas of Anjaw district (Beniwal and Haridarsan1992). Therefore, in this study, a species distribution model of *T. baccata* in the Shi-Yomi district of Arunachal Pradesh was attempted based on occurrence records and environmental parameters to comprehend the suitable areas of this valuable medicinal plant. The outcomes of the work would help understand the natural habitat and thereby in the conservation of the plant.

MATERIALS AND METHODS

Study area

The study area is a newly created district named Shi-Yomi, bifurcated from the West Siang district with its headquarters at Tato. It is located between 27°32' to 28°17' N latitudes and 93°58' to 94°83' E longitudes. The district is bounded on the north by China, Upper Siang, and Siang districts on the east, West Siang on the south, and Upper Subansiri district of Arunachal Pradesh on the west (Fig. 1). The main inhabitants are Pai-Libos, Ramos, Bokars, Membas and few populations of Tagin tribe. There are four administrative units viz., Mechuka Circle (34 villages), Monigong Circle (46 villages), Pidi Circle (14 villages) and Tato Circle (22 villages). The area is mostly characterized by temperate forests with an altitudinal range of 1500–4000 m, some parts under sub-tropical forest (below 1500 m) and alpine zone (above 4000 m). The climatic conditions during summer are warm and temperate while in winter it is cold with snowfall in high-altitude areas and mountain peaks.

Occurrence data

A field survey was conducted from February 2022 to February 2023 in Mechuka and Monigong to collect the geographic coordinates and altitude of *T. baccata* with the help of the Global Positioning System (GPS). The survey recorded more than 200 live plants of *T. baccata* in the area. The spatial thinning method (spThin package) was used in R (Hijmans et al. 1999) to reduce spatial sampling bias, following which 30 geo-referenced points were selected for the final model building. The methodology applied in this study is shown in Figure 2.

Environmental parameters

To generate the distribution modelling of *T. baccata*, a set of environmental data, such as, topographical, climatic, land use/land cover and soil properties with 30 m spatial resolution have been acquired from various sources like WorldClim, ESRI land cover, and World Soil Information (ISRIC). The parameters include 19 bioclimatic variables, 5 soil variables, and 1 land use/ cover. Additionally, the topographical variables like altitude, slope, aspect, and proximity to drainage have been derived from the Advanced Space Borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM) database with 30 m spatial resolution using ArcGIS 10.3. The highly correlated parameters have been removed because such parameters affect the model performance negatively and lead to inaccurate

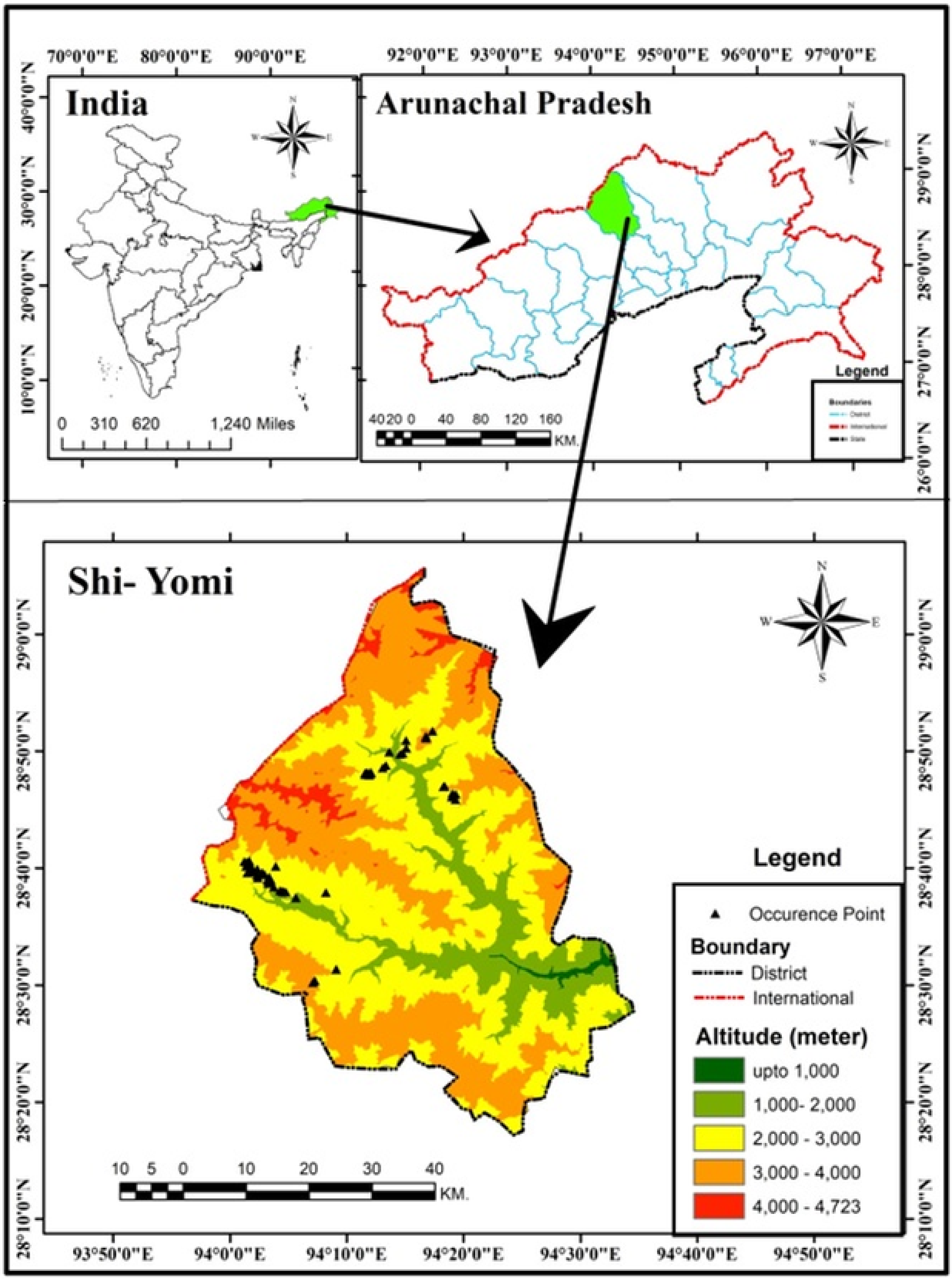

Figure 1. Location map of the study area

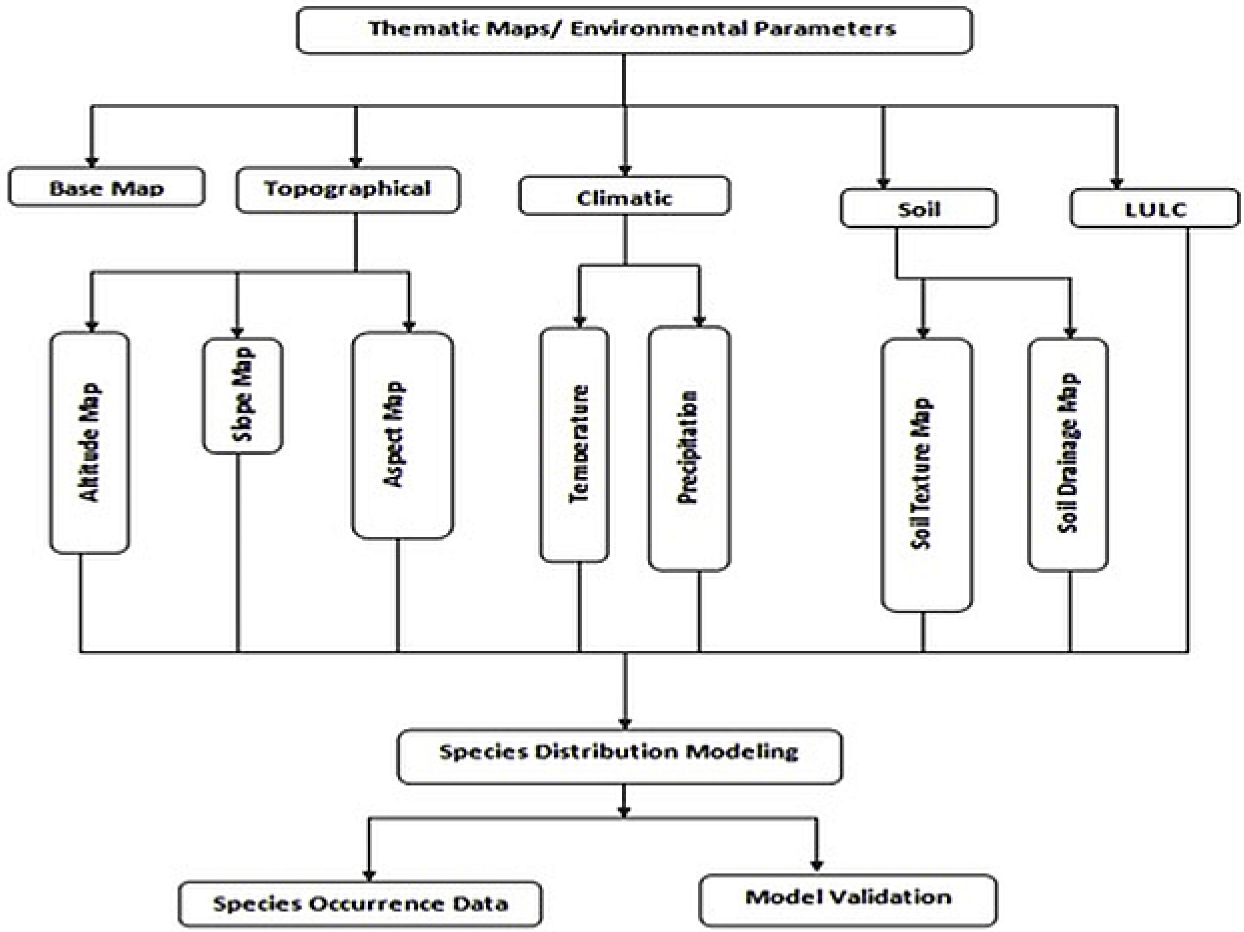

Figure 2. Methodology flowchart

predictions (Parolo et al. 2008, Merow et al. 2013, Dormann et al. 2013, Manzoor et al. 2018). The ideal correlation between predictor variables should be |r| > 0.7 (Dormann et al. 2013, Manzoor et al. 2018, Sony et al. 2018, Farrell et al. 2019, Feng et al. 2019). After performing a multicollinearity test using the usdm package in R (Naimi and Araújo 2016), 12 predictor variables, namely Mean Diurnal Range (BIO2), Isothermality (BIO3), Temperature seasonality (BIO4), Min Temperature of Coldest Month (BIO6), Temperature Annual Range (BIO7), Precipitation of Driest Month (BIO14), Precipitation seasonality (BIO15), elevation, slope, aspect, drainage density and soil type were included in the final model (Fig. 3, Table 1).

Model settings and evaluation

The species distribution modelling of *T. baccata* was generated using MaxEnt (version 3.4.1). This technique has been considered more reliable than other methods due to its accurate prediction for small sample sizes (Hernandez et al. 2006, Wisz et al. 2008, Baldwin 2009). Moreover, it is resilient to spatial errors and sampling-biased occurrence data (Baldwin 2009, Graham et al. 2008). Various studies mentioned the performance of MaxEnt better than other niche modelling techniques (Phillips et al. 2006, Peterson et al. 2008, Phillips 2008, Radosavljevic and Anderson 2014, Nimasow et al. 2016). The model used 500 iterations, 0.00001 convergence threshold, 0.5 prevalence, 10,000 background points, 10 percentile training presence, and 3 replicate model runs with cross-validation technique to ensure and assess the model reliability (Pearson et al. 2004).

RESULTS

Model performance

The study employed suitable environmental parameters that play a crucial role in the growth, development, and distribution of *Taxus baccata*. The final model demonstrated reasonably good and

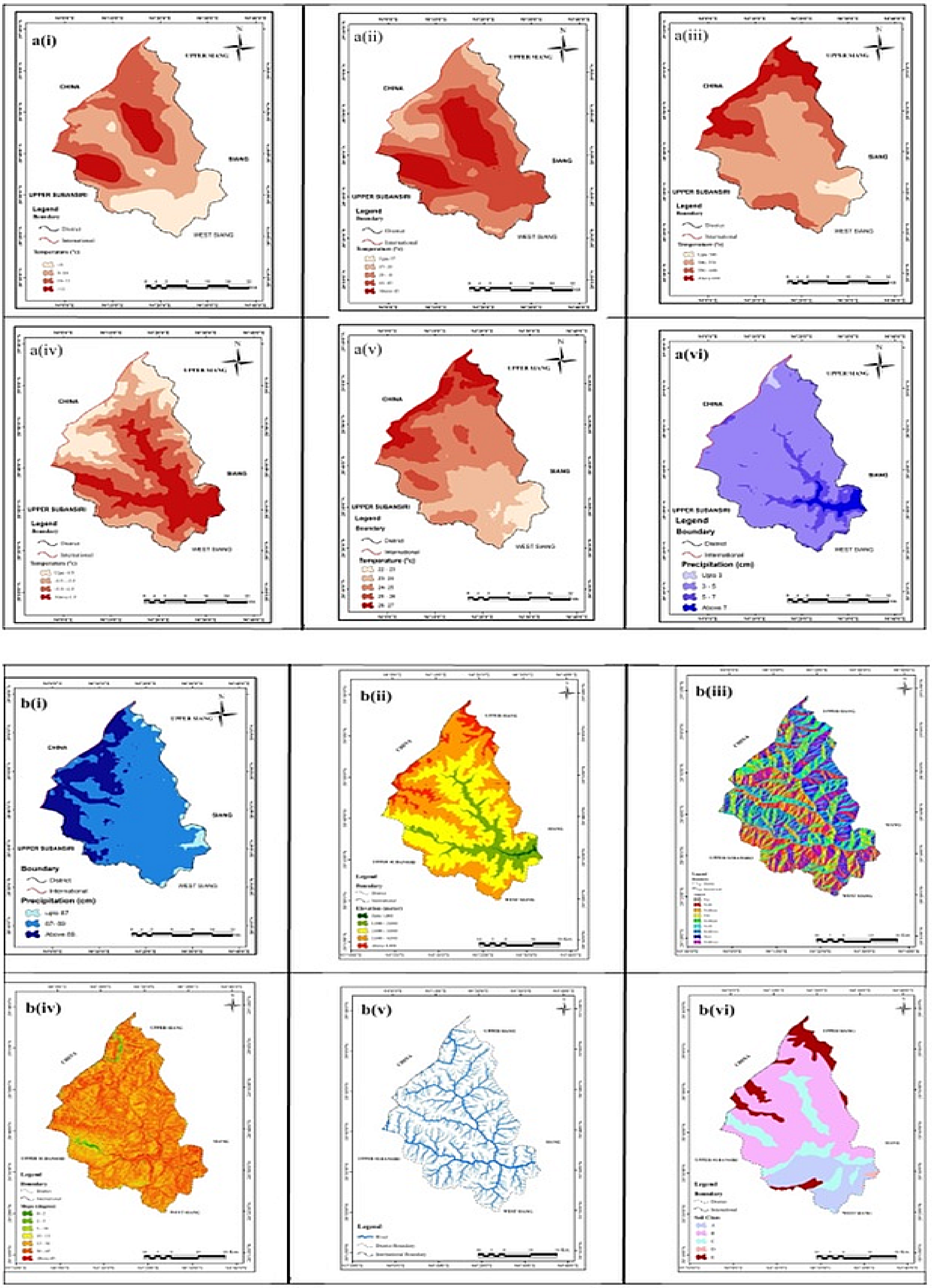

Figure 3. Environmental parameters [a(i) = BIO2, a(ii) = BIO3, a(iii) = BIO4, a(iv) = BIO6, a(v) = BIO7, a(vi) = BIO14, and b(i) = BIO15, b(ii) = Elevation, b(iii) = Aspect, b(iv) = Slope, b(v) = Drainage density and b(vi) = Soil type]

Table 1. Environmental parameters used in the final model.

Sl. No.	Environmental variables	Code	Units
1.	Mean Diurnal Range (Mean of monthly (max temp-min temp))	BIO2	°C
2.	Isothermality (BIO2/BIO7) (x 100)	BIO3	°C
3.	Temperature seasonality (standard deviation x 100)	BIO4	°C
4.	Min Temperature of Coldest Month	BIO6	°C
5.	Temperature Annual Range (BIO5-BIO6)	BIO7	°C
6.	Precipitation of Driest Month	BIO14	Cm
7.	Precipitation seasonality (Coefficient of Variation)	BIO15	Cm
8.	Elevation	elevation	Meter
9.	Slope	slope	Degree
10.	Aspect	aspect	~
11.	Drainage density	Drainage_den	~
12.	Soil type	Soil_type	~

consistent performance with a mean Area under curve (AUC) of 0.934 and a standard deviation of 0.018 (Fig. 4). The jackknife test revealed that the distribution of *T. baccata* was primarily constrained by Isothermality (BIO3), which accounted for 33.4% of the explained variable. Precipitation seasonality (BIO2) and Mean Diurnal Range (BIO15) were the next significant variables, contributing 28 and 25.1%, respectively. The contribution of other parameters was relatively lesser viz. drainage density (5.9%), aspect (2.1%), Min. Temperature of Coldest Month (1.6%), and Temperature seasonality (1.3%), respectively. Slope, elevation, precipitation, and driest month showed minor influences on the distribution of *T. baccata* (Table 2, Fig. 4).

Species distribution modelling of *T. baccata*

The suitability model predicted the distribution of *T. baccata* in the Shi-Yomi district of Arunachal Pradesh in the range of 0 – 0.9 (Fig. 5) which was categorized into three suitable categories, namely least suitable (0 – 0.3), moderately suitable (0.3 – 0.6) highly suitable (0.6 – 0.9). The results show an area of 2444.01 km^2 (88.78%) as least suitable, followed by 237 km^2 (8.62%) as moderately suitable and only 72.01 km^2 (2.62%) under the highly suitable category (Table. 3). An examination of the final model reveals majority of the northeastern part of the district is suitable for *T. baccata* due to its high altitude, steep slope, and lower temperature. On the other hand, the foothill areas characterized by lower slopes, high temperatures, and high rainfall showed the least suitable areas of *T. baccata*. The model predicted Mechuka and Monigong regions as suitable areas of *T. baccata* in the Shi-Yomi district of Arunachal Pradesh. These areas are characterized by warm and temperate summers and cold winters with snowfall in the high-altitude mountain peaks.

Table 2. Parameter contributions (Jackknife)

Parameters	Contribution (%)
Isothermality	33.4
Mean diurnal range	28.3
Precipitation seasonality	25.1
Drainage density	5.9
Aspect	2.1
Minimum temperature of coldest month	1.6
Temperature seasonality	1.3
Slope	0.8
Elevation	0.6
Precipitation of driest month	0.6

Table 3. Suitability categories of *T. baccata* in the study area

Suitability categories	Area	%
Least suitable	2444.01	88.77
Moderately suitable	237.06	8.61
Highly suitable	72.01	2.62
Total	**2753.08**	**100.00**

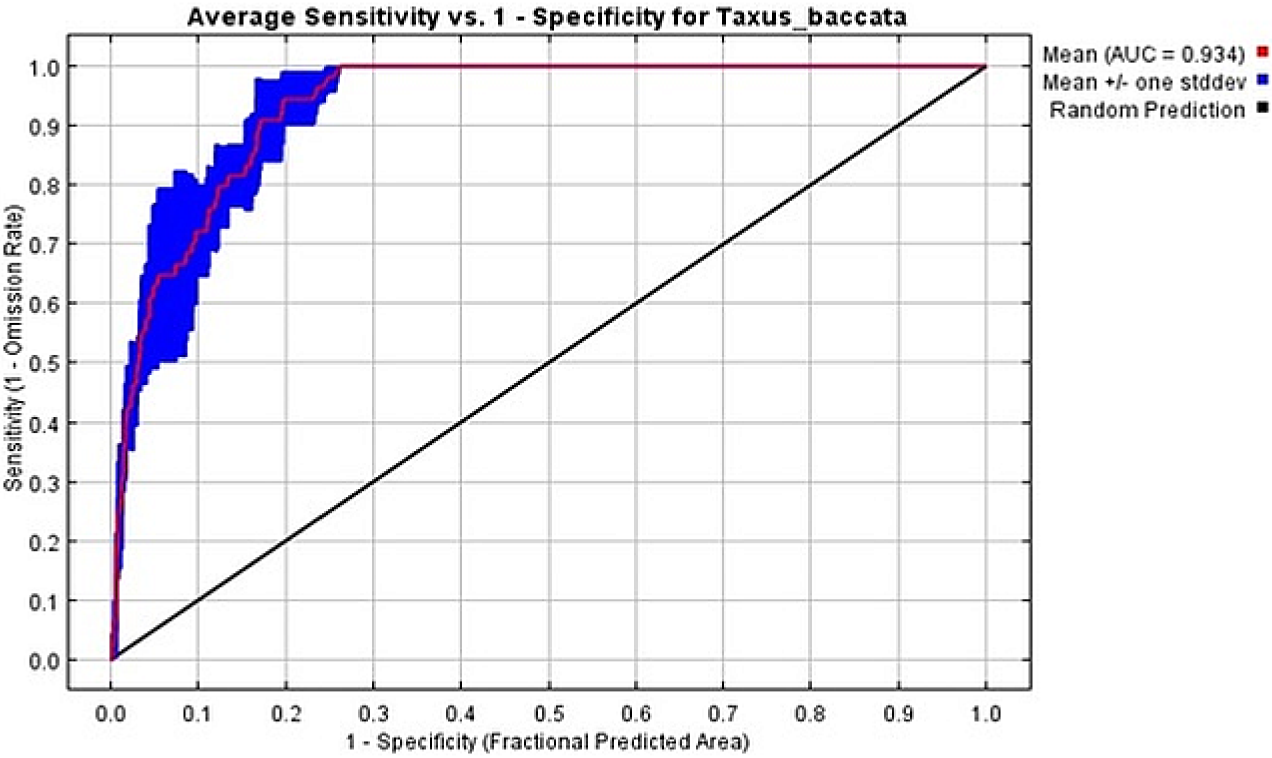

Figure 4. Area under the receiver operating characteristic curve (AUC-ROC)

DISCUSSION

The model performed reasonably well with a mean area under the curve (AUC) value of 0.934, which is excellent predictive performance (Swets 1988). The jackknife test shows isothermality (BIO3) as the most important parameter in the distribution of *Taxus baccata*, followed by precipitation seasonality (BIO2) and mean diurnal range (BIO15). These variables are related to temperature and precipitation patterns that play crucial roles in the growth and distribution of plant species (Pearson and Dawson 2003). The model predicted only a small portion (2.62%) of the study area as highly suitable for *T. baccata* while most of the area was predicted as least suitable (88.78%). The findings are consistent with the ecology of *T. baccata*, which prefers cool, temperate climates and higher elevations (Price 1990, Purohit et al. 2001, Thomas and Polwart 2003). The suitable areas were mostly concentrated in the northeastern part of the district, characterized by high altitude, steep slopes, low temperatures, and moderate rainfall, which align with the preferred habitat of *T. baccata*. The findings conform with previous studies on *T. baccata* and other yew species. For instance, in Denmark, Svenning and Skov (2004) found temperature-related variables, such as growing degree days and continentality, as the most important predictors of *T. baccata* distribution. Species distribution modelling techniques can be used to explore the additional areas of a known species. The MaxEnt method has been successfully used to predict the distribution of *T. baccata* and plant species (Phillips et al. 2006, Rinnhofer et al. 2012, Nimasow et al. 2016). The finding of the new populations will help in conservation planning in remote areas (Pearson 2007). The outcomes of the present study thus could serve as a model for the conservation of endangered and rare plant species with economic and ecological importance. Additionally, it could give ample scope to future researchers for more holistic studies by applying this approach.

CONCLUSION

The study used the MaxEnt method to model the suitable habitats of *T. baccata* in the Shi-Yomi district of Arunachal Pradesh. We used the occurrence records of *T. baccata* and the environmental parameters viz. topographic, bioclimatic, land use/

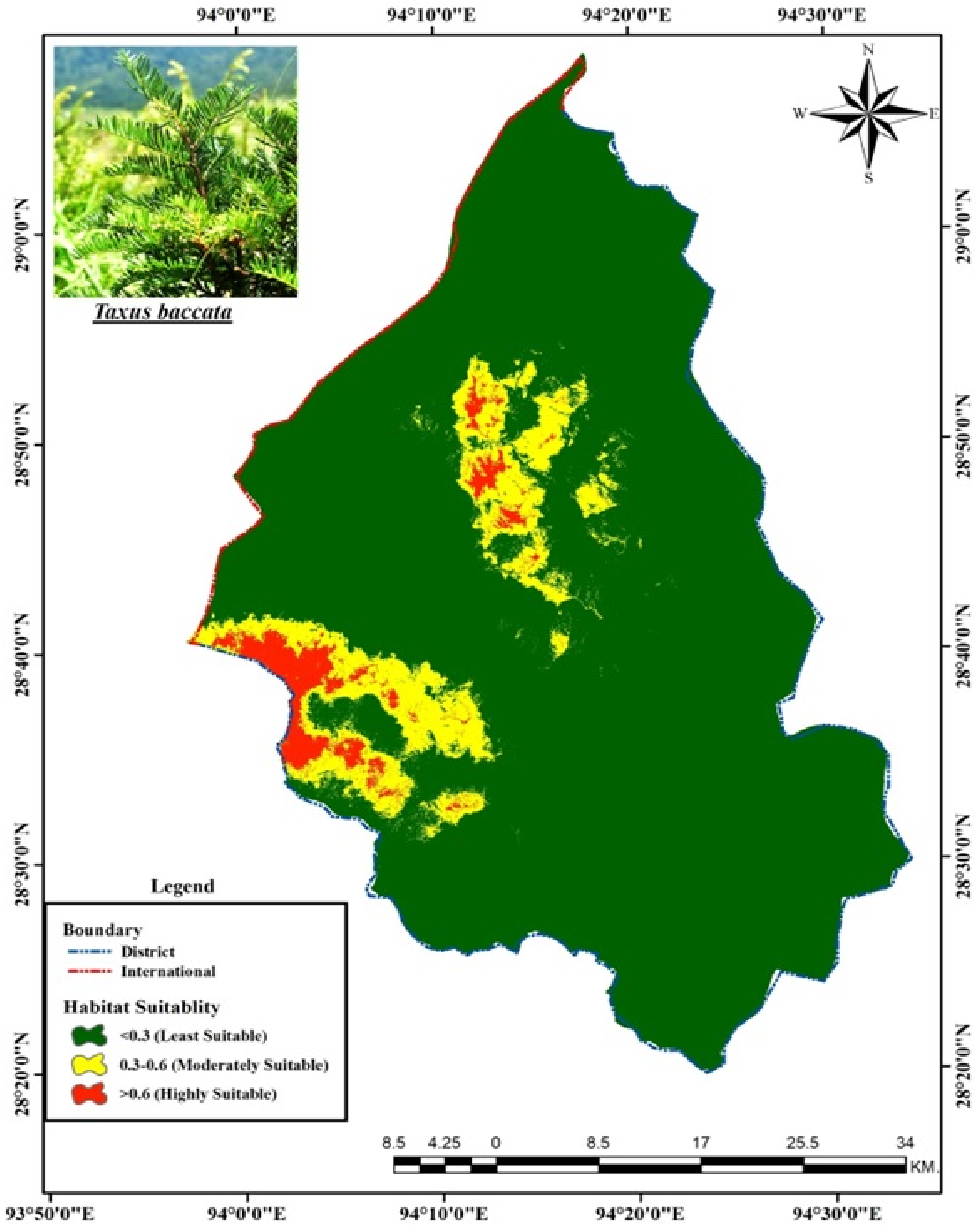

Figure 5. Habitat suitability map of *Taxus baccata* Linn. in the study area

land cover, and soil variables to run the model. The model performed reasonably well. The model predicted only 2.62% of the total area as highly suitable which may be attributed to its restricted area of occupancy. However, the model also predicted about 8.61% of the area as moderately suitable that needs to be explored for confirming the occurrence of the species. The survey recorded more than 100 live plants of *Taxus* in the area but mostly localized in some specific locations. Hence, the area can be considered as one of the natural habitats of *T. baccata*. Of late, some initiatives are in place to cultivate the plant. The Commercial Field Project and Drying Unit in Mechuka are some of the examples. Besides, the local people are unaware of the medicinal and economic values of the plant. Therefore, awareness programs through community participation, especially in the remote villages of the Shi-Yomi district of Arunachal Pradesh are essential. Based on the findings, we recommend evolving suitable strategies to explore the potential habitats of *T. baccata* and lessening human activities like overexploitation, unsustainable collection, and deforestation in suitable habitats of *T. baccata*.

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Authors' contributions: GT (1st author) conceived the idea, designed the methodology, collected the data, and prepared the original manuscript draft. GN (2nd author) supervised, edited, and revised the original manuscript draft. Both authors finally read the manuscript and approved it for publication.

Conflict of interest: The authors do not have any conflict of interest.

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