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ACKNOWLEDGEMENTS. We thank BRNS, Department of Atomic Energy for providing financial assistance. N.R. thanks UGC, New Delhi for financial support in the form of UGC Dr D. S. Kothari Post Doctoral Fellowship.

Received 26 June 2014; revised accepted 31 July 2015

doi: 10.18520/cs/v110/i2/214-219

# Remote sensing and GIS-based suitability modeling of medicinal plant (*Taxus baccata* Linn.) in Tawang district, Arunachal Pradesh, India

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***Taxus baccata*** **is a valuable plant for taxol extraction used in preparation of anti-cancer drugs, Kaposi's sarcoma and over 20 such other indications. It is a slow-growing evergreen tree found in the altitudinal range 1500–3000 m. Around 2–3 million kg of biomass is harvested annually, whereas the sustainable rate of harvesting is estimated to be 0.6 million kg/year. Linear transect recorded 118** ***Taxus*** **plants, out of which 99 were live and 19 were dead. The importance value index was calculated for** ***T. baccata*** **and five associated plants** ***T. mertensiana*** **recorded the highest with 78.32 and** ***T. baccata*** **lowest with 34.22 out of 300. The MaxEnt and SMCE models were used for suitability modeling of** ***Taxus*****. The occurrence points and environmental layers – current global climate, altitude, slope and aspect were used for the MaxEnt. The results show 5.31% area under highly suitable and suitable and 80.14% not suitable. For SMCE, the digital elevation model from USGS website, LISS 3, IRS-P6 (Resourcesat), row/path 110/052 (25 November 2011) the annual average rainfall, temperature and humidity were used. The results show 61.66% under highly suitable and suitable and only 2.8% under not suitable**

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**category. The MaxEnt results are specific and target-oriented, whereas the SMCE results appear more generalized. The region is potential area for occurrence of *T. baccata* in natural stand as well as suitable area for regeneration.**

**Keywords:** Medicinal plants, suitability modeling, taxol, *Taxus baccata*.

TAXUS BACCATA (Himalayan yew) is a small to medium-sized tree, with red berries, valuable for taxol or paclitaxel extraction[1] used in the preparation of anti-cancer drugs, in addition to other medical uses in Ayurveda and Tibetan medicine[2]. It is found in the temperate and least disturbed forests due to inaccessibility and unsuitability for other land uses[3]. However, the ideal altitudinal zone where the tree occurs is between 2000 and 2500 m (ref. 4). The tree has spreading branchlets and leaves arranged in two whorls which are 2.5–3.5 cm long and linear. They are glossy green above and pale beneath which distinguishes it from *Cephalotaxus* and *Tsuga*, which have white leaf undersurface. Fruits are 0.7–1 cm long with succulent bright red disc that covers the blackish olive green seed. It flowers during March to May and seeds are produced during October to November. Natural regeneration is more pronounced under broken canopy[5]. Earlier Pacific yew had been the only source of taxol, but in 1995 Asian yew (*Taxus wallichiana* Zucc.) a closely related plant that grows in the Himalaya has been listed in Appendix II of CITES[6]. Taxol was first isolated from the bark of *Taxus brevifolia*[7]. However, but in India and other parts of the world pharmaceutical companies have succeeded in isolating it from the leaves[8]. Although all 11 species of *Taxus* make taxol, the natural stands of these trees are often small and remote[9]. Moreover, only 0.01–0.03% of the dry phloem weight is taxol; yet as much as 2 g of purified taxol is required for a full regimen of anti-tumour treatment[10]. It is reported that a 20-year-old tree can yield up to 30 kg of leaves and 5 kg of bark, which in turn produce 4 g of taxol priced at Rs 3 lakhs at a conservative estimate[3]. The non-cancer uses are coating of stents (anti-angiogenesis), treatment for Alzheimer, multiple sclerosis and polycystic kidney disease[11]. The bark paste is applied as a plaster on the fractured bone, as well as for relief from headache[12], and the leaves and bark extracts are used for the treatment of bronchitis, asthma, poisonous insect bites and also as an aphrodisiac[13]. The worldwide demand of taxol is 800–1000 kg annually[11]. An estimated 30,000 kg of *T. baccata* biomass is needed to produce 1 kg of paclitaxel. The Tolchha and Marcha Bhotia communities and other traditional societies of the buffer zone in Nanda Devi Biosphere, Garhwal Himalaya, have been collecting the bark mainly for making traditional tea and for curing cold and cough, besides using it for thatching, wood carving, house construction and honey-bee shelter[14]. *T. baccata* is reportedly found in moist temperate Himalaya at an altitude between 1600 and 2700 m in West Kameng, Tawang, Lohit and Dibang Valley districts of Arunachal Pradesh. Tawang district has been identified as one of the important regions where Himalayan yew grows naturally[15,16].

There are several remote sensing and GIS-based techniques used worldwide for habitat/ecological niche modeling of both flora and fauna. Some of the GIS procedures are DOMAIN, BIOCLIM, genetic algorithm for rule set production (GARP), ecological niche modeling (ENM), maximum entropy (MaxEnt), ecological niche factor analysis (ENFA) and SMCE. The ecological niche or habitat of the species can be defined as a ‘set of ecological conditions within which species are able to maintain populations without immigration’[17]. Carpenter *et al.*[18] have described DOMAIN procedure and modeling approach for plant and animal distribution. Saqib *et al.*[2] have used DOMAIN for modeling potential distribution of *T. wallichiana*. Meyer *et al.*[19] applied ENM for species distribution modeling and conservation. Similarly, Menon *et al.*[20] predicted the population of critically endangered species through ENM. According to Phillips *et al.*[21], the MaxEnt approach estimates a species environmental niche by finding a probability distribution that is based on a distribution of MaxEnt (with reference to a set of environmental variables). On the other hand, Benito *et al.*[22] calculated extinction risk through species distribution model for an endangered plant, while Singh *et al.*[23] used multi-criteria model in GIS for tiger habitat suitability and distribution evaluation in Corbett Tiger Reserve.

Tawang district is a part of the Eastern Himalayan biodiversity hotspot that is rich in both floral and faunal diversity, but its ecosystem has been considered fragile and ranked 200 among the ecologically important regions of the world. It lies approximately between 91°30′–92°45′E long. and 27°22′–27°50′N lat. (Figure 1). The district shares an international border with Tibet and Bhutan. The topography of the district is mostly mountainous and its greater part falls within the higher mountain zone, consisting of tangled snow-clad peaks and valleys. The district has distinct physiographic setting based on specific lithology. Tawang Chu and Nyamjang Chu are the main rivers. On the basis of structural and compositional characteristics, the vegetation of the district is broadly classified into temperate, sub-alpine and alpine forests. On an average the area receives 1653 mm rainfall annually and mean maximum and minimum monthly temperatures are 20.88°C and –0.07°C. Tawang district has a total population of 49,977 with 29,151 males and 20,826 females (census 2011). The inhabitants of the district are mainly Monpa tribes of Tibeto-Mongoloid stock.

Intensive transect surveys with the help of local experts, hunters and semi-nomadic herders were conducted randomly to locate *Taxus* trees. Information was also collected through informal interaction with the villagers.

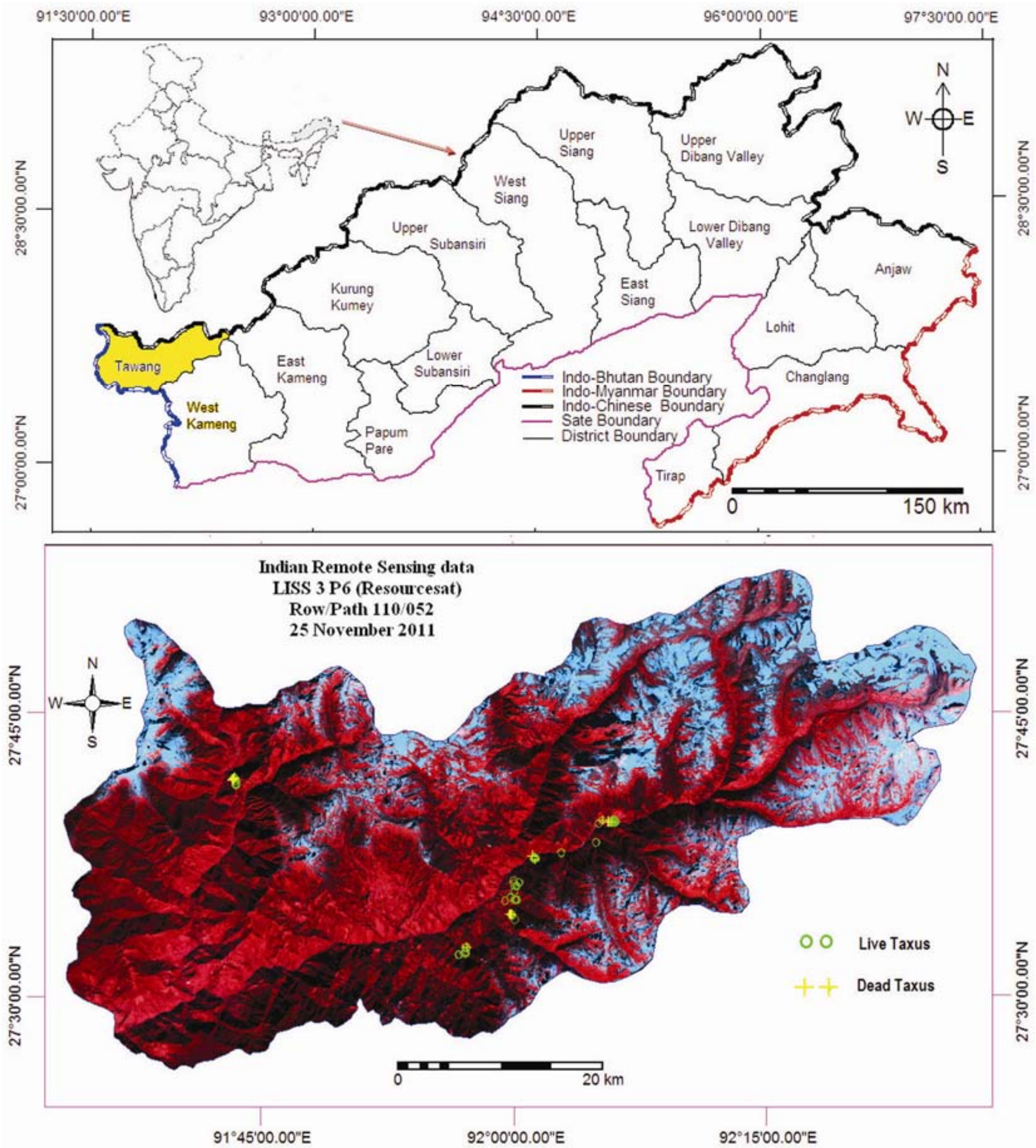


**Figure 1.** Location map of Tawang district, Arunachal Pradesh, Idnia.

GPS was used to record the latitude, longitude and the altitude of the targeted species. At each GPS location the soil moisture, temperature and pH were recorded. Soil samples were also collected for soil textural analysis (hydrometer). Conservation strategies through awareness campaigns, workshops, poster display, pamphlets, calendar, talks, etc. were carried out. The awareness workshops were followed by plantation of *Taxus* plants in and around the Yuthembu Gonpa (Figure 2).

The importance value index (IVI) was calculated to quantitatively determine the importance of *T. baccata* and five closely associated plants in the community structure. Random linear transact measuring $100 \times 100$ m in five different locations has been carried out and the number of individual species, occurrence and basal area have been counted/measured. The percentage values of relative frequency, relative density and relative dominance have been summed up and the resultant value out of 300 designated as the IVI of the species[24]. Relative density is the numerical strength of a species in relation to the total number of individuals of all the species which is calculated as follows:

Relative density =

$$\frac{\text{No. of individuals of the species in all quadrates}}{\text{No. of individuals of all the species in all quadrates}} \times 100.$$

Relative frequency is the degree of dispersion of individual species in an area in relation to the number of all the species that occur.

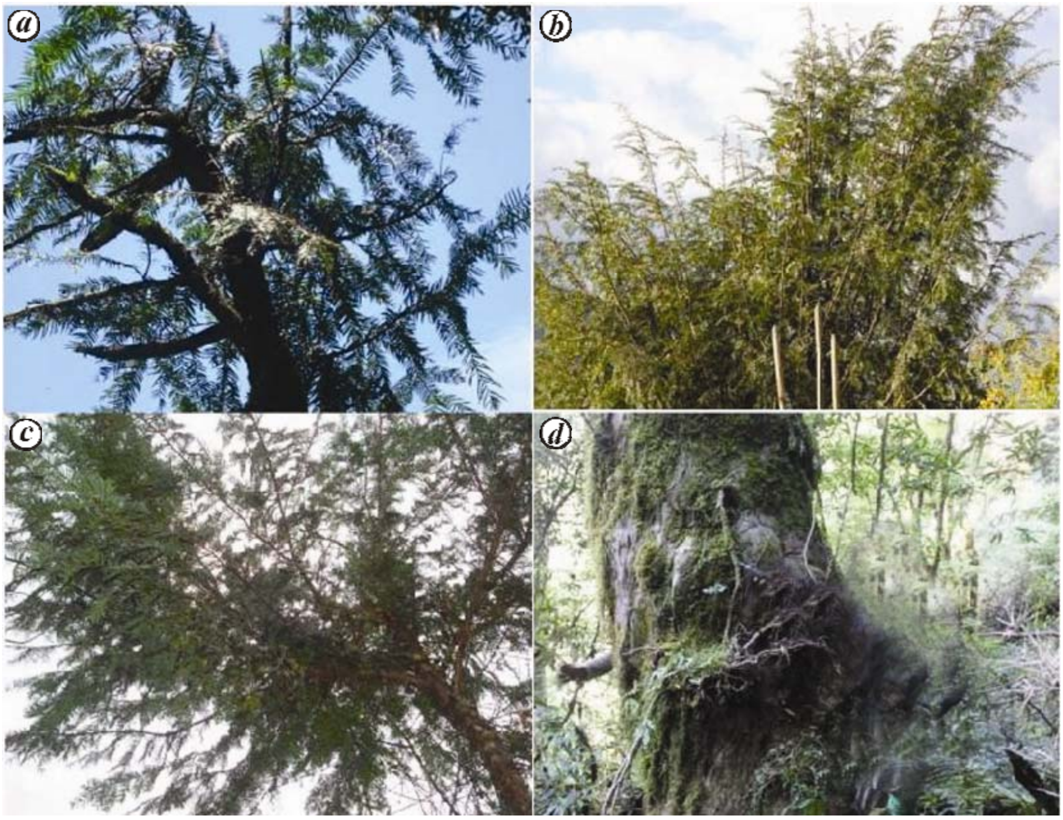

**Figure 2.** *Taxus baccata* near: ***a***, Mukto; ***b***, Jang; ***c***, Zemithang; ***d***, P.I. locating plants with GPS.

Relative frequency =

$$\frac{\text{Number of individuals of the species}}{\text{Number of individuals of all the species}} \times 100.$$

Dominance of a species is determined by the value of the basal cover. Relative dominance is the coverage value of a species with respect to the sum of coverage of the rest of the species in the area.

Relative dominance =

$$\frac{\text{Total basal area of individual species}}{\text{Total basal area of all the species}} \times 100.$$

The total basal area was calculated from the sum of the total diameter of immerging stems. The basal area was measured at breast height (1.5 m).

The occurrence data (GPS points of *T. baccata*) were converted into .CSV format using MS Excel. The environmental layers tile in .BIL format which includes the current global climate data and altitude at 30 arcsec was downloaded from www.worldclim.org. The slope and aspect were generated using surface analysis of ESRI ArcGIS software. Out of the 19 bioclimatic variables, Bio_1 (annual mean temperature), Bio_5 (maximum temperature of the warmest month), Bio_6 (minimum temperature of coldest month), Bio_12 (annual precipitation), Bio_13 (precipitation of wettest month) and Bio_14 (precipitation of driest month) have been used as environmental layers. All the environmental layers were cropped to match the area of interest and submitted to MaxEnt software 3.3.3k for species suitability modeling. The MaxEnt output in .ASC format was imported into ArcMap and the value domain of 0–1 converted to different suitable categories.

The SRTM DEM tile in GeoTIFF format was downloaded from USGS seamless server and cropped for the study area. The 1 arcsec DEM with 30 m spatial resolution was generated from the 3 arcsec SRTM DEM through bicubic polynomial interpolation method[25]. The final DEM was used for deriving altitudinal zones, slope, aspect, and TWI. The 8-bit digital data of Indian Remote Sensing (IRS) LISS 3, IRS-P6 (Resourcesat), row/path 110/052 (25 November 2011) with spatial resolution of 23.5 m of November 2011 were used to derive normalized differential vegetation index (NDVI), normalized differential wetness index (NDWI) and soil brightness index (SBI). The land-use map of 2011 was prepared using LISS 3 data along with NDVI, NDWI, SBI and DEM. Supervised classification technique was used for image classification. It is an essential tool used for extracting quantitative information from remotely sensed image

**Table 1.** Importance value index of *Taxus baccata* and associated plants

| Species | No. of points of occurrence | No. of plants | Total basal area | Relative frequency (F) | Relative density (D) | Relative dominance (DO) | IVI (F + D + DO) |
|---|---|---|---|---|---|---|---|
| *Tsuga mertensiana* | 30 | 45 | 3243 | 30/119 = 25.21 | 45/157 = 28.66 | 3243/12052 = 24.45 | 78.32 |
| *Tsuga canadensis* | 23 | 32 | 2287 | 23/119 = 19.33 | 32/157 = 20.38 | 2287/12052 = 17.24 | 56.95 |
| *Quercus* spp. | 19 | 22 | 2167 | 19/119 = 15.97 | 22/157 = 14.01 | 2167/12052 = 15.59 | 45.57 |
| *Illicium griffithii* | 16 | 23 | 1645 | 16/119 = 13.45 | 23/157 = 14.65 | 1645/12052 = 15.66 | 43.76 |
| *Rhododendron* spp. | 18 | 20 | 887 | 18/119 = 15.13 | 20/157 = 12.74 | 887/12052 = 13.31 | 41.18 |
| *Taxus baccata* | 13 | 15 | 1823 | 13/119 = 10.92 | 15/157 = 9.55 | 1823/12052 = 13.75 | 34.22 |
| | 119 | 157 | 12052 | 100.00 | 100.00 | 100.00 | 300.00 |

data[26]. The sufficient known pixels were collected to generate representative parameters for each class of interest (training). Maximum likelihood classification has been applied to generate the land-use/land-cover map. The point layer of rainfall, temperature and humidity was interpolated through moving average method into raster layers of climatic parameters. Each parameter was standardized into SMCE criteria tree separately for the species according to the ecological requirements. The parameters with value domains were grouped as cost, benefit and combination. Values with positive correlation to goal, i.e. occurrence of species were standardized as benefit and values with negative correlation to goal were standardized as cost. Finally, the SMCE module resulted into a composite map that was sliced into desired layers to produce ecological niche of *T. baccata*.

Linear transects in the vicinity of Jang, Chaagar, Hot Spring, Mukto, Nangsam, Narum Dzong, Pangi, Thnigbu, Sangdongmetse and Zemithang areas of Tawang district recorded a total of 118 *Taxus* plants, out of which 99 were live and 19 were dead plants. Among the 99 live plants, 10 are seedlings, 30 are saplings and 59 are full-grown trees. Most of the plants appeared unhealthy and recovering with regenerated new leaves. Most plants were concentrated in the altitudinal range 2500–3000 m. Only few plants were found in altitudes below 2500 m and above 3000 m. This indicates localized distribution of the species, limited by altitudinal range or other favourable conditions. The live plants are located at an elevation range 2479–3088 m, whereas the dead plants are located in elevation range 2481–2916 m. *Taxus* plants are seen closely associated with *Tsuga mertensiana*, *Tsuga canadensis*, *Illicium griffithii*, *Rhododendron* spp., *Quercus* spp., *Cephelotaxus*, bamboo, etc. Litter-decomposed black soil, brown soil, blackish-brown and sandy soils with small pebbles were the soil types observed. Most of the soil samples have silt loam texture and some have sandy and clayey texture with presence of organic matter and litter. The soil temperature ranges from 8°C to 23°C. The pH value varies from 4.9 to 7 and the soil moisture from 11% to 71%.

The IVI analysis of *T. baccata* and five other closely associated plants – *T. mertensiana*, *T. canadensis*, *I. griffithii*, *Rhododendron* spp. and *Quercus* spp. was carried out to determine the quantitative importance of plants in the community structure. The highest relative frequency, density, dominance and IVI were recorded in *T. mertensiana* as 25.21, 28.66, 24.45 and 78.32 respectively. *T. canadensis* recorded an IVI of 56.95, followed by *Quercus* spp. with 45.47, *I. griffithii* with 43.76 and *Rhododendron* spp. with 41.18 out of 300. *T. baccata* recorded the lowest relative frequency, density, dominance and IVI with 10.92, 9.55, 13.75 and 34.22 respectively (Table 1). The higher values of IVI indicate dominance of the species in the community structure. Therefore, *T. baccata* with lowest IVI is a rare and threatened plant in the area due to illegal trade, forest fire, deforestation, grazing and climate change.

The 120 GPS points of *T. baccata* recorded during the linear transect survey were used as georeferenced occurrence data. The species name, latitude and longitude were entered into Excel spreadsheet and converted to .CSV format as input layer. Out of 120 occurrence points, 17 presence records were used for training and 2866 points were used to determine MaxEnt distribution (background and presence points). Bio_1, Bio_5, Bio_6, Bio_12, Bio_13 and Bio_14, altitude, slope and aspect (generated from altitude map through surface analysis of ArcGIS) were used as input layers of environmental variables. The regularized training gain was 1.623, unregularized training gain was 2.167 and algorithm converged after 400 iterations (5 sec). The relative contributions of the environmental variables to the MaxEnt model show that the highest gain when used in isolation is Bio_6, which therefore appears to have the most useful information regarding species distribution. The environmental variable that decreases the gain the most when it is omitted is aspect, which therefore appears to have the most information that is not present in the other variables. The final output in .ASC format was imported to ArcMap and the value domain of 0–1 was redistributed into five suitable classes, viz. 0–0.17 (not suitable), 0.17–0.34 (slightly suitable), 0.34–0.51 (moderately suitable), 0.51–0.68 (suitable) and 0.68–0.85 (highly suitable). The area under not suitable category constitutes 80.14% of total area followed by slightly suitable with 9.09%. The areas under moderately

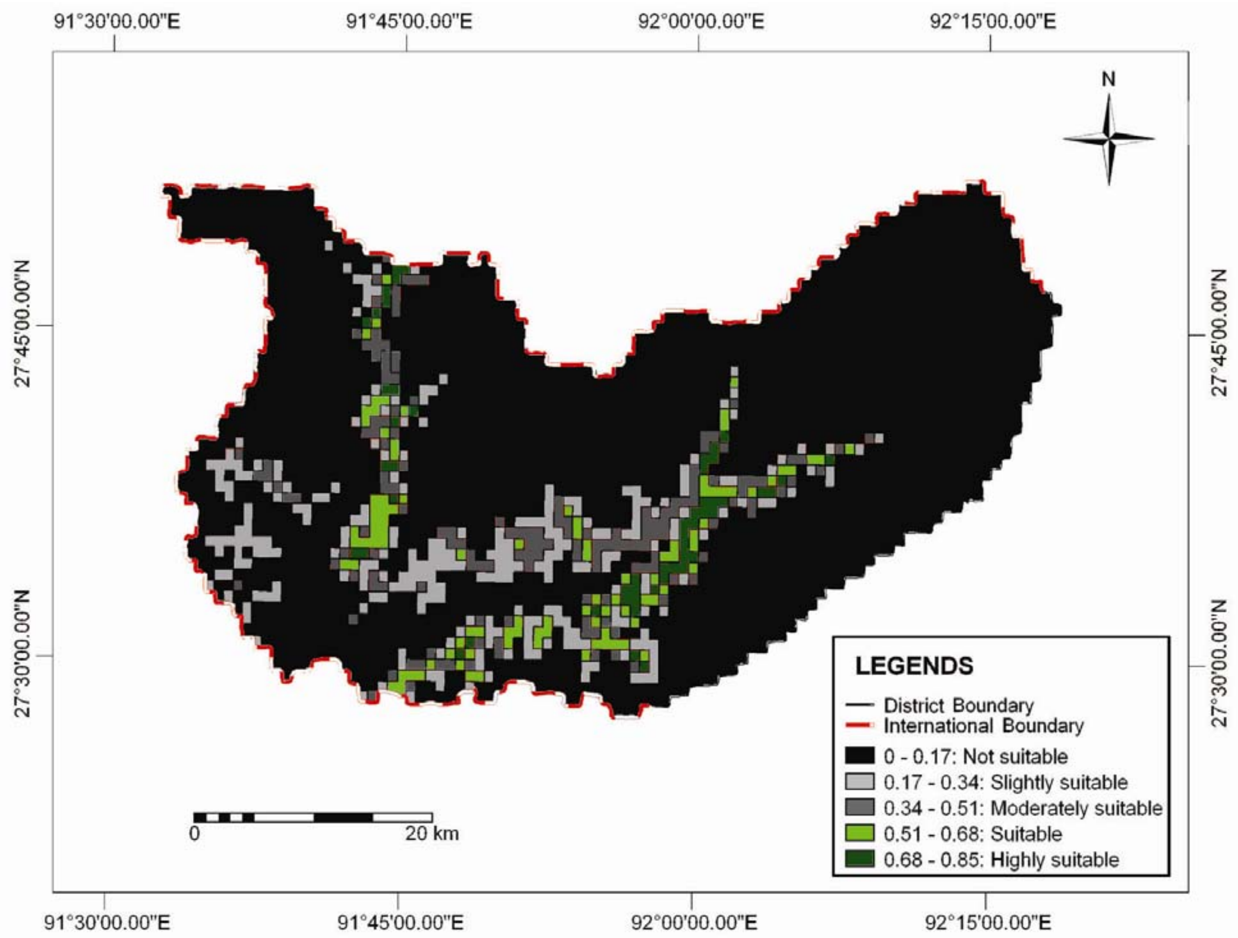


**Figure 3.** MaxEnt suitability modelling of *T. baccata* Linn.

**Table 2.** MaxEnt suitability categories of *Taxus baccata*

| Suitability index | Category | Area (sq. km) | Area (%) |
|---|---|---|---|
| 0–0.17 | Not suitable | 1724.16 | 80.14 |
| 0.17–0.34 | Slightly suitable | 195.60 | 9.09 |
| 0.34–0.51 | Moderately suitable | 117.40 | 5.46 |
| 0.51–0.68 | Suitable | 74.58 | 3.46 |
| 0.68–0.85 | Highly suitable | 39.71 | 1.85 |

suitable, suitable and highly suitable constitute 5.46%, 3.46% and 1.85% respectively (Table 2 and Figure 3). Hence, the suitability modeling of MaxEnt appears more localized and specific to the environmental variables and the georeferenced occurrence data of the species. However, there are limitations in the derivation and use of environmental layers in the model. Some of the important variables like land use/land cover, NDVI, NDWI, SBI, etc. could not used in the model.

DEM derivates such as altitude, slope, aspect and TWI exercise dominant influence on vegetation type, climatic condition and soil type of an area and thereby indirectly modifies the distribution of plant species. The altitude ranges from 907 to 6429 m with an average of 3755 m. Slope angle ranges between 0° and 84° with an average of 28°. The aspect ranges from 0 to 360, which have been divided into eight directions and plain/flat area. Maximum slope in the study area decline towards southwest. TWI ranges from 4.18 to 23.15. The highest values occur on the rivers and lowest values occur along the ridges and peaks. The land use/land cover of 2011 shows 22% area under alpine forest followed by barren surface (20.38%), temperate forest (16.53%), alpine grassland/degraded forest (11.71%) and water body (7.58%). The settlements cover 7.49%, deciduous forests 4.08%, snow 3.33% and agriculture 3.32%. About 2.86% area is under shadow due to declination of the Sun, while subtropical and tropical forests have a meagre share of 0.63% and 0.09%. NDVI ranges between < –0.4 and > 0.5 with an average of 0.13. Similarly, NDWI varies from <–0.4 to >0.7 with an average of 0.2. SBI varies from 17.95 to 305.24 with an average of 74.41. The average annual rainfall fluctuates between 1745 and 2025 mm. Similarly, the average annual temperature ranges from 13.07°C to 16.42°C. The average annual relative humidity ranges from 66.87% to 72.23%. All the parameters were submitted to SMCE to

**Table 3.** SMCE habitat suitability categories of *T. baccata*

| Suitability index | Category | Area (sq. km) | Area (%) | GPS points | |
|---|---|---|---|---|---|
| | | | | Pixel | Percentage |
| 0.09–0.26 | Not suitable | 69.72 | 2.8 | 0 | 0 |
| 0.26–0.43 | Less suitable | 350.16 | 14.08 | 0 | 0 |
| 0.43–0.59 | Moderately suitable | 533.60 | 21.46 | 0 | 0 |
| 0.59–0.76 | Suitable | 928.06 | 37.32 | 56 | 47.46 |
| 0.76–0.93 | Highly suitable | 605.14 | 24.34 | 62 | 52.54 |
| | Total | 2486.68 | 100 | 118 | 100 |

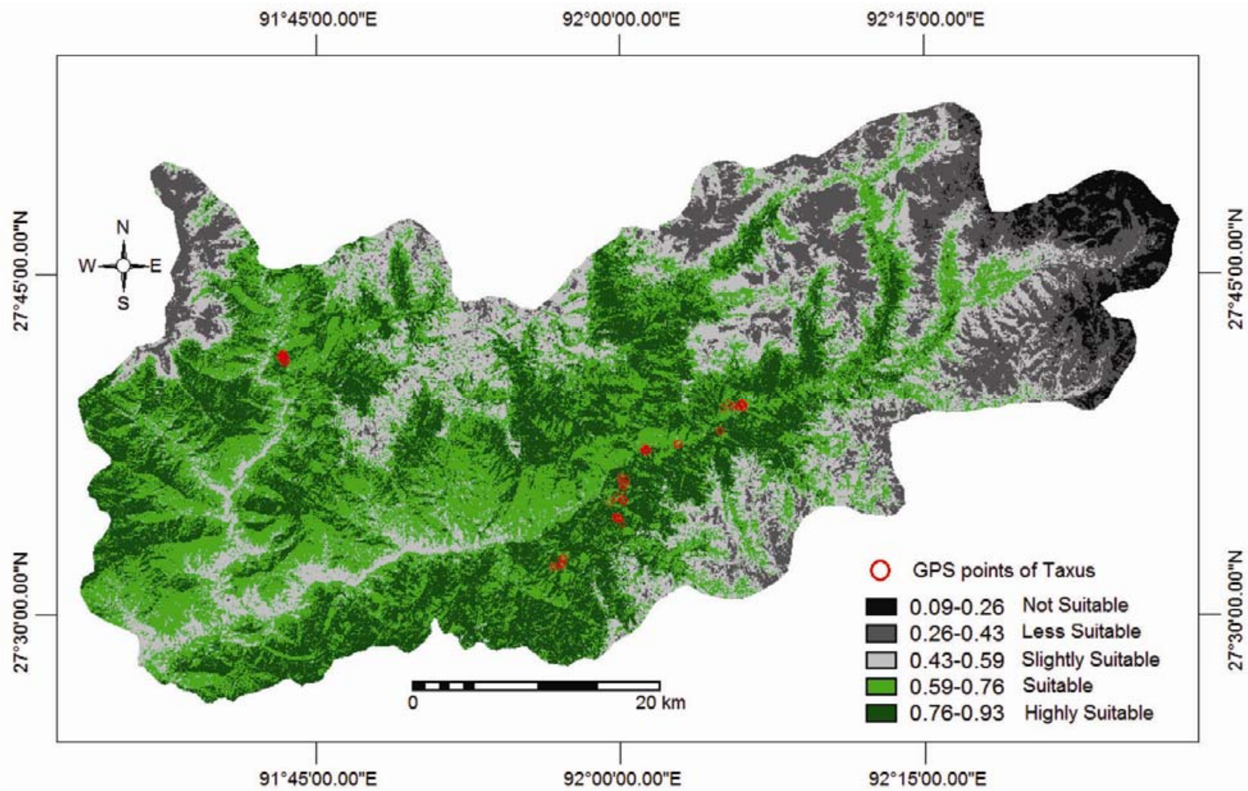


**Figure 4.** SMCE suitability modelling of *T. baccata* Linn.

analyse the ecological niche modelling of *T. baccata*. The area has been divided into five suitable classes on the basis of composite index derived from the parameters. Areas with composite index ranging from 0.09 to 0.26 have been bundled into not suitable category, which constitutes only 2.8% of the total area. The less suitable category, with composite index of 0.26–0.43 covers 14.08% (Table 3 and Figure 4). Maximum area falls under suitable category (37.32% of the total area) followed by highly suitable (24.34%) and moderately suitable (21.46%). The GPS points of *Taxus* plants have been overlaid on top of suitability map for cross verification of the results. All the 118 GPS points occurs in the highly suitable and suitable zones which support the results of modeling. However, errors cannot be ruled out in the absence or lack of parameter data for the growth of *Taxus* plants.

Large-scale exploitation of *Taxus* plants has taken place during 1990s in the study area. The villagers reported that *Taxus* (locally known as *Tesiang*) is now not found within 8–10 km radius from the villages. The linear transect in the forests reveal many dead plants. Similar plight of *Taxus* trees is also observed in Sanglem, Morshing, Domkho, Mandlaphudung, New Bomdila and Palizi–Ramda areas of the adjacent West Kameng district[27]. The complete extraction of leaves resulted in the death of the plants. In the absence of standard lopping method, the leaves were pruned mercilessly to the extent that it the plants died. Moreover, the pressing demands and associated lucrative price have lured middlemen and villagers to plunder this scarce resource pushing it to near extinction. The villagers expressed ignorance about the importance and vulnerability of the tree. Surprisingly, even the seedlings or young plants are conspicuous by their absence in the vicinity of the dried up trees. This confirms the reported poor regeneration, germination and survival rates of the plant[4]. However, there could be many reasons attributed to this phenomenon. First, the dense forest with thick undergrowth may have prevented the growth of seedlings as the natural regeneration is reported to be good in broken canopy than dominant canopy. According the IVI analysis, the dominance of *Taxus* is less in compared to the associated plants like *T. mertensiana*, *T. canadensis*, *I. griffithii*, *Quercus* spp. and *Rhododendron* spp. The second reason is the browsing of wild animals, cattle and fowls. Thirdly, illegal trade also cannot be ruled out. Clandestine trading of the species is taking place in some states where young saplings raised by the locals are being collected by agents and sold abroad through an established network[28]. In 2001, Assam forest officials at Tezpur seized 220 bags of *Taxus* leaves loaded in three trucks from Arunachal Pradesh, which strongly suggests deeply entrenched nexus among politicians, contractors and forest officials operating in Arunachal Pradesh[15]. A local firm in West Kameng district had entered a lease agreement with the state Forest Department in November 2001, to collect *Taxus* leaves from West Kameng and Tawang districts for 15 years. In the context of rapid changes owing to such forest losses, vegetation cover and species population are expected to decrease over small spatial scale[29]. The excessive species loss could also lead to collapse of the ecosystem[30]. Land-use changes also contribute to shrinking yew habitat, through logging of old-growth stands, often in combination with grazing and burning[31]. Such activities have transformed the forest landscape and affected vegetation dynamics, especially shade-tolerant and late-successional species like yew[32].

In order to carry out habitat suitability modeling, the most widely used MaxEnt model and SMCE module were used to compare the results. The results show varied probable distribution pattern of the species. The MaxEnt results show maximum area under not suitable category, and least area under suitable and highly suitable categories. On the other hand, the SMCE results show maximum area under suitable and highly suitable categories, and least area under not suitable category. Keeping in view the occurrence data recorded during the field survey, the results of MaxEnt appear more accurate and specific on the possible distribution of the plant. The advantage of MaxEnt model is the use of occurrence data as an input layer while performing the suitability modeling. The SMCE results are more generalized as the occurrence data are overlaid externally on top of the suitability model to verify the results. Moreover, errors in the generation of parameter characteristics cannot be ruled out. The area under not suitable category, i.e. only 2.8% is also questionable as there are barren lands, rivers, settlements and agricultural fields. The presence of a well-structured adult population, suggests that climate, topography and vegetation of an area create conditions that favour yew survival[33]. Yew was mainly found at 1000–1600 m elevation on mesic exposures (north and west), and intermediate slopes of 30–60% (ref. 31). The multiple approach model shows that the distribution of *Taxus* is influenced by precipitation variables, less resistant to grazing livestock, more confined to inaccessible places, and regeneration is negatively influenced by soil nitrate[34]. This region is the potential area for the occurrences of *T. baccata* in natural stands. In other words, the highly suitable and suitable zones are the best areas for regeneration of this species.

The rampant exploitation of *Taxus* has occurred in many areas of West Kameng and Tawang districts of Arunachal Pradesh during 1990s. Since no regulatory mechanism and standardized harvesting techniques were adopted, the trees dried up once their leaves were harvested. Consequently, *Taxus* is not available in the area except a sacred grove or preserved forest area in Zemithang that has about 30–40 trees in natural stands. No systematic approaches have been made to regenerate the plant through active participation of the communities and the people are also not coming forward to take up such challenges. The State Forest Research Institute, Itanagar and National Medicinal Plant Board have started a nursery and propagation trial project near Bomdila. But, the nurseries lack maintenance and regular care leading to drying up of *Taxus* saplings. Thus, the findings show adverse effects of exploitation on *Taxus* plant, poor natural regeneration, localized natural growth and no tangible efforts to regenerate the plants. The regeneration of the plant involves risk and uncertainty to the villagers. Besides, there is a need of special care and additional financial involvement in providing proper fencing to protect the plants from browsing animals. The farmers are reluctant to regenerate *Taxus* plants on their own, even if they have a huge demand in the pharmaceutical industries. Therefore, systematic strategies through larger awareness, community participation, suitable propagation techniques, *in situ and ex situ* trials, demonstration, financial and infrastructural assistance, adequate remuneration and suitability modelling of the plant could conserve and regenerate this valuable medicinal plant. More importantly, there is also a need of regulatory mechanism and standardized harvesting techniques for sustainable use. The results of habitat suitability of MaxEnt and SMCE show the probable areas of species occurrence in the district. Such areas need to be explored through field visits to verify the presence of the plant. Besides, regeneration efforts in the suitable and highly suitable areas could play a significant role in successful conservation of this important medicinal plant.

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ACKNOWLEDGEMENTS. We thank the villagers of Tawang district, Arunachal Pradesh, India for their cooperation and participation works. We also thank University Grants Commission, New Delhi for providing funds through a major project on the status and conservation of *Taxus baccata* in the study area.

Received 18 November 2014; revised accepted 5 August 2015

doi: 10.18520/cs/v110/i2/219-227