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Original article

The relationship of Himalayan Yew (*Taxus baccata* L.) with Other Plant Communities and Environmental Factors in the Western Part of Bhutan

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ABSTRACT

Taxus baccata L. is a rare and lesser known tree species with important medicinal values. However, very sparse data, related to its occurrences in western Bhutan, is available. In this study, the distribution and abundance of the species was determined in relation to the environmental variables (soil nutrients, soil texture, and topography), through the non-aligned systematic sampling method. The data were analyzed using multivariate and univariate statistical techniques. The study recorded 48 tree species under 21 families, from 70 sampled plots. *T. baccata* was present only in 10 plots, where 28 tree species under 15 families were recorded. In the plots with *T. baccata* , the tree species with higher importance values were *T. baccata*, *Rhododendron arboreum, Quercus lamellosa, Acer campbellii,* and *Tsuga dumosa,* whereas the species with a higher basal area were *T. baccata*, *Tsuga dumosa, Quercus lamellosa, Acer campbellii,* and *Rhododendron arboreum*. The means of environmental variables between plots with and without *T. baccata* showed a highly significant difference for the potassium content and elevation, whereas the soil texture variables did not show any significant differences. Logistic regression analysis of all the covariates indicated that sand and magnesium level, elevation, and aspect as being somewhat significant for the presence of *T. baccata*. In contrast, the calcium content had a negative influence but was not significant for the presence of *T. baccata*. The study indicated that the occurrence of *T. baccata* was dependent on specific environmental factors. This information will be useful for the ecological management of the *T. baccata* species in Bhutan.

Keywords: Himalayan Yew, *Taxus baccata*, plant communities, distribution, environmental factors,

INTRODUCTION

Within the Taxaceae family, *Taxus* is a genus of morphologically similar looking species distributed in the northern hemisphere. Among the different *Taxus* species, *Taxus baccata* L. is distributed in Europe, North Africa, the Caucasus, Iran, and the temperate regions of the Indian sub-continent (Lanker *et al.*, 2010). *T. baccata* is also known as Himalayan Yew (hereafter referred to as *T. baccata*). Though distributed widely in the Himalayas from Afghanistan in the west to Bhutan in the east at altitudes between 1,800 and 3,400 meters above sea level (masl), this under-canopy species never forms an extensive cover and commonly occurs in patches (Shaheen *et al.*, 2015). Similarly, *T. baccata* is found in Pakistan, southwest China, Nepal and Bhutan in the altitudinal range from 1,800 to 3,300 masl (Lanker *et al.*, 2010). In the Indian Himalayas, it is found in Jammu and Kashmir, Himachal Pradesh, Uttarkhand, Meghalaya, Nagaland, and Manipur (Poudel *et al.*, 2013). *T. baccata* is found mainly along with oak and spruce in the western Himalayas and in eastern Himalayas, it is found alongside silver fir, hemlock, spruce, and rhododendron (Lanker *et al.*, 2010).

In the past, timber from *T. baccata* was used for manufacturing bows (Katsavou and Ganatsas, 2012) and as colorful wood to be used in veneer furniture, combs, tool handles, pegs, and various art objects (Voliotis, 1986). In the recent years, studies have indicated that the *Taxus* species is an important source of the anti-cancer drug Taxol (Malik *et al.*, 2011). Taxol was first isolated from the bark of *Taxus brevifolia,* one of the species from genus *Taxus* (Bissery *et al.*, 1991; Gordaliza, 2008). The demand for Taxol drug is growing at an annual rate of 20% (Nimasow *et al.*, 2015). The leaves are used for the internal treatment of asthma, bronchitis, hiccups, indigestion, rheumatism, and epilepsy (Manoharachary and Nagaraju, 2016). Externally, the leaves are used in a steam bath as a treatment for rheumatism. At high altitude Himalayan regions, the local inhabitants use its bark for making a traditional tea for the treatment of cough and cold (Purohit *et al.*, 2001), while the bark paste is applied externally to cure headache (Maikhuri *et al.*, 2000).

T. baccata belongs to a rare and endangered species in the Central and East-European countries (Iszkulo *et al.*, 2005). This species has been exploited in the Himalayas (Shaheen *et al.*, 2014), due to a large number of leaves ebing plucked and the peeling of bark (Perrin and Mitchell, 2012). Over-harvesting of *T. baccata* from the forests along the Indian Himalayas along with poor natural regeneration is collectively responsible for the rapid decline in population of *T. baccata* in this region (Rikhari *et al.*, 1998; Lanker *et al.*, 2010). Garcia *et al.* (2000) has deemed *T. baccata* as an 'endangered' species in the Himalayan region.

T. baccata is considered as a flagship tree, one of the longest living in the world, with a tremendous cultural, natural, and scientific heritage value. It has a special status under the laws of some EU countries and some of the population is included within the habitat-type “Forests Mediterranean *T. baccata*”. Such species have been declared a priority for conservation in the Annex I of the Habitats Directive (Piovesan *et al.*, 2009; Peragon *et al.*, 2015).

According to Grierson and Long (1983), *T. baccata* is the only representative of Taxaceae family in Bhutan. The species is included in the Schedule-I (totally protected plant species) of the Forest and Nature Conservation Act of Bhutan (RGOB, 1995), Forest and Nature Conservation Rules of Bhutan (RGOB, 2006), and in the subsequent acts and rules. However, there is a paucity of information on the species distribution, stand characteristics, and the influence of environmental factors on the habitat selection of *T. baccata* in Bhutan. This lack of information is restricting planners and policy makers in formulating conservation and management strategies for this ecologically and economically important tree species. Therefore, this study investigates the distribution and abundances of *T. baccata* and the influence of environmental factors on the presence of *T. baccata* in the western part of Bhutan.

MATERIALS AND METHODS

1. Study area

The study site is located in the western part of Bhutan within the Thimphu District (27º27’39.71” N to 27º 32’04.11” N and 89º43’05.43” E to 89º47’56.17” E). The research area covered an altitude range from 1,700 to 3,500 masl, with varying geographical aspects and slope gradients. It included a contrasting Blue pine forest on the dry western slopes and a wet oak-laurel forest on the eastern slopes, separated by the Dochula ridge (3,185 masl) consisting of a humid cool Mixed conifer forest.

The forest changed from a Broadleaved forest type in the lower valley to Blue pine forest, mixed conifer forest, and to a Fir forest on the ridge top. At the bottom of the valley, the climatic conditions are dry, warm, and mostly sunny compared to that on the ridge top, which has a higher humidity and cloud cover for most part of the year. The upper slopes of the study area are topographically steep and consist of several knolls and gullies along the altitudinal gradient which made the vegetation heterogeneous in many places (Wangda and Ohsawa, 2006).

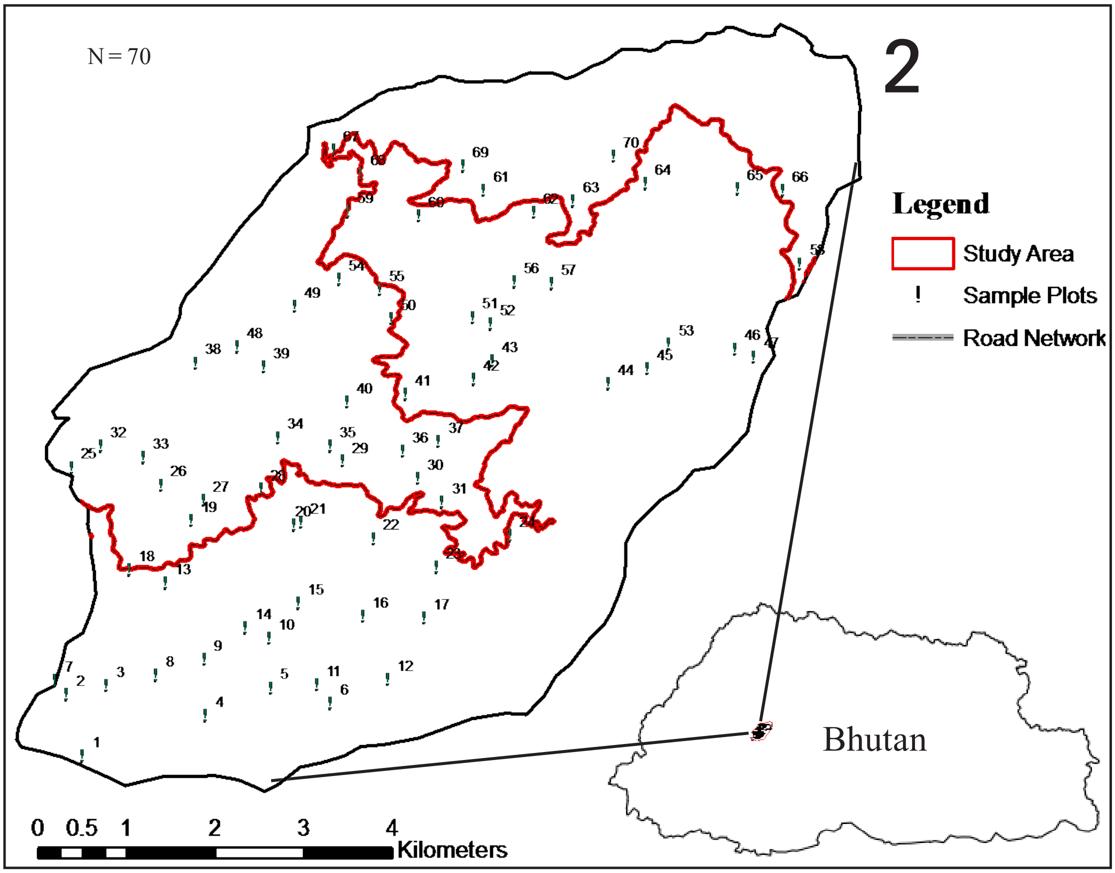

Figure 1 Location map showing the sample plots in the study site.

2. Data collection

In total, 70 stands (N = 70) were sampled (Figure 1) using the Non-Aligned Systematic Sampling Method (Kalkhan, 2011), by randomly selecting one plot within a 600 m x 600 m gridline. Three major forest types (Blue Pine Forest, Broadleaved Forest and Mixed Conifer Forest) were considered in this study. Trees with diameter at breast height at 1.3 m (DBH) $\geq$ 10cm were selected for basal area calculation. The height and DBH were classified for the determination of height and diameter class distribution. Aspect, slope gradient, and elevation were also recorded. Composite soil samples were collected from all 70 plots for the analysis of soil nutrients (calcium or Ca, magnesium or Mg, cation exchange capacity or CEC, available potassium or K, pH, available phosphorus or P, organic matter, and total nitrogen or N), soil texture (sand, silt, and clay) and topographical variables (aspect, slope, and elevation).

3. Data analysis

The data were analyzed using both univariate and multivariate statistical techniques. Importance values of the tree species were obtained by summing up the relative density and relative dominance. Canonical correspondence analysis (CCA) was used to investigate the relationship of importance values with the environmental variables. The plant community data were analyzed using the "vegan" package version 2.5-2 (Oksanen *et al*., 2018) available on the R platform (R Core Team, 2013). The soil data were analyzed using the "soiltexture" package version 1.4.6 (Moeys, 2018). The soil pH was analyzed using the soil-water suspension method, available K was analyzed using the segmented flow analyzer and flame photometer method, available P using the Bray and Kurtz method. The total N content was determined using the Kjeldahl flow analyzer method, CEC using ammonium acetate method, and Ca and Mg by using the atomic absorption spectrophotometer. A binary logistic regression was used to test the important covariates responsible for the presence of *T. baccata*.

RESULTS AND DISCUSSION

1. Overall Plant Community Structure and Species Composition

All the 70 plots were sampled (along different altitudes, slopes, and aspects) and analyzed. In the tree species (DBH ≥ 10cm) category, 48 tree species from 21 families and 35 genus were recorded. Within these, 32 species were evergreen and 16 species were deciduous (during the dry season).

The dominant families were: Ericaceae (8 species), Fagaceae (5 species), Pinaceae, Betulaceae, Rosaceae, Symplocaceae and Lauraceae (4 species each), Magnoliaceae (2 species) and Primulaceae, Aquifoliaceae, Salicaceae, Cupressaceae, Hydrangeaceae, Anacardiaceae, Fabaceae, Moraceae, Sapindaceae, Oleaceae, Taxaceae, Pentaphylacaceae, and Araliaceae (1 species each).

Dominant species containing higher importance values were *Pinus wallichiana* A. B. Jacks., *Acer campbellii* Hook. f. & Thomson ex Hiern, *Tsuga dumosa* (D. Don) Eichler, *Castanopsis hystrix* Hook. f. & Thomson ex A. DC. and *Quercus glauca* Thunb., with values of 17.35, 16.31, 16.28, 13.55, and 10.32, whereas *Tsuga dumosa* (D. Don) Eichler, *Acer campbellii* Hook. f. & Thomson ex Hiern, *Quercus lamellosa* Sm., *Castanopsis hystrix* Hook. f. & Thomson and *Pinus wallichiana* A. B. Jacks had higher basal areas with values of 4.19, 2.33, 2.27, 1.77, and 1.72 m^2 ha^{-1}, respectively. Similarly, the dominant species with higher densities were *Pinus wallichiana* A. B. Jacks. *Rhododendron arboreum* Sm., *Quercus semecarpifolia* Sm., *Tsuga dumosa* (D. Don) Eichler and *Acer campbellii* Hook. f. & Thomson ex Hiern, with density values of 30.25, 23.69, 23.40, 19.41, and 18.55 trees/ha, respectively. Overall, the average species richness, evenness, and diversity were 4.29, 0.78, and 1.11, respectively.

1.1 Structure and species composition of the Blue pine forests

There were 12 sample plots in the Blue pine forest (Figure 2a), with 14 different tree species in 13 genus and 9 families. Of the total species, 11 species were evergreen and 3 were deciduous. The dominant families were Ericaceae and Pinaceae (3 species each), Fagaceae (2 species), Salicaceae, Cupressaceae, Sapindaceae, Taxaceae, Aquifoliaceae, and Rosaceae (1 species each), respectively. Species with a high importance values were: *Pinus wallichiana* A. B. Jacks., *Tsuga dumosa* (D. Don) Eichler, *Quercus semecarpifolia* Sm., *Picea spinulosa* (Griff.) A. Henry, and *Quercus lamellosa* Sm. with values of 106.00, 38.09, 16.50, 12.40, and 9.78, respectively. The average species richness, evenness, and diversity in Blue pine forest were 3.75, 0.72, and 0.98, respectively.

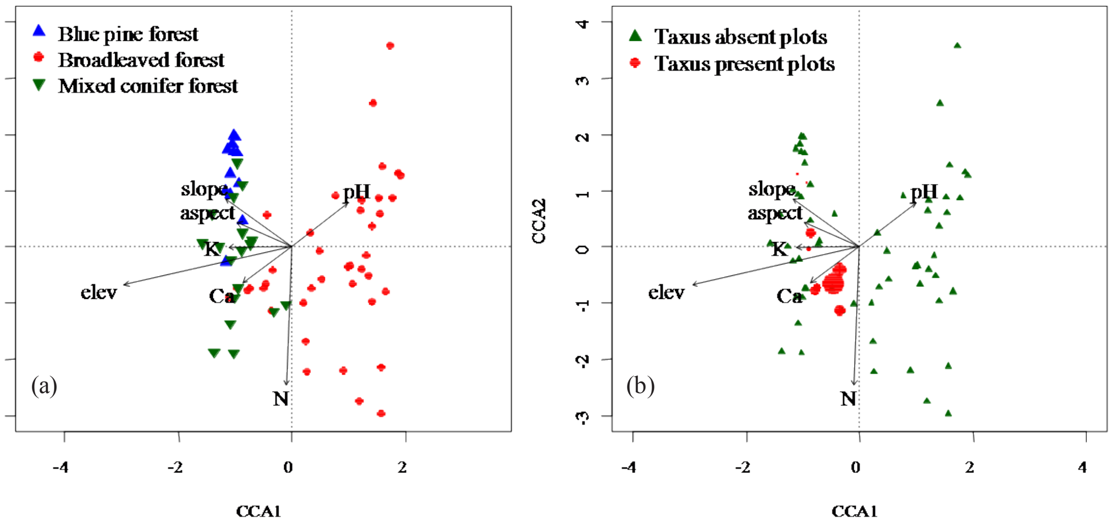

Figure 2 Bi-plot resulting from CCA: (a) plant communities and environmental variables, (b) variables in plots with and without *T. baccata,* based on importance values. (elev=elevation, k=potassium, Ca=calcium, N=nitrogen).

1.2 Structure and species composition of the Broadleaved forest

In total, 40 sample plots were located in the Broadleaved forest (Figure 2a), with 41 different tree species in 30 genus and 19 families. Out of the total, 28 species were evergreen and 13 were deciduous. The dominant families were Ericaceae (6 species), Fagaceae (5 species), Symplocaceae and Lauraceae (4 species each), Betulaceae, Rosaceae and Pinaceae (3 species each), Magnoliaceae (2 species) Aquifoliaceae, Araliaceae, Hydrangeaceae, Anacardiaceae, Primulaceae, Moraceae, Sapindaceae, Oleaceae, Taxaceae, Pentaphylacaceae, and Fabaceae (1 species each), respectively. Species with a high importance values were: *Castanopsis hystrix* Hook. f. & Thomson ex A. DC., *Acer campbellii* Hook. f. & Thomson ex Hiern, *Quercus glauca* Thunb., *Symplocos sumuntia* Buch.-Ham. ex D. Don and *Quercus oxyodon* Miq. with values of 23.06, 22.97, 18.06, 15.23, and 11.92, respectively. The average species richness, evenness, and diversity in Broadleaved forest were 4.13, 0.77, and 1.08, respectively.

1.3 Structure and species composition of the Mixed conifer forests

In total, 18 plots were sampled (Figure 2a) containing 29 different tree species in 23 genus and 13 families. There were 20 evergreen and 9 deciduous species. The dominant families were: Ericaceae (7 species), Pinaceae and Rosaceae (4 species each), Betulaceae and Fagaceae (3 species each), Taxaceae, Araliaceae, Cupressaceae, Aquifoliaceae, Sapindaceae, Lauraceae, Pentaphylacaceae, and Hydrangeaceae (1 species each), respectively. Tree species with a high importance values were: *Tsuga dumosa* (D. Don) Eichler, *Rhododendron arboreum* Sm., *Quercus lamellosa* Sm., *Rhododendron barbatum* Wall. ex G. Don, and *Picea spinulosa* (Griff.) A. Henry with value of 27.97, 19.38, 18.39, 15.95, and 15.08, respectively. The average species richness, evenness, and diversity in Mixed conifer forest were 4.94, 0.83, and 1.25, respectively.

1.4 Forest type and environmental factors

CCA was applied to investigate the relationship between different forest types (Blue pine, Broadleaved, and mixed conifer) and the environmental variables, as shown in Table 1. When all the environmental factors (Ca, Mg, CEC, pH, OM, N, P, K, sand, silt, elevation, slope, aspect) were investigated, the total inertia was 12.70 and the constrained value was 2.96. When the total variance explained by the CCA was calculated, the sum of all constrained eigenvalues divided by the total variance (inertia) was 23.30%. CCA1 explained 5.52% of the variance , the CCA2 3.50%, and cumulatively, the CCA1 and CCA2 explained 9.02% of the total variance. The first four CCA axes were readily interpretable and the eigenvalues obtained were 0.70 (axis1), 0.44 (axis2), 0.40 (axis3), and 0.28 (axis4), with subsequent axes < 0.25.

However, when the significant variables (Ca, pH, N, K, elevation, slope, and aspect) were investigated, the total inertia was 12.70 and the constrained value was 1.97. The total variance explained by the CCA was 15.52%. CCA1 explained 5.37% of the variance , the CCA2 3.32%, and cumulatively, CCA1 and CCA2 explained 8.69% of the total variance. The first four eigenvalues obtained were 0.68 (axis1), 0.42 (axis2), 0.27 (axis3), and 0.19 (axis4), with subsequent axes < 0.18.

Table 1 Total inertia, eigenvalues, and variances resulting from a CCA of the environmental variables obtained from 70 sample plots.

	Constrained	Total	CCA1	CCA2	CCA3	CCA4
All the covariates						
Inertia	2.96	12.70				
% Proportion	23.30	100.00				
Eigenvalue			0.70	0.44	0.40	0.28
% Variance explained			5.52	3.50	3.12	2.19
% Cumulative variance			5.52	9.02	12.13	14.32
Significant covariates						
Inertia	1.97	12.70				
% Proportion	15.52	100.00				
Eigenvalue			0.68	0.42	0.27	0.19
% Variance explained			5.37	3.32	2.14	1.51
% Cumulative variance			5.37	8.69	10.83	12.34

Note: CCA = Canonical Correspondence Analysis

The results in Figure 2(a) indicate that the soil pH strongly associated with Broadleaved forest whereas potassium had a negative association. Blue pine forests were found on the steeper north facing slopes compared to the two other forest types. The mixed conifer forests were found at higher elevations and had a positive correlation with potassium and calcium.

The study also investigated the relationship between the importance values of *T. baccata* and environmental variables using CCA (Figure 2b). The results showed that *T. baccata* was strongly associated with calcium, nitrogen, and elevation, whereas potassium, slope, and aspect were weakly associated. In contrast, the soil pH was negatively associated with *T. baccata*.

2. Tree species composition in *T. baccata* stands

T. baccata was found in 10 (including trees, saplings, and seedlings) out of the 70 sampled plots. In total, 28 tree species (DBH≥10cm) in 15 families and 24 genus were recorded. From the total, 20 species were evergreen and 8 were deciduous.

The dominant families were Ericaceae (5 species), Pinaceae (4 species), Rosaceae, Fagaceae and Lauraceae (3 species each), Sapindaceae, Betulaceae, Hydrangeaceae, Taxaceae, Salicaceae, Aquifoliaceae, Symplocaceae, Pentaphylacaceae, Araliaceae, and Oleaceae (1 species each), respectively.

Five dominant tree species with a high importance values were *T. baccata* L. (36.29), *Rhododendron arboreum* Sm. (30.61), *Quercus lamellosa* Sm. (18.90), *Acer campbellii* Hook. f. & Thomson ex Hiern (16.49), and *Tsuga dumosa* (D. Don) Eichler (15 .92), respectively.

Behera *et al.*, (2000) reported *T. baccata* growing in the Broadleaved forests alongside with *Quercus lamellose* Smith, *Rhododendron arboreum* Sm., *Acer* sp., and conifers such as *Tsuga dumosa* (D. Don) Eichler. Tree species with a high basal area were *T. baccata* L. (3.59 m^2/ha^{-1}), *Tsuga dumosa* D. Don Eichler (3.26 m^2/ha^{-1}), *Quercus lamellosa* Sm. (1.50 m^2/ha^{-1}), *Acer campbellii* Hook. f. & Thomson ex Hiern (1.04 m^2/ha^{-1}), and *Rhododendron arboreum* Sm. (0.89 m^2/ha^{-1}), respectively. The study conducted by Purohit *et al.* (2001) in the Nanda Devi Biosphere Reserve (NDBR), India, found the *T. baccata* growing in close association with *Betula utilis*, *Abies pindrow*, *Acer caesium,* and *Pinus wallichiana.* It was also found growing in small patches in the understory *Quercus semecarpifolia* and *Rhododendron arboretum* in the other parts of Himalayas. The five dominant species with high densities were *Rhododendron arboreum* Sm. (23.55 trees/ha), *Pieris formosa* (Wall.) D. Don (17.12 trees/ha), *T. baccata* L. (15.70 trees/ha), *Quercus semecarpifolia* Sm. (9.99 trees/ha), and *Acer campbellii* Hook. f. & Thomson ex Hiern (9.99 trees/ha). The average species richness, evenness, and diversity were 6.56, 0.86, and 1.58, respectively.

There were 28 individuals trees of *T. baccata* (22 individuals in the tree category and 6 in the seedling category) in 10 sampled plots. The species were classified to investigate the distribution based on topographical variables (slope, aspect, and elevation), as shown in Figure 3. The results indicated that a higher number of individual *T. baccata* trees (16 individuals) on the northwest-facing slopes compared to the other aspects. The study conducted by Purohit *et al.* (2001) in the NDBR, India, also found *T. baccata* growing in a natural habitat on the north and north-west slopes.

In the study area, *T. baccata* was found growing at elevations between 2,725 to 3,152 masl, with the highest number of individuals (12) found between 3,101 and 3,200 masl. Purohit *et al.* (2001) also identified *T. baccata* as an understory tree distributed in the temperate zone of Himalayas between 1,800 and 3,300 masl. Similarly, *T. baccata* was found at the lowest slope percentage value of 35% to the highest value of 101%. However, a large number of *T. baccata* trees were present at slope values between 76 and 90%. Thomas and Polwart (2003) stated that the slope was rarely a limiting factor for the growth of *T. baccata,* which occurs on moderate to steep slopes.

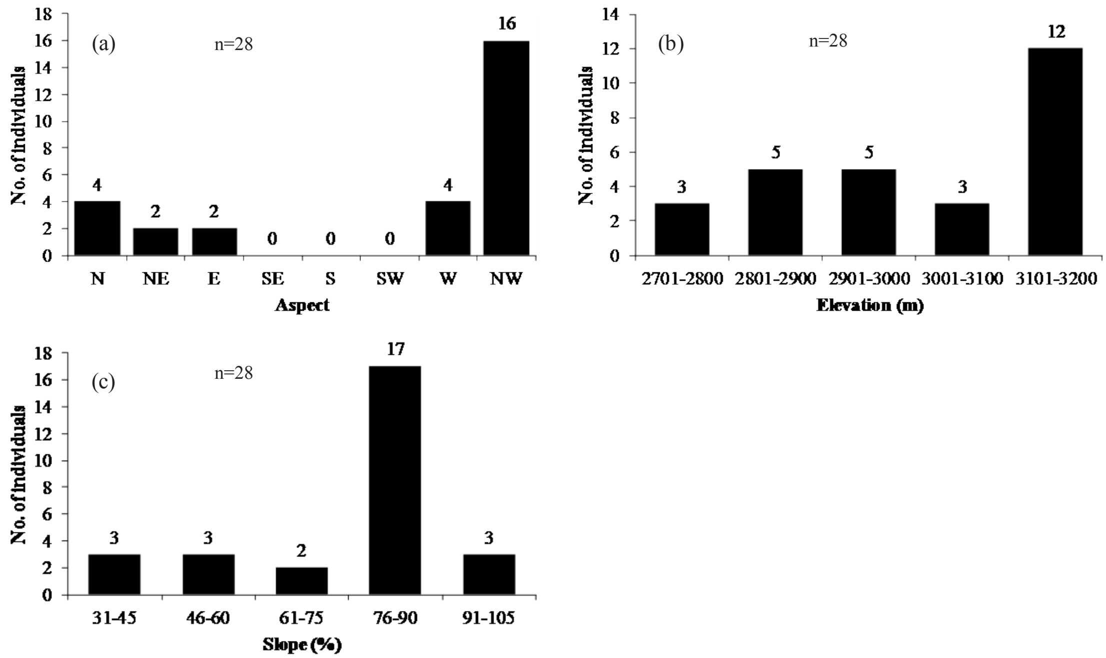

Figure 3 Topographical variables (a) Aspect, (b) Elevation, and (c) Slope affecting abundance of *T. baccata*. (N=North, NE=Northeast, E=East, SE=Southeast, S=South, SW=Southwest, W=West, NW=Northwest, m=Meter).

Soil texture is an important soil characteristic that influences the storm water infiltration rate. A soil texture triangle (Figure 4a) was constructed, using the R package version 1.4.6, based on Moeys, (2018), to identify the association of various soil types with presence or absence of *T. baccata*. The results showed that most of the *T. baccata* were present in a sandy loam soil (3 plots) followed by loamy sand (2 plots), loam (2 plots), silty clay loam (1 plot), clay loam (1 plot), and sand (1 plot).

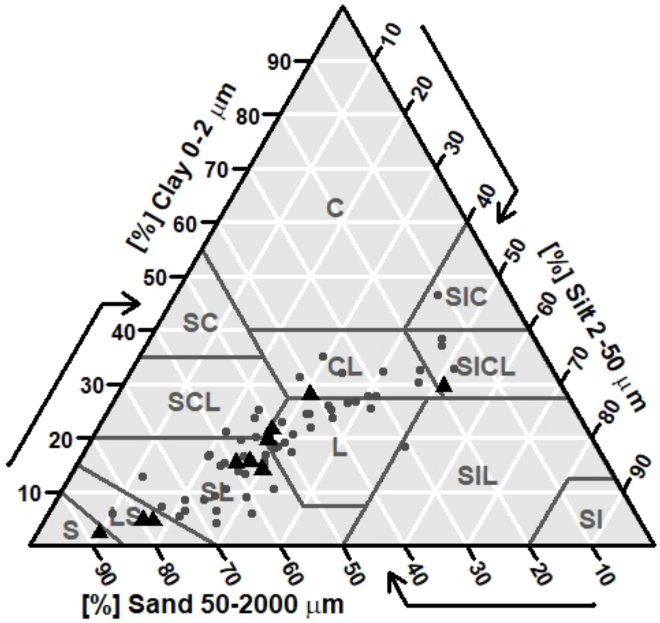

Figure 4 Soil texture classification derived from 70 sample plots (• = plots without *T. baccata*, ▲ = plots with *T. baccata*).

From a total 28 individuals, 22 individuals of *T. baccata* were in the tree category (DBH≥10cm) which was found in 9 sample plots. The individuals were classified into height and DBH classes to investigate the distribution. The species was most abundant in the height class 6-10m (13 individuals) compared to the other height classes (Figure 5a). Thomas and Polwart (2003) reported *T. baccata* as being a native, evergreen, non-resinous, gymnosperm tree, growing up to 20 m, often with multiple trunks and a spread, rounded, or pyramidal canopy.

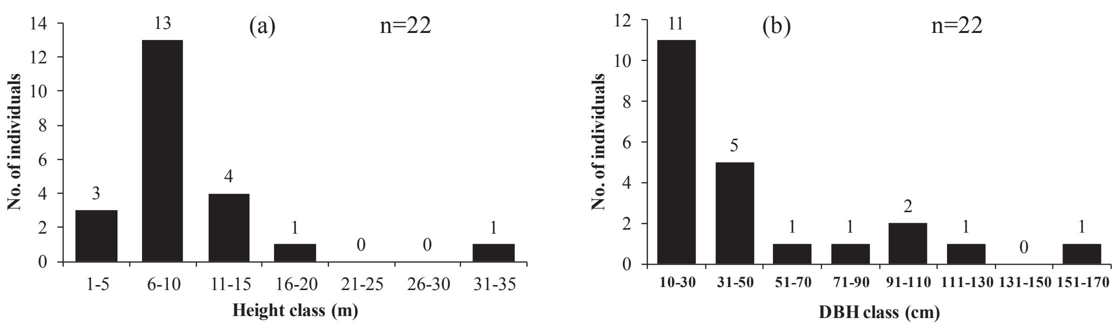

Figure 5 Distribution of *T. baccata* by (a) height class and (b) DBH class (9 plots, DBH ≥ 10 cm).

Similarly, the number of individual *T. baccata* trees was higher in the DBH class of 10-30 cm (11 individuals) compared to other DBH classes, as shown in Figure 5(b). Tracing back the history, some decades ago, the area was heavily exploited due to unmanaged tree felling and timber harvesting. It is very likely that *T. baccata* trees in the good height and diameter class, along with other tree species may have been cut during that period of time. This could be the probable reason why young *T. baccata* trees were observed as indicated by their height and diameter classes, as shown in Figure 5(a) & (b).

3. Influence of environmental variables on the presence of *T. baccata*

The comparison of means of the environmental variables between the plots with and without *T. baccata,* is shown in Table 2. The environmental variables were the soil nutrients (Ca, Mg, CEC, K, pH, P, OM, N), soil texture (sand, silt, and clay) and topographic variables (aspect, slope, and elevation). An independent *t*-test was used to compare the means. The results showed that there was a highly significant difference with K ($p<0.001$), which indicated that the availability of K determined the occurrence of *T. baccata*. However, the mean comparison among the soil texture (sand, silt, and clay) between plots with and without *T. baccata* did not show any significant difference ($p>0.05$), which indicated that the soil texture was more or less similar in both plots. *T. baccata* has a high tolerance for cold and heat, sunny and shady positions, wet and dry soils, exposure, and pH and thrives in almost any soil, acid or alkaline, as long as it is well-drained (Peragon, 2015). The comparison of means of topographical variables (elevation, aspect, and slope), with plots with and without *T. baccata* showed that there was a highly significant difference with elevation ($p<0.001$), which indicated that the presence of *T. baccata* was dependant on the altitude.

Table 2 Influence of the environmental variables on plots with and without *T. baccata*.

Variable	Presence/Absence	n	Mean	SE	t-test	p-value
Soil nutrient						
Ca (mg kg^{-1})	Absence	60	785.97	66.44	-0.102	0.927 ns
	Presence	10	804.00	167.11		
Mg (mg kg^{-1})	Absence	60	77.04	8.57	-1.123	0.889 ns
	Presence	10	103.44	26.17		
CEC (cmol kg^{-1})	Absence	60	22.75	1.83	-0.288	0.614 ns
	Presence	10	24.17	4.95		
K* (mg kg^{-1})	Absence	60	74.04	4.57	-0.947	0.001***
	Presence	10	93.66	20.20		
pH	Absence	60	4.55	0.06	1.091	0.089 •
	Presence	10	4.38	0.10		
P (mg kg^{-1})	Absence	60	3.76	1.19	0.613	0.274 ns
	Presence	10	1.95	0.84		
OM (%)	Absence	60	10.44	0.94	1.203	0.568 ns
	Presence	10	7.40	2.55		
N (%)	Absence	60	0.38	0.02	-0.685	0.614 ns
	Presence	10	0.42	0.05		
Soil texture						
Sand (%)	Absence	60	49.27	2.17	-1.474	0.760 ns
	Presence	10	57.97	6.39		
Silt (%)	Absence	60	30.90	1.15	1.395	0.745 ns
	Presence	10	26.47	3.57		
Clay (%)	Absence	60	19.83	1.21	1.330	0.914 ns
	Presence	10	15.56	3.01		
Topography						
Elevation* (m)	Absence	60	2778.15	51.71	-2.362	0.000***
	Presence	10	2940.60	45.35		
Slope (%)	Absence	60	55.20	3.17	-1.673	0.476 ns
	Presence	10	69.00	6.71		
Aspect (°)	Absence	60	150.26	15.26	-1.884	0.916 ns
	Presence	10	226.92	39.50		

*Equal variances not assumed,

Note: n = No. of plots, SE = Standard Error, •=p<0.1, ***=p<0.001, ns = Not significant

The study evaluated the influence of environmental factors, soil nutrients, soil texture, and topography on the presence of *T. baccata*. A binary logistic regression, using the step-wise backward selection method, was applied to determine the significant covariates (Table 3).

Amongst the soil nutrients (model 1), Mg and pH were influential but not significant ($p>0.05$) for the presence of *T. baccata*. However, pH was negatively correlated with the presence of *T. baccata*. Boratynski *et al.*, (2001) indicated that sites in which *T. baccata* was present of had soils rich in Mg. The Cox and Snell and Nagelkerke R^2 values for model 1 were 0.058 and 0.103 (Table 4).

The soil texture variables (model 2) did not showed any significant difference ($p>0.05$) with R^2 values (0.000, 0.000). Similarly, when topographical variables (model 3) were used, slope, and aspect were somewhat significant for the presence of *T. baccata* ($p<0.10$) with R^2 values 0.089 and 0.160.

The study evaluated the presence of *T. baccata* in different forest types (Blue pine forest, Broadleaved forest, and mixed conifer forest) (model 4) . A chi-square test indicated that there was no association between the presence of *T. baccata* and the forest type ($p>0.05$), with R^2 values 0.000 and 0.000. Thus, it can be concluded that *T. baccata* can grow in all the three forest types.

Table 3 Selected variables from different sets of environmental variables for various logistic regression models of *T. baccata,* based on backward stepwise selection.

Variable	**Coefficient**	**SE**	**Wald**	***p*-value**	**Odd ratio**	**Nagelkerke R^2**
Soil nutrient (model 1)						0.103
Mg (mg kg^{-1})	0.009	0.005	2.954	0.086 •	1.009	
pH	-1.553	0.945	2.701	0.100 ns	0.212	
Soil texture (model 2)						0.000
Topography (model 3)	0.160					
Slope (%)	0.028	0.017	2.790	0.095 •	1.029	
Aspect (°)	0.006	0.003	3.384	0.066 •	1.006	
Forest type (model 4)						0.000
Over all covariates (model 5)						0.273
Ca (mg kg^{-1})	-0.002	0.001	2.577	0.108 ns	0.998	
Mg (mg kg^{-1})	0.012	0.007	3.020	0.082 •	1.012	
Sand (%)	0.050	0.026	3.800	0.051 •	1.051	
Elevation (m)	0.002	0.001	3.161	0.075 •	1.002	
Aspect (°)	0.006	0.004	2.797	0.094 •	1.006	

Note: SE = Standard Error, •=$p<0.1$, ns = Not significant

However, the overall logistic regression analysis of environmental variables (model 5) indicated that sand, Mg, elevation, and aspect were somewhat significant ($p<0.10$)

for the presence of *T. baccata,* with R^2 values 0.153 and 0.273. In contrast, Ca had a negative influence but was not significant (p>0.05) for the presence of *T. baccata*.

Overall, the significance of a model can be explained by the ratio of the regressor's (independent variables) influence on the total variance of the presence of *T. baccata* (dependent variable) through the R^2 value, where a value close to 1 indicates a strong influence (Constantin, 2015). The summary of models indicated that an overall covariate model (model 5) was the best, with the highest Nagelkerke R^2 value of 0.273 as compared to a Cox and Snell R^2 value of 0.153 in predicting the influence of environmental variables on the presence of *T. baccata*. However, the model had a low explanation power and thus, other environmental variables should be considered (Table 4).

Table 4 Summary of logistic regression models.

Variable	Cox and Snell R^2	Nagelkerke R^2
Soil nutrient (model 1)	0.058	0.103
Soil texture (model 2)	0.000	0.000
Topography (model 3)	0.089	0.160
Forest type (model 4)	0.000	0.000
Overall covariates (model 5)	0.153	0.273

CONCLUSION

The study was conducted in three different forest types (Blue pine forest, Broadleaved forest, and mixed conifer forest). Out of 70 plots which were sampled, 48 tree species (DBH≥10cm) in 21 families were recorded. Within the plots which had *T. baccata* , 28 tree species (20 evergreen and 8 deciduous) in 15 families were recorded. The dominant tree species with a high importance values were *T. baccata, Rhododendron arboreum* Sm., *Tsuga dumosa* (D. Don) Eichler, *Acer campbellii* Hook. f. & Thomson ex Hiern, and *Quercus semecarpifolia* Sm. The average species richness, evenness, and diversity in the *T. baccata* stands was 6.56, 0.86, and 1.58, respectively. A comparison between the mean soil nutrients with the presence and absence of *T. baccata* indicated to K as being highly significant (p≤0.001). However, the soil texture (p>0.05) did not show any significant difference. Likewise, the mean comparison among the topography variables showed highly significant difference (p<0.001) with elevation. A logistic regression analysis of the environmental variables indicated that sand, Mg, elevation, and aspect were somewhat significant (p<0.10) for the presence of *T. baccata*. In contrast, Ca had a negative influence but had a somewhat influence (p<0.10) on the presence of *T. baccata*.

In summary, *T. baccata* was able to grow in association with a wide variety of plant communities, in three different forest types, under specific environmental conditions including topography and soil properties. The results can be useful for the forestry planners and policy makers in Bhutan in developing future management and conservation guidelines for *T. baccata* . The current study was confined to a small localized area. Thus, a future study should be conducted at a larger scale to adequately understand the plant species association and occurrence of *T. baccata* in different locations within the country. Similarly, future research should consider studying all the important environmental factors to understand the intricate relationship of *Taxus* species.

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