

**Population structure and microhabitat
preference of the Himalayan Yew (*Taxus
wallichiana. Zucc*) in Uttarkashi**

**Dissertation Submitted to
Saurashtra University, Rajkot**

**In partial fulfilment of
Master's Degree in Wildlife Science
By
Rhea Ganguly**

**Under the Supervision of
Dr. GS Rawat
Dr. Gautam Talukdar
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**भारतीय वन्यजीव संस्थान
Wildlife Institute of India**



CERTIFICATE

This is to certify that Ms. Rhea Ganguly has carried out an original piece of research in partial fulfilment of Master's Degree in Wildlife Science of the Saurashtra University, Rajkot. The topic of her dissertation is "Population structure and microhabitat preference of the Himalayan Yew (*Taxus wallichiana*) in Uttarkashi". The study was carried out under our supervision from December 2010 to June 2011. We hereby certify that this work has not been submitted for any degree to any university.


Dr. G.S. Rawat
Scientist - G
Supervisor


Dr. Gautam Talukdar
Scientist - C
Co-supervisor

Date : 20.06.2011

Place : Dehradun

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Understanding choices made by any species at a micro level is intrinsic to detecting patterns in ecological space. On the other hand, understanding how variations in micro site in turn affect the populations of any species is important in terms of ecological time. This study compares population structure of *Taxus wallichiana* Zucc, a threatened medicinal tree endemic to Himalaya, across different habitat types and to studies micro site preferences (over space) exhibited by the species.

The study maps the distribution of *Taxus* encountered and based on it, predicts areas which are likely to have *Taxus*. It also studies how differences in habitats affect the population structure of the species. Using generalized linear models, the microhabitat preferences of the species was modeled. This study is merely the preliminary to further insights to the species choices for a habitat and responses to habitat changes. The findings of the study are as below:

1. Population structure revealed significant differences between age class structure across habitat types ($p < 0.0001$). Older age classes were found in association with Sub alpine forests while the younger classes were found more in Warm Temperate and Cool Temperate forests.
2. The sex ratio of the Population also varied across habitat types with a bias towards female individuals. This difference was significant at $p < 0.0001$.
3. The age structure across different disturbance gradients varied significantly ($p < 0.0001$) with varying disturbance gradients.
4. The potential distribution of *Taxus* was found to be dependent on the minimum temperature of the coldest month, elevation and the precipitation during the warmest month.

5. The microhabitat variables that influenced *Taxus* presence and abundance were found to be a combination of the slope, litter depth and the interaction between the aspect and temperature.

6. Associate species or immediate neighbor species of *Taxus* were found to be *Abies pindrow*, *Quercus semecarpifolia*, *Picea smithiana* and *Quercus dilatata*

1. INTRODUCTION

1.1 General Overview

All species make choices with regards to habitat (Levins 1968). In animals, this choice making process is apparent through their movement to favourable sites and behavioral changes. In case of plants, however, the lack of mobility plays an important role making habitats the proximal factors for choice making. It is the habitat which proximally decides which of the species that disperse into a habitat actually establish (Gordon and Wittenberger 1991). In the long run, through the process of evolution, plants adapt to certain types of habitats making them the ultimate choice makers (Bazzaz 1991). Habitat selection in plants may be driven by density (Gersani et al. 1998) or driven by evolutionary factors over a period of time (Bazzaz 1991) or exhibited by phenotypic plasticity, which is an inherent trait in plants to adapt to less favorable conditions (Bradshaw 1965, Huey et al. 2002). Plants clumped in their distribution are more specific in their selection of habitat. Whereas habitat selection studies in tropical regions on angiosperms (Svenning 1999) have been undertaken, much less is known about their gymnosperm counterparts.

Differential selection of habitat is not only seen across species but also between the sexes of the same species. Several studies deal with the existence of ecological differences between males and females in populations of dioecious plants along some environmental gradient (Williams and Dodson 1972, Grant and Mitton 1979). Studies also reveal that in some dioecious species, the individuals tend to be present with other individuals of the same sex (Williams and Dodson 1972). Dioecy, as a life history strategy, is widespread in angiosperms, being recorded in 37 out of Engler & Prantl's 51 orders (Bawa 1980). Evolution of dioecy is said to arise from proximate as well as ultimate causes. Dioecy as a life history strategy has been found to be associated with perenniality, fleshy fruits and seed dispersal by animals (Bawa 1980, Renner and Ricklefs 1995). A majority of these studies on dioecy, however, deal with tropical or angiospermic forms. Species of the temperate regions have not been studied that well. Studies also reveal that large number of dioecious plant species are able to alter their sexual state in response to changes in the surrounding

environment(Freeman et al. 1980). Sex change is adaptive where female reproductive costs are greater than male costs (Doust and Cavers 1982).

Exhibiting all the above mentioned strategies of life history, *Taxus* is a unique member of the Gymnosperms. It is dioecious in nature, dispersed by birds and animals, pollinated by wind, highly clumped in distribution and not much is known about the habitat preferences the species exhibits. The species is made more unique by the fact that it is an important medicinal plant. Wani et al. (1971) first discovered the drug taxol which is anti cancerous in nature. Without any knowledge of its status in the wild and scanty knowledge about its ecological requirements, the injudicious use of the plant for commercial purposes is enough to drive the species towards its extinction. Populations may be vulnerable and factors such as population size, degree of isolation and fitness (Ellstrand and Elam 1993) can help predict their fate. Not yet known to be successfully regenerated by artificial means, and characterized by poor regeneration in nature (Svenning and Magård 1999, Perrin et al. 2006), an insight into its microhabitat preferences will be useful for future assisted regeneration programmes. In vitro techniques have also been suggested and tried(Nhut et al. 2007).

Moreover, even though a brief description of their distribution exists, due to patchiness, knowledge about existing patches is scarce as locating them becomes difficult for monitoring and management. On this front, studying the species, and modeling and predicting their distribution with the help of GIS techniques could help fill the existing lacunas. Predictive modeling of *Taxus wallichiana* has been attempted in Talle valley(Behera et al. 2000) and in Pallas valley(Saqib et al. 2006).

1.2 Distribution and Habitat Selection among Taxales: Literature Review

Gymnosperms are ancient plant groups having their origin in the Permian era, 200-300 million years ago (Beck 1966). They exhibit extremely interesting palaeohistory by the fact that they have a comparatively intact fossil record and are represented by relatively few extant taxa i.e., 63 genera and 750 species (Sahni 1990). Though outnumbered by angiosperms in terms of species richness, gymnosperms, especially the conifers dominate the

world's forest types (GBO 2001) , occurring across huge landscapes of the temperate zones of both hemispheres. However, many species are faced with extinction as single populations stand as the last living examples (Sahni 1990). A unique family among the gymnosperms, whose position in the classification systems has been a source of controversy, is Taxaceae. Earlier belonging to the order Coniferales (cone bearing plants), the family was shifted out to a separate order of itself called Taxales (Sahni 1990). The justification being, that Taxaceae did not bear cones. In India, the family is represented by two genera, namely *Taxus* and *Amentotaxus* (Sahni 1990).

Confined mainly to the temperate regions (mid latitudes) of the Northern hemisphere, the genus *Taxus* comprises of ten species (Sahni 1990). Of these, only one species i.e., the Himalayan Yew (*Taxus wallichiana*.Zucc) is found in India, which is indigenous to the Himalayan region. The Himalayan Yew occurs from Kashmir to Arunachal Pradesh in an altitudinal belt of 1800m to 3300m (Troup 1921, CSIR 1976). The forest types in which *Taxus wallichiana* has been recorded in India are (Champion and Seth 1968):

1. Montane Temperate Forests (Type IV)

- Group 12- Himalayan Moist Temperate Forests
 - CI- Lower Western Himalayan Temperate Forest
 - * b – *Moru* oak forests (*Quercus dilatata*)
 - * c – Moist deodar forest (*Cedrus deodara*)
 - * d – Western mixed coniferous forests (Spruce, blue pine, silver fir)
 - * e – Moist temperate deciduous forests
 - C2- Upper Western Himalayan Temperate Forest
 - * a – *Kharsu* oak forest (*Quercus semecarpifolia*)
 - * b – West Himalayan upper oak /fir forest
 - * c – Moist temperate deciduous forest

2. Sub Alpine Forests (TypeV)

- Group 14- Sub Alpine Forests

- CI- West Himalayan sub-alpine birch/ fir forests (Betula/Abies)

- * a – West Himalayan sub-alpine fir forest

An evergreen tree species, as most conifers, *Taxus wallichiana* grows either as a small under canopy tree or a shrub. The bark is thin reddish brown, and scaly. In the Himalayan region, needles are shed in May and June; flowers appear from March to May and the fruits ripen from September to November (Troup 1921). Male flowers have globose heads on common stalk whereas the female flowers consist of a single erect ovule surrounded by a disk, on a peduncle covered with imbricate scales. The tree is dioecious in nature, having the male and female flowers on separate trees. The female does not bear a cone but a fruit which is a solitary seed, half enclosed in a red aril. Dispersal of seeds is carried out by animals such as Langurs (Minhas et al. 2010) and birds (Troup 1921). Thrushes (Martínez et al. 2008) are known to disperse the seeds of *Taxus*. Seeds of *Taxus* are predated on by rodents (García et al. 2005) and rabbits (Watt 1926).

Population studies on yew reveal interesting patterns and life history strategies. Shrubs have been reported to assist the establishment of Yew woodlands (Watt 1926, Svenning and Magård 1999, Garcia et al. 2000, Thomas and Polwart 2003b). But once the woodlands oust the shrubs, regeneration of *Taxus* is hampered (Watt 1926). *Taxus* also inhibits self-regeneration and seedling survival, prompting concerns for the long-term preservation of the species (Piovesan et al. 2009). This has been a point of controversy though, as in a study by Iszkulo (2005), no evidence of negative effects of yew adults on saplings was found. Regeneration hurdles may be classified into pre and post germination factors. Pre germination, factors that influence establishment are availability of mother trees (seed source), availability of perch sites (McClanahan and Wolfe 1993), availability of dispersers and availability of suitable habitat for germination, presence of seed predators (García et al. 2005). Since *Taxus* falls under k-strategist species, it is density dependent and availability of suitable habitat plays an important role (Gersani et al. 1998). Post germination factors like optimum light, nutrient requirement, protection from grazing (Hulme 1996) are also key to the survival of the species.

Table 1.1 Chosen studies on the ecology of the genus *Taxus* based on the relevance to the current study

Study	Author	Year
Pollen Production and Plant Density Affect Pollination and Seed Production in <i>Taxus canadensis</i>	Taber D. Allison	1990
The Influence of Deer Browsing on the Reproductive Biology of Canada yew (<i>Taxus canadensis</i> Marsh.). II. Pollen Limitation: An Indirect Effect	Taber D. Allison	1990
Ecology of Pacific Yew (<i>Taxus brevifolia</i>) in Western Oregon and Washington	Richard T. Busing et al.	1995
Population ecology and conservation status of the last natural population of English yew (<i>Taxus baccata</i>) in Denmark	Jens-Christian Svenning et al	1999
Preliminary Studies on Interconnections among the Main Tree Populations of <i>Taxus chinensis</i> var. <i>mairei</i> Community.	Li Xiankun, et al	1999
Microsporogenesis, Pollination, Pollen Germination and Male Gametophyte Development in <i>Taxus brevifolia</i>	Erika D. Anderson et al.	2000
Yew (<i>Taxus baccata</i> L.) regeneration is facilitated by fleshy-fruited shrubs in Mediterranean environments	Daniel García et al.	2000

The Holocene history of *Taxus baccata* (yew) in Belgium and neighbouring regions Deforce, Koen et al. 2007

Population ecology of yew (*Taxus baccata* L.) in the Central Apennines: spatial patterns and their relevance for conservation strategies Gianluca Piovesan et al. 2009

The tree is long lived, but the growth is extremely slow, seeds having a long germinating interval (Troup 1921). Dormancy of 1.5-2 yrs has been recorded (Nhut et al. 2007) When young, the seedling are demanding in terms of moisture and shade (Khanna 1977 (Svenning and Magård 1999), but under artificial regeneration, once established, bear transplanting well (Troup 1921). In a study on *Taxus baccata*, however, it was found that reproductive activity, strobilus production and recruitment were enhanced in well lit microsites (Svenning and Magård 1999). Whereas, according to Troup (1921), moist and shady places are the optimum site conditions for the Himalayan yew. Its life strategy has been described as "stress-tolerant" (Svenning and Magård 1999). Factors such as grazing (Alverson et al. 1988, Perrin et al. 2006) and non availability of microhabitats (Hulme 1996) have been attributed to poor regeneration success.

Very little information about the ecology of the species is available and it falls under category Data Deficient (Baillie et al. 2004). Its population status in the wild is not known. Utilization value of the tree both local and commercial purposes makes it vulnerable to exploitation. The main aim of the study is to fill in the gaps that exist in terms of ecological literature and to attempt to find out the status of the species in the wild for one of the potential *Taxus* zones (Uttarkashi district), and to map its current distribution in the study area based on the locations

that it is encountered in. Generating a model for predicting its distribution for the rest of Uttarakhand based on presence only data has also been attempted.

Mapping the distribution of the species and predictive modelling for it would help in generating resource use and availability maps which would throw light on resource use patterns of species dispersing it. Moreover, patchiness in distribution makes it difficult for managers to monitor patches on a long term basis. Maps with potential and actual *Taxus* locations would help them to efficiently manage areas containing the species.

1.3 Objectives

The main objectives of the study are:

1. *Mapping distribution and predicting potential sites for Taxus.*
2. *To compare the population structure of Taxus wallichiana across different habitat types*
3. *To study micro site preferences and associates of the species*

1.4 Key Research Questions

Distribution

- a) What are the environmental variables that effect the distribution of *Taxus*?

Population Structure

Taxus wallichiana is known to grow in a variety of moist habitat types, forming under canopy associations with several species. It would be interesting to see if the population structure (in terms of age classes, sex ratio, disturbance levels) under different habitat conditions varies.

- b) Does population structure vary significantly with habitat for the species?

- c) What factors govern the variation in population structure for the species?

Microhabitat Selection

Since the species grows in various habitats, there but is clumped in distribution, there must be some micro site characteristics which favour their growth. The questions arising from this are,

- d) What are the covariates that govern the occurrence of *Taxus* on any particular site?
- e) What are the main associate species of *Taxus*?

2.1 Location and Extent

The study comprises the district Uttarkashi, of the state Uttarakhand. Total area of the district is 8016 km² of which 39.23% is under forest cover (FSI 2009). Almost 88 % of the total area of the district is administered by the Forest Department. There are three forest divisions (FDs) present in the district viz., Tons, Uttarkashi and Upper Yamuna FDs. Only the latter two were selected for the study. The area extends from 31° 27' 34" N to 31° 13' 22" N latitudes and 77° 58' 51" E to 78° 53' 32" E longitudes. The total area of the Upper Yamuna Forest Division (UYFD) is 1029.53 km² whereas Uttarkashi Forest Division (UFD) spans over 2618.54 km².

The UYFD is divided into five forest ranges namely, Yamunotri (272.82 km²), Kuthnor (259.74 km²), Rawain (196.03 km²), Mugarsanti (142.88 km²) and Naugaon (158.06 km²). UYFD is divided into six forest ranges, Badahat 324.36 km², Dharasu 350.32 km², Dunda 257.23 km², Gangotri km², Mukhem 288.15 km², Taknaur (724.86 km²).

2.2 Drainage

Three main rivers, Tons, Yamuna and Bhagirathi, drain the entire district of Uttarkashi. The UYFD has the river Yamuna running across its landscape, starting from the origin of River Yamuna (in Saptarshi – Bandarpunch Glacier) till the district boundary in Nainbaug. On the other hand, UYFD is drained by the Bhagirathi which originates in Gaumukh in Gangotri glacier at 4000m asl. Important tributaries of these rivers are Hanuman Ganga, Janhavi and Bhilangana. There are many rivulets, locally known as *Gads*, emerges from different watersheds of catchment area of these rivers are Kamal Ganga, Badiyargad (Kedar Ganga), Jadhganga, Jalandhari, Pilangana and Assi Ganga. Along these rivers, several hydro-power projects have been initiated to provide power to the state.

2.3 Climate

The climate of Uttarkashi is temperate, marked by seasonal variations in temperature. It is also affected by tropical monsoons. January is the coldest month, with daily high temperatures averaging below freezing in the north and near 21 °C in the southeast. In the north, July is the hottest month whereas in the southeast, May is the warmest month. Most of the annual precipitation (1500mm) is brought by the southwest monsoon, which blows from July through September. Floods and landslides are problems during the rainy season in the lower stretches of the valleys. Snowfall is common between December and March.

2.4 Geology and Soil

Uttarkashi falls under the Garhwal group of geological formations. The higher ranges and snow covered peaks consist entirely of high grade metamorphic rocks such as quartzites, marble and various types of micaceous schists and gneisses and slightly lower altitudinal areas with sedimentary and low grade metamorphic rocks such as limestones and sericite biotite schists (Wadia 1975). The quality of soil is determined by the kind of rocks in the subsoil. In Himalaya very shallow skeletal to very deep soil are found. The surface soil is richer in organic matter and darker in colour. The soil in steep slopes ($>30^\circ$) are shallow due to erosion and mass wasting processes. Soil in general is acidic except those developed from limestones which are neutral to slightly alkaline (Awasthi 2001). The three main soil types encountered in the study area were, brown forest soil, red loam and glacial soils.

2.5 Intensive Study Area

The study area ranges from c. 800 m asl to 6700 m asl with few high peaks like Bhagirathi group of Peaks (6607m) and Bandarpunch (6720m). For conducting the study, an altitudinal belt of

2000m to 3500m was taken. Plots and transects were laid in this belt (potential *Taxus* habitats) throughout the study area.

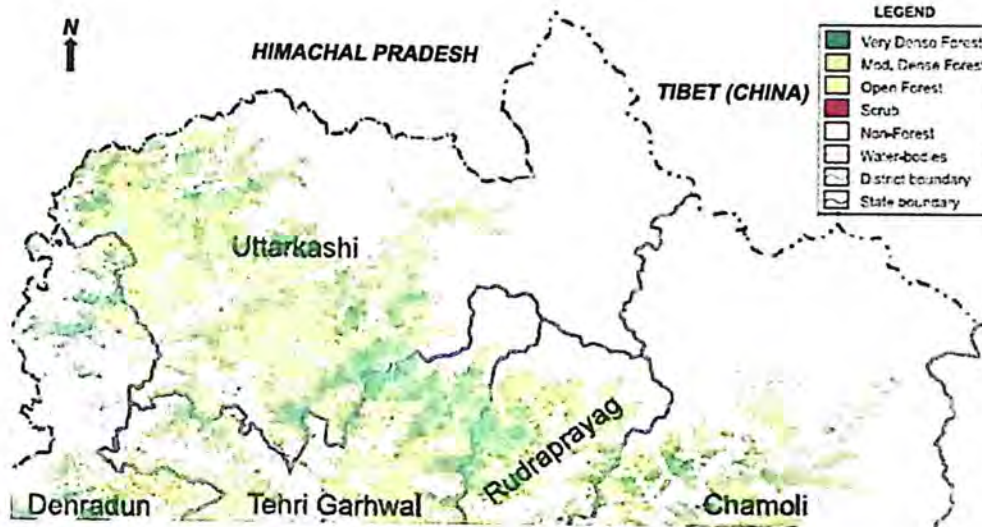


Figure 2.1 Forest density of Uttarkashi District (Adapted from FSI 2009)

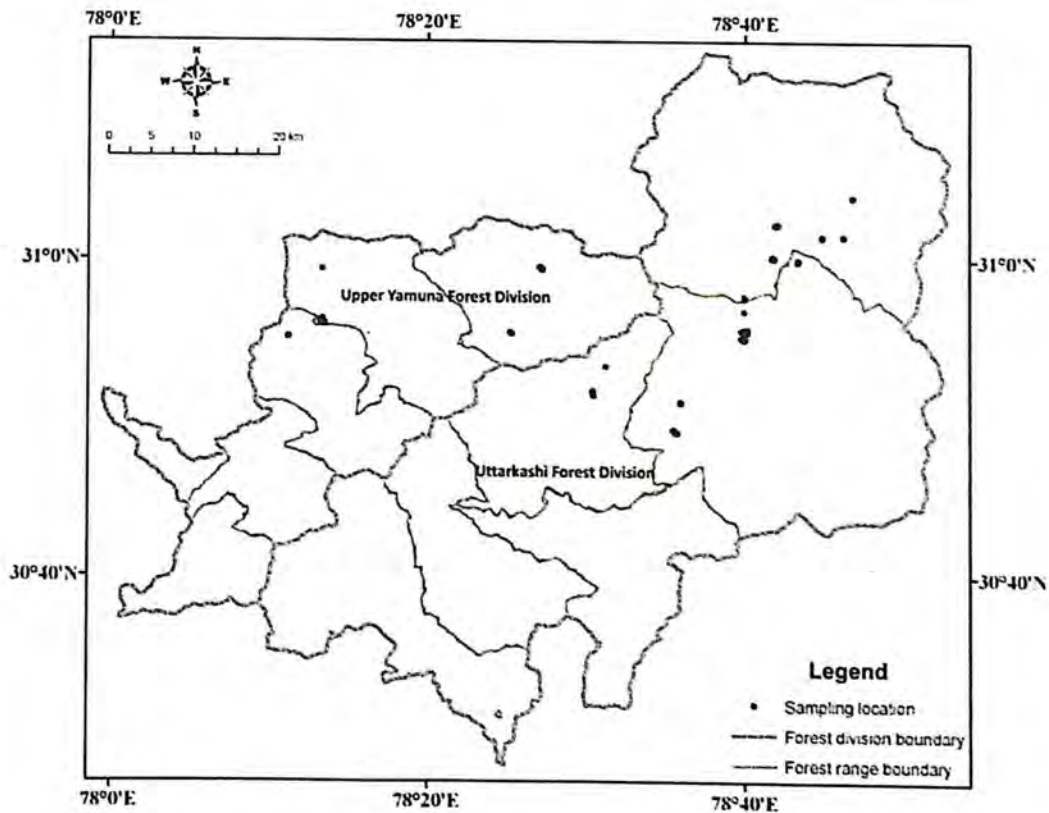


Figure 2.2 Study area showing sampling locations

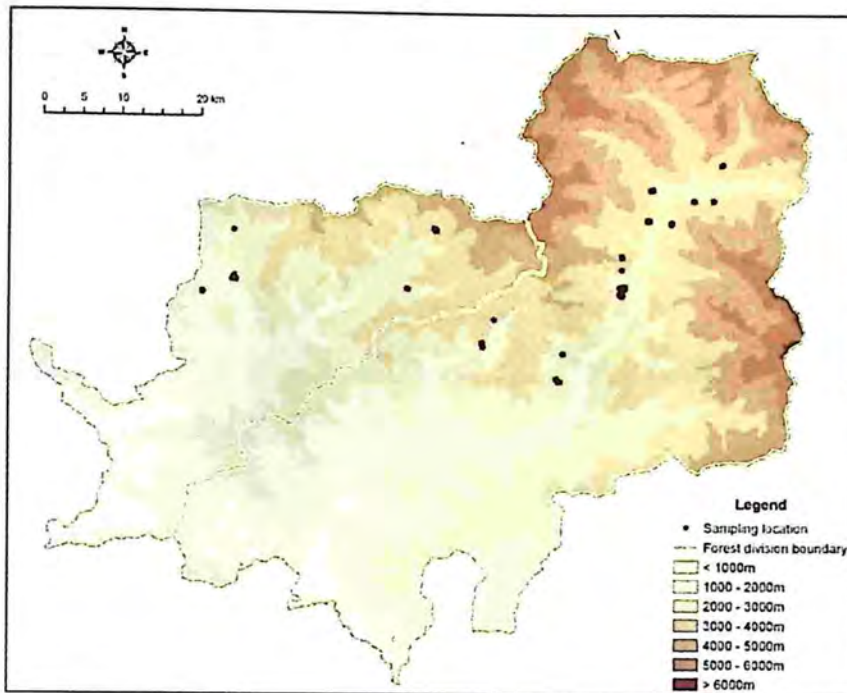


Figure 2.3: sampling locations at different altitudinal gradient

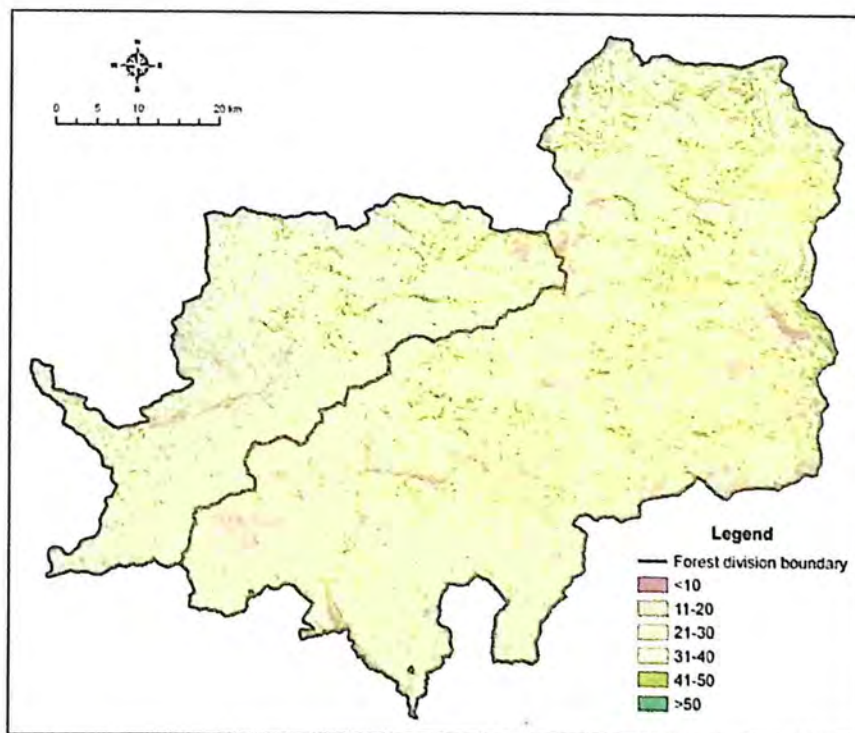


Figure 2.4: Distribution of Slope classes in the study area

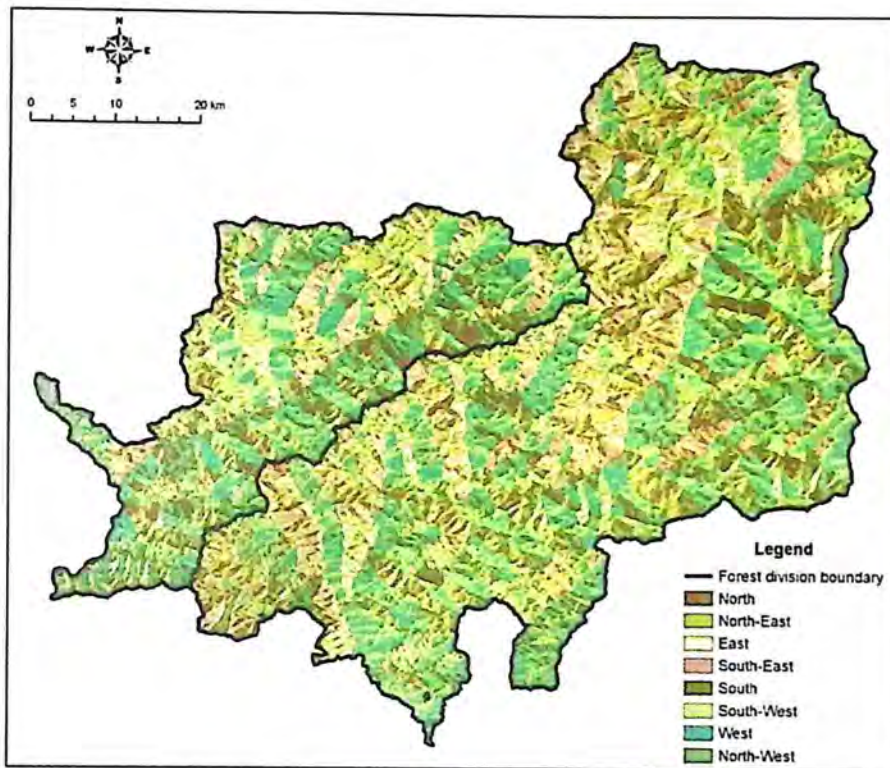


Figure 2.5: Distribution of aspect classes in the study area

2.6 Forest and Vegetation

The widely varying climate and topography produce a wide range of vegetation and serve as habitats to diverse species of wild life. Forest formation ranging from *Euphorbia* scrub to dry alpine scrub makes the area a unique habitat for different forest types. According to Champion and Seth's classification (1968) forest categories viz., Subtropical pine forest, Himalayan Moist Temperate Forest, Himalayan Dry Temperate Forest, Sub-alpine Forest, Moist alpine Scrub and Dry Alpine Scrub, are found here.

Pine forests occur roughly between the altitudinal range of 900-2000 m. The temperate zone lying between 1500-3000m is usually dominated by Oaks (*Quercus* spp), occasionally patches of

Deodar forests between 2000-3000 m are present; Fir and Spruce forests over 3000 m and Kharshu, Birch and Junipers forests upto the height of 4000 m are common. Above the Fir and Spruce forest zone, alpine pastures are found between the height of 3500 m to 5000 m asl.

The study area is known to host many high value medicinal plants, *Aconitum heterophyllum*, *Allium stracheyi*, *Dactylorhiza hatagirea*, *Bergenia stracheyi*, *Taxus wallichiana*, *Zanthoxylum armatum*, *Swertia chirayita*, *Cinamomum tamala*, *Phyllanthus emblica*, *Berberis asiatica* are to the name few (Rawat et al. 2004, Rawat 2005, WII 2010, Raut et al. 2010).

2.7 People and culture

Population of the district is 2, 94,179 (Census 2001). In addition to local *Garhwalis*, *Jadhs* is the tribal community lives in some areas of study area. Other transhumant community is *Gujjar*, who are semi-nomadic people moves between Bhabhar belt of Dehra Dun district and to high altitude meadows. Most of the people except tribal communities have agriculture as their main occupation. Generally, wool based trade and rearing of sheep and goat has been traditional occupation of *Jadhs*.

Gangotri and Yamunotri, being sacred places, lakhs of people come to visit these places not only from India but from entire world. In addition to these places, high altitude meadows, locally known as *Bugyal* (Rawat 2005), and many high altitude pass are tourists' attraction. This has helped to increase tourism in the study area.

3. METHODS

3.1 Field Methods

Within the study area, the recorded range for the species was sampled. The area was stratified into three broad altitudinal zones of:

2000-2500m

2500-3000m

3000-3500m.

Sampling was done in these altitudinal ranges only. Aspects were classified as Aspect I (0° - 135° N) and Aspect II (135° - 360° N). for the study.

Table 3.1 Plots and Transects laid across elevation zones, aspects and forest types

	Elevation Class(m)			Aspect		Forest Types		
	2000-2500	2500-3000	3000-3500	I	II	I	II	III
No of transects	5	9	5	NA	NA	4	9	6
No of plots	50	93	45	91	98	NA	NA	NA

The objective specific methods are described below.

3.1.1 Objective 1. Mapping species distribution and predictive modeling

GPS locations were recorded from all individuals encountered. For individuals too close to each other, the distance from reference tree and bearing was also taken to help calculate locations later on. These presence only locations were used to model species distribution using maximum entropy method (Charniak and Johnson 2005).

3.1.2 Objective 2: To compare the population structure of the species across different habitat types.

Transects were laid (Anderson et al. 1979, Stohlgren et al. 1995) in each of the altitudinal categories. Within the transects, adaptive sampling was carried out. Wherever individuals are observed, the parameters given below were recorded.

Forest type (Champion and Seth 1968): The forest type was categorized by looking at the associate species as well as the altitudinal range. Depending on that, each patch was put into one of the three categories i.e. Lower Western Himalayan Temperate Forest or Warm Temperate Forest, WTF(<2500m); Upper Western Himalayan Temperate Forest or Cool Temperate Forest, CTF(2500m-3000m); and West Himalayan sub alpine birch/fir Forest or Sub Alpine Forest, SAF(3000m-3500m).

Canopy closure: Using a spherical densiometer, four sets of observation from each patch were taken and later averaged out.

No. of individuals: The number of individuals encountered in each patch was recorded. For larger patches, with over 800-1000 trees, this was not possible.

Height of individuals: Using a Christens Hypsometer, the height of every individual encountered was recorded.

Girth: The girth measurements were taken using a measuring tape.

Soil moisture and pH: the pH and moisture was measured using a Kelway Soil Tester. The Kelway tester operates on the principle of electrical potential between two dissimilar metal plates. When inserted into moist soil the HB-2 registers degree of acidity on the upper scale. The lower scale shows degree of moisture (% saturation) when the switch button is held depressed.

Aspect: Aspect was recorded using a compass.

Sex: The sex of individual plants was arrived at by the presence of reproductive structures. At first this was difficult, as the season for fruiting and seeding was already up, but with time the individuals became easier to sex as remnants of the fruit were often found on the female tree. For the males, the cones appear in February but green reproductive structures appear by the beginning of January in clusters. For some of the individuals, it was hard to determine the sex and they were recorded as unidentified.

Presence of saplings or seedlings, altitude and associates. The GPS location of each individual observed was recorded. For individuals too close to each other, the distance and bearing to the next individual was noted.

Disturbance factors (lopping, fire, grazing,) were also recorded (Appendix IV).

3.1.3 Objective 3: To study micro site preferences and associates of the species.

To meet this objective, the same transects were used but 5m circular plots were laid on either sides at every 100m. The parameters taken into account were:

Aspect, measured using a compass; slope, with the help of a clinometer; canopy cover, using a densiometer; altitude, soil temperature, soil moisture and soil pH, with a Kelway soil tester, slope (measured using a clinometers), .immediate neighbors, distance from immediate neighbours (Cottam et al. 1953), other associates and leaf litter depth. The GPS locations were also be recorded for each individual encountered.

3.2 Analytical Methods

Analysis was done mainly using Microsoft Excel for data entry, SPSS and R software for running models and creating a dendrogram. The parameter settings developed in this study were used

3.2.1 Objective 1

Creating models that can be used to predict distributions in a larger landscape was done using Maxent software. This is based on maximum-entropy approach for species habitat modeling. A

set of data of environmental variables (such as elevation, precipitation, etc.) extracted from 19 Bioclim variables were used. Collinearity was first tested for among the 19 bioclimatic variables. Only those variables were selected for the model which was not correlated. Data preparation was done using Arc GIS, Microsoft Excel and ERDAS Imagine.

and range for a given species is predicted. Maxent uses regularization, which produce models with few non-zero coefficients and encourages parsimony (Williams 1995, Phillips et al. 2004). It uses generative approach, modeling the species distribution directly, whereas regression-based methods are discriminative (Phillips et al. 2004). It uses species georeferenced occurrence locations (presence-only data).

The bio climatic factors which were used for modeling the distributions were

BIO3: Isothermality ((BIO2/BIO7) * 100)

BIO6: Min Temperature of Coldest Month

BIO11: Mean Temperature of Coldest Quarter

BIO13: Precipitation of Wettest Month

BIO18: Precipitation of Warmest Quarter

Apart from these layers, three additional factors, slope, aspect and elevation (DEM) was also used.

3.2.2 Objective 2

For assessing population structure across habitat types, a contingency framework was used. G test and Chi square test were used to test the difference in age class structure across habitat types and disturbance levels. Since the sample size was small (19) non parametric methods were used. Using regeneration as the response variable, a binomial logistic regression model was constructed to test the effect of disturbance, sex ratio, average height and forest type.

3.2.3 Objective 3

For microhabitat preferences analysis, generalized linear models were used. All types of possible two way interactions were also accounted for. The response variable was the count of *Taxus*. A negative binomial distribution was assumed. Collinearity was tested for before running the model. Analysis involved model simplification and the model with the least AIC value was selected.

For arriving at associates for *Taxus*, a hierarchical cluster analysis based on Average distance was used. The analysis was run using SPSS.

4.1 Mapping and predicting distributions for Taxus

A total of 2519 points were collected, distributed over 19 patches. For the analysis only points which fell in different grids were used. The grid size used for maxent is 0.7X0.7 sq km. All points falling within a grid are taken as one. Since most of the points were clumped together, only 56 points were used for the analysis. Of the 56, presence records of 42 points were used as training and 14 as testing. Based on this, the predicted distribution of Taxus (Figure 4.1.1) was obtained.

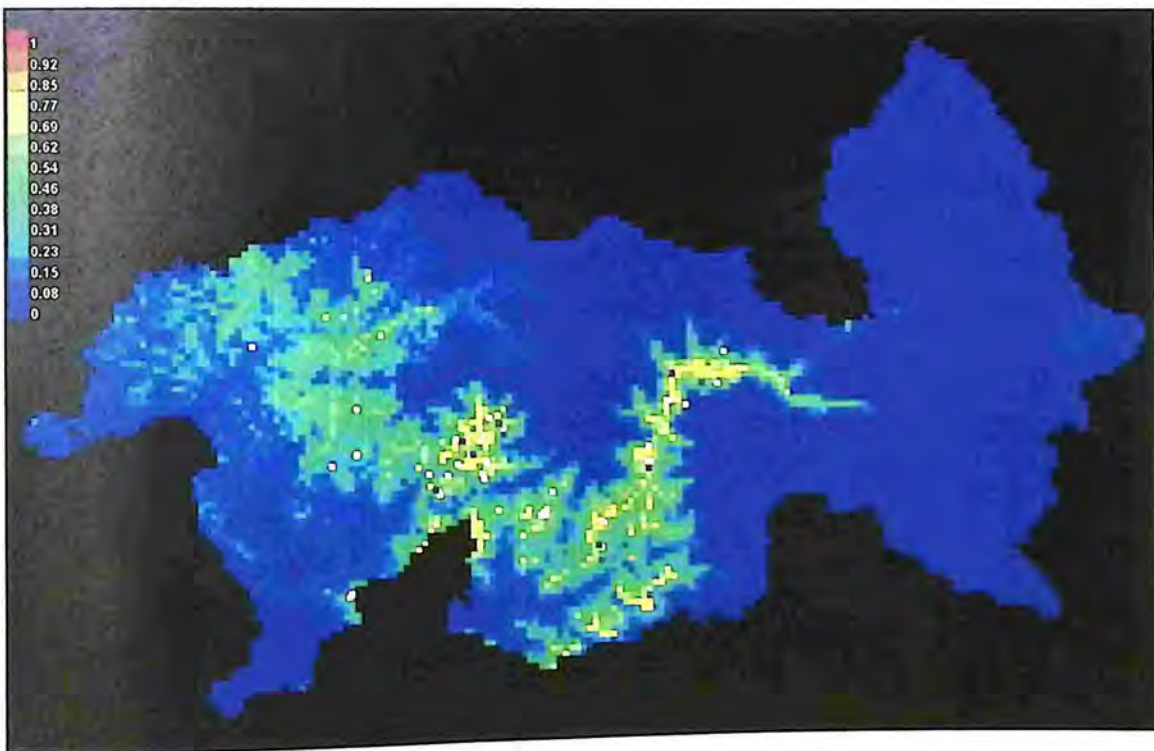


Figure. 4.1.1 Predicted Distribution of Taxus across Uttarkashi (as obtained via Maxent)

The probability of occurrence of the species is indicated in the legend of the Figureure (Figure. 4.1.1) above.

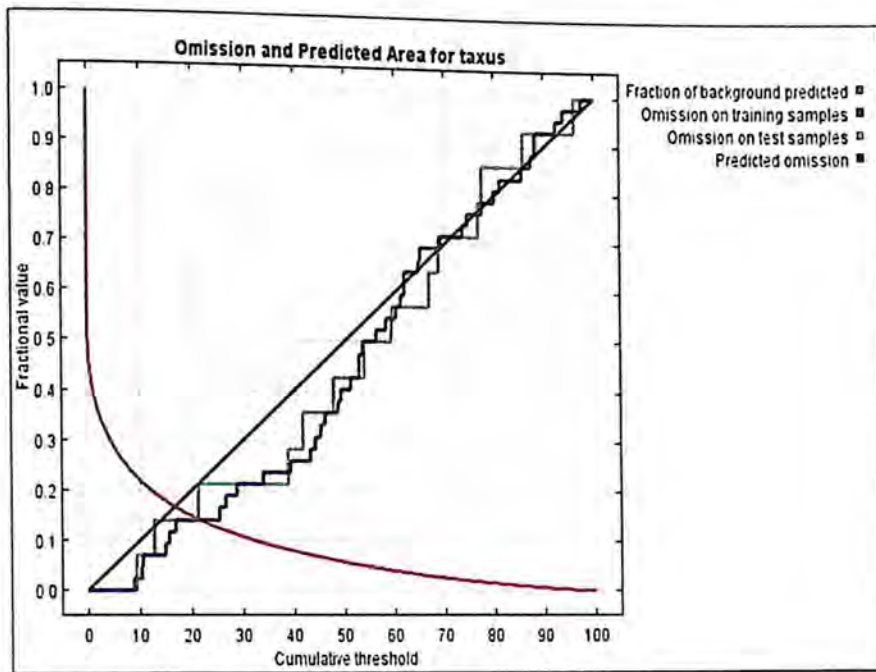
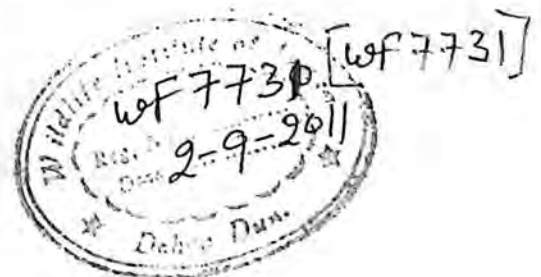


Figure 4.1.2 Omission and Predicted area for Taxus

The graph in Figure 4.1.2 tells us the validity of the model. The black line is the predicted omission. The suitable conditions for presence are predicted above the threshold and unsuitable below. The omission on test samples is a reasonable fit for the predicted omissions. The predicted omission is drawn from the Maxent distribution itself. Given below are the set of factors selected for the running the model after removing collinearity. A detailed list of the 19 Bioclim variables initially considered is given in Appendix III. The graph (Figure 4.1.2) is a threshold dependent diagnostic of model fit.

Table 4.1.1 List of variables and their contribution to the model

Variable	% Contribution	Permutation importance
Mean temperature of the coldest quarter	4	2.1
Elevation	6.9	3.2
Precipitation of the warmest quarter	11.1	12.9
Min. temperature of the coldest month	10.8	76.8
Precipitation of the wettest quarter	8.4	0.9
Isothermality	7.4	4.4
Aspect	3.1	1.1
Slope	0.1	0.7



It is observed that the permutation importance of the minimum temperature of the coldest month is much higher than any of the other variables. This can be explained by the fact that other variables, such as mean temperature of the coldest month and isothermality are dependent on it. Minimum temperature of the coldest month is also influenced by the elevation. These variables alone, themselves contribute significantly to the model. Hence, the permutation combination is a value as high as 76.8.

Response Curves

1. Response to Slope

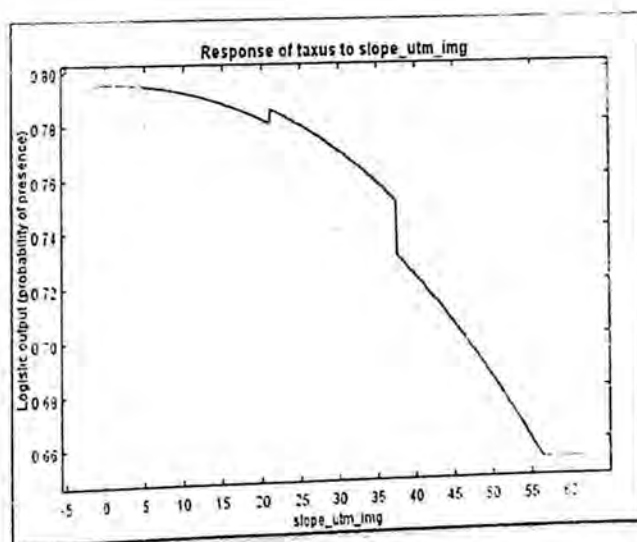


Figure. 4.1.3 Response of Taxus to slope

The graph above, gives the response of Taxus to slope. According to the graph, the steeper the slope, lesser is the probability of Taxus being present. However, one should take notice that the percentage contribution of slope to the model is not too much..

2. Response to Aspect

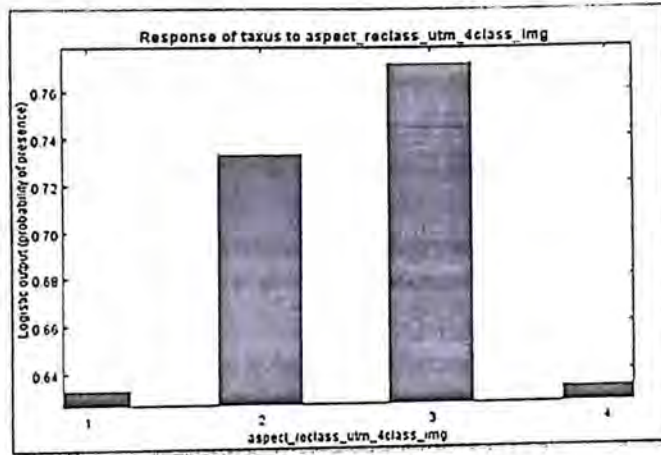


Figure 4.1.4 Response of Taxus to aspect (1= Northern,2= Eastern,3= Southern, 4= Western)

The variable aspect had been categorized into four main classes; Northern (315° - 45°), Eastern (45° - 135°), Southern (135° - 225°) and Western (225° - 315°). The contribution of aspect to the model is not substantial when compared to other variables.

3. Response to Elevation

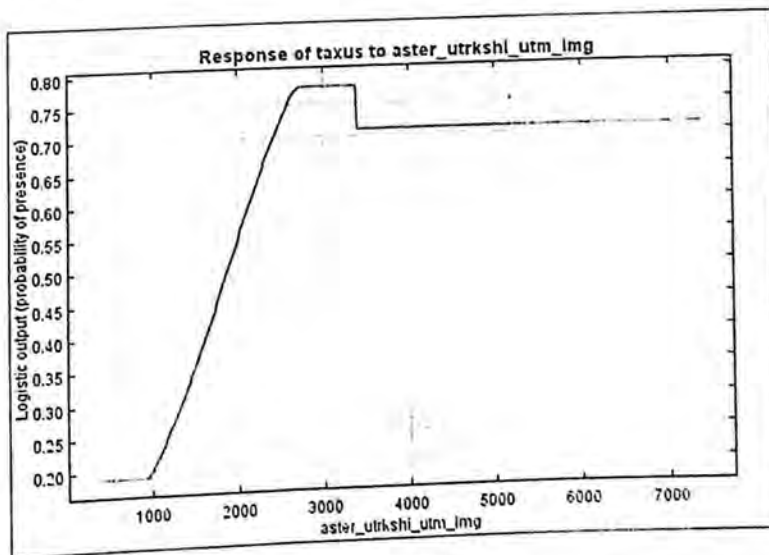


Figure 4.1.5 Response of Taxus to elevation

Unlike slope and aspect, the effect of elevation on the presence of Taxus is important. The probability of presence goes as high as almost 0.8 in the elevation zone of 2500m to 3500m. This

is in agreement with the actually documented elevation zone for the species. The species has not been recorded beyond 3500m and the curve drops at this point.

4. Response to Isothermality

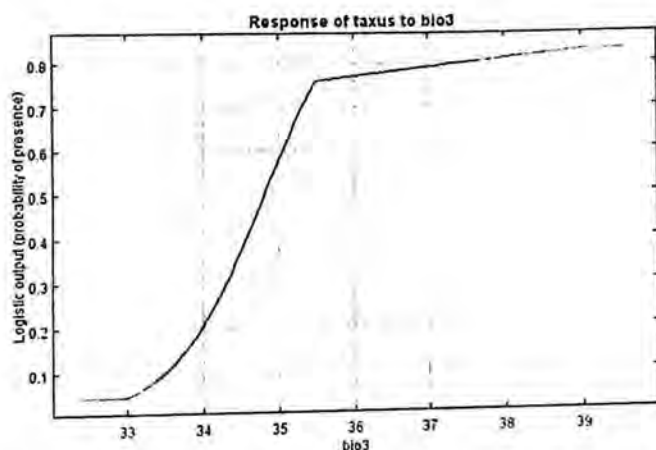


Figure 4.1.6 Response of Taxus to isothermality

Isothermality here has been defined as, $(\text{Mean annual range}/\text{temp annual range}) \times 100$. The probability of presence for the species keeps increasing, first exponentially till a value of 35.5 and then, decreasingly after that (Figure 4.1.6)

5. Response to Minimum Temperature of the Coldest Month (Bio 6)

In the graph below (Figure 4.1.7), the probability of presence of the Himalayan yew increases with a decrease in Bio6. The curve reaches a maximum value when the value of Bio 6 approaches 0. Beyond 0, the probability of occurrences decreases. Ecologically, this would translate to the interpretation that Taxus requires chilling for its survival and growth. The minimum temperature of the coldest month has the highest permutation importance among all other factors. It contributes 10.8 per cent to the model.

It must be taken into notice that temperature values of Bioclim data are multiplied by a factor of 10. Thus, 50 in the graph should be read as 5 degree celsius.

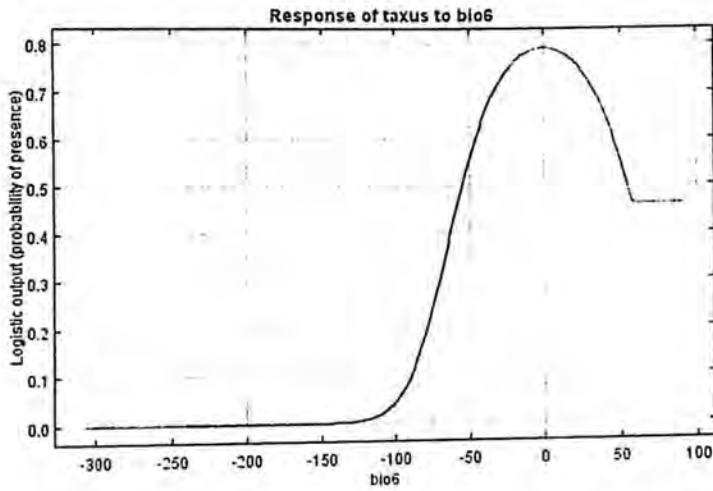


Figure 4.1.7 Response of Taxus to min temperature of coldest month

6. Response to Mean Temperature of the Coldest Quarter

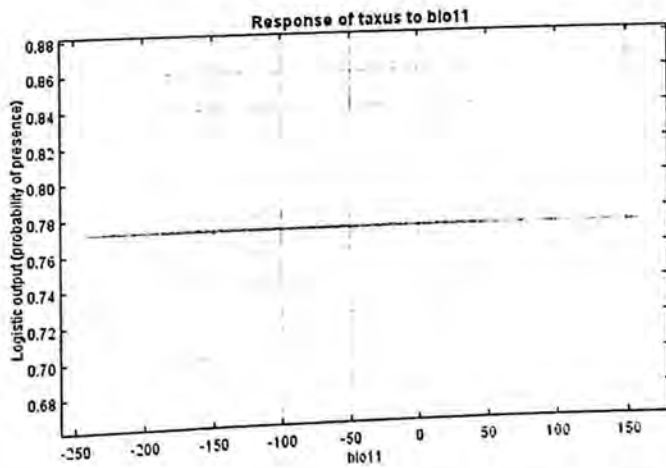


Figure 4.1.8 Response of Taxus to mean temperature of coldest quarter

There seems to be no significant response of Taxus to changes in the mean temperature of the coldest quarter. Its contribution to the model itself is neither insignificant nor too much. The permutation importance of the variable however, cannot be ignored.

7. Response to Precipitation in the Warmest quarter

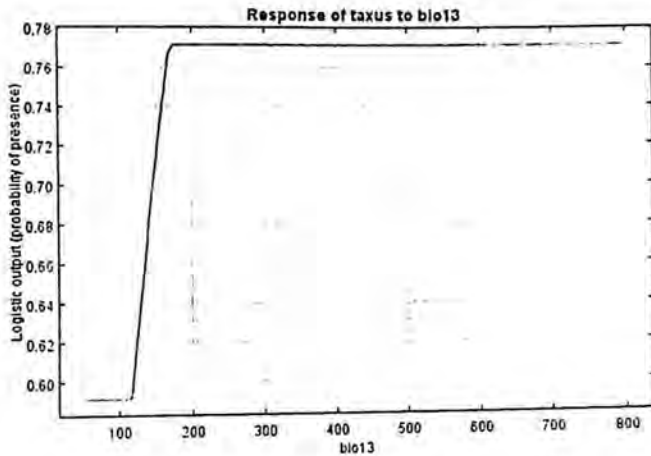


Figure 4.1.9 Response of Taxus to precipitation of wettest month

Probability of presence increases only till the precipitation values reach close to 200mm, after which, there is no significant response to the variable.

8. Response to Precipitation in the Warmest Quarter

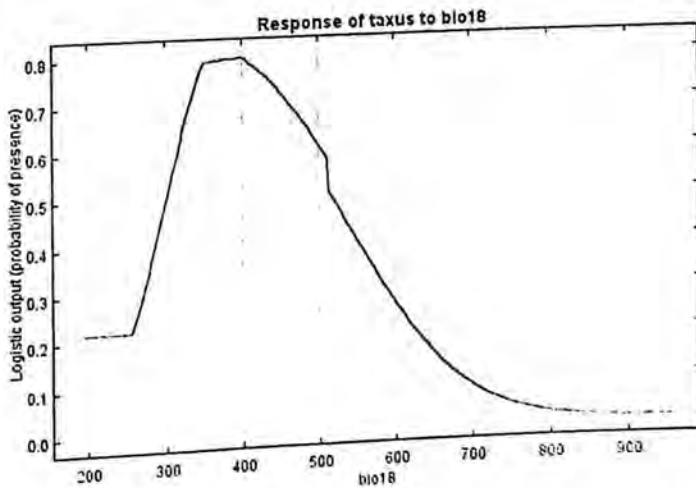


Figure 4.1.10 Response of Taxus to precipitation of warmest quarter

As a response to the precipitation of the warmest quarter, the probability of presence of Taxus increases till a value of 400m, where it peaks and then declines with further increase in precipitation.

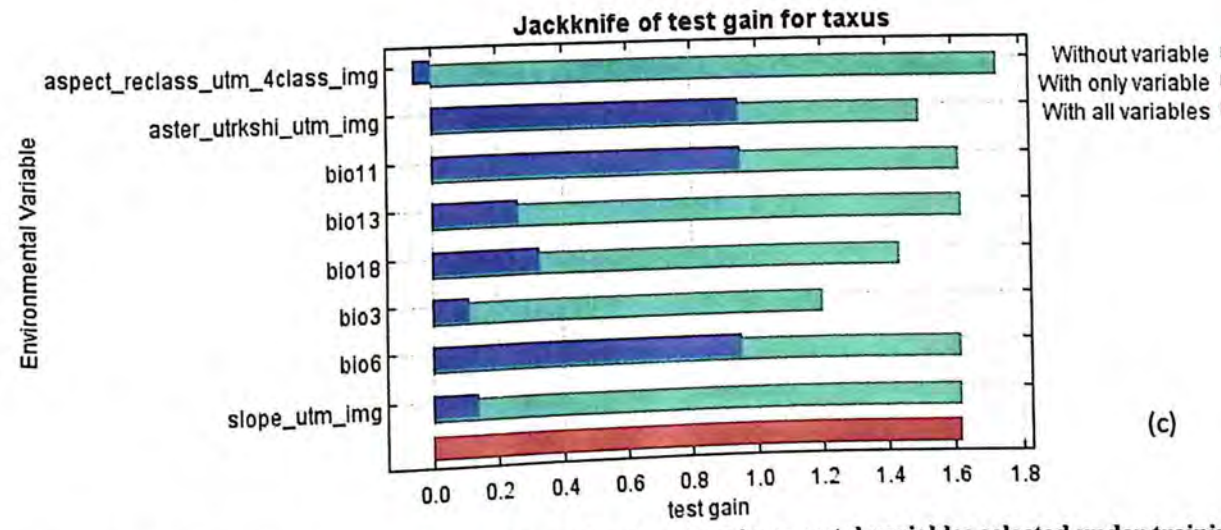
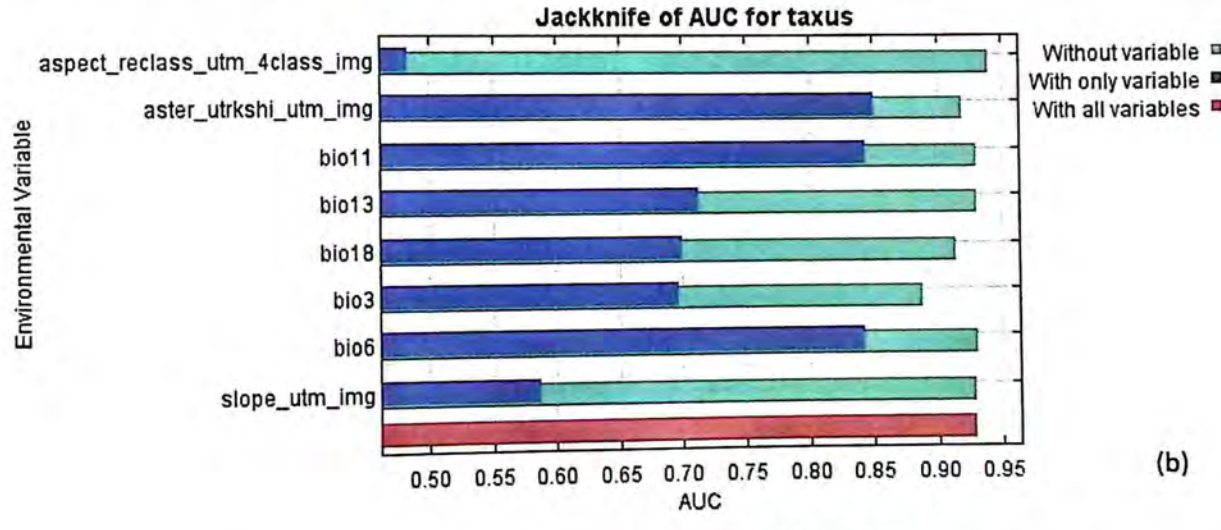
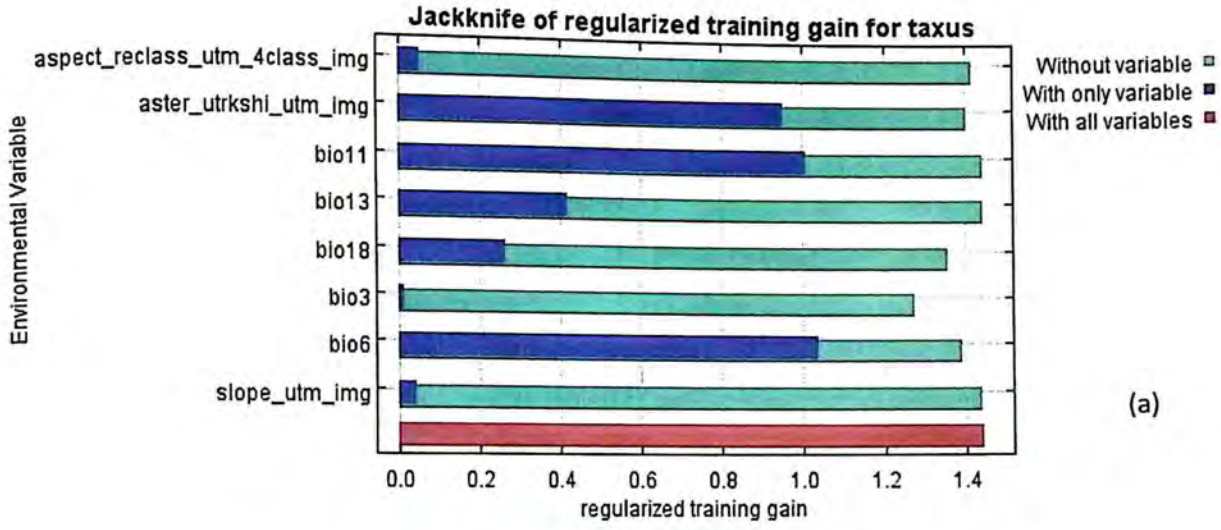


Figure 4.1.11 Permutation importance and contribution of environmental variables selected under training gain(a), test gain(c) and AUC(b) for Taxus

The set of Figureures (Figure 4.11) represents the importance of each variable to the model. The variable's contribution alone and the loss of gain on omission of the variable are given above. Under all three scenarios, elevation, minimum temperature of the coldest month and mean temperature of the coldest quarter had the maximum predictive contribution. On the other hand, omission of isothermality (Bio 3), takes away maximum information from the model.

4.2 Does population structure vary significantly with habitat for the species?

Of the 19 patches visited (refer to Appendix I), 11 belonged to the Bhagirathi river valley while 7 to the Yamuna river valley. A majority of the patches belonged to the CTF zone. In both valleys, the CTF zone had the maximum number of *Taxus* containing patches. The existence of almost pure *Taxus* stands was observed only in Bhagirathi valley above Harsil and Suki. Trees in these patches showed excessive branching; there was absence of any canopy cover for these patches. The effect of avalanches was evident at Cholmi (the patch above Harsil), as all trees were crooked and bent and appeared stunted. Most importantly, no regeneration was observed in these patches even though there had been enough seeding. Some trees still bore the fleshy arils while some trees bore the remanents. At Suki specially, a lot of seeds were observed to have fallen on the floor, but, there was no sign of regeneration.

Fruiting or seeding in *Taxus* is recorded to occur from September to November. However berries may last on the mother tree till late December depending on weather conditions. Time of flowering and fruiting may vary slightly between patches but within the patch it is synchronous. Not all individuals flower/fruit. Mature trees may or may not bear any flowers/fruits. Soil type observed in most patches is a humus rich brown forest soil. The depth of soil seems to have a direct relation with the presence of *Taxus*. Boulders and broken ground seem to be places apt for saplings and seedlings to establish. Regeneration was seen to do well if the *Taxus* stand was interspersed well with other species like Fir and Kharsu mainly. Patches which had been subjected to slight disturbances and hence breaks in the canopy had regeneration. The most profuse regeneration was observed near patch 13 a distance away from the main patch. The area was typically shrubby and heavily used by people and cattle. The nearest mother trees had been lopped and did not bear any seeds or fruits. However, there was profuse regeneration in between

the shrubs and a future *Taxus* forest seemed to be on the way. None of the seedlings observed were younger than 3 to 4 years old. The area was typically undergoing secondary succession.

4.2.1 Effect of habitat on age class distribution

Assuming a forest type to be a particular habitat type, the patches were categorized into three main forest types, according to Champion and Seth's classification. Four age categories were created (Troup, 1920) using the girth measurements (Table 4.2.1). An average annual increment of 0.35cm was taken for calculation of the classes as specified by Troup (1920).

Table 4.2.1 Corresponding age classes in *Taxus* according to girth

Age Classes	Girth Classes
0-55yrs	0-40cm
55- 170yrs	41-100cm
170- 281yrs	101-160cm
>281 yrs	>160cm

Table 4.2.2 Age classes across forest types of Himalayan Yew in Uttarkashi

Forest Type	Age Class I	Age Class II	Age Class III	Age Class IV
WTF	92	129	34	1
CTF	240	642	336	155
SAF	27	242	137	42

Since the sample size was only 19, non parametric statistical methods were used to test for differences. A G test was done instead of a chi squared test (since one of the values was below 5) and the following results were obtained (Table 4.2.3).

Table 4.2.3 Critical values for G test

G (adj)	153.01
df	6
P value	0.000
G(crit)	12.59

The G value of 153.01 was highly significant at $p < 0.0001$. Age class distribution showed significant variation across forest types. While older age classes were not abundant in Lower Western Himalayan Temperate Forests(WTF), the younger age classes were scanty in West Himalayan sub alpine birch/fir (Betula/ Abies) forest(SAF) type.

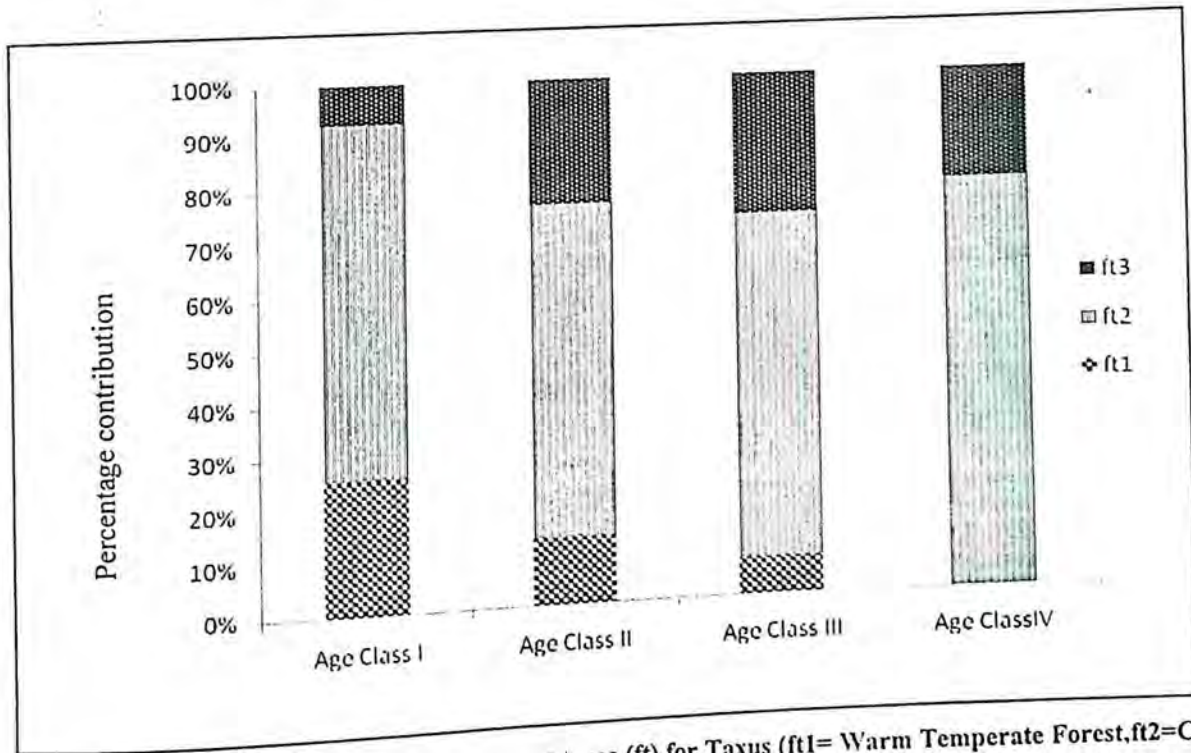


Figure. 4.2.1 Age class distribution across forest types (ft) for Taxus (ft1= Warm Temperate Forest, ft2=Cool Temperate Forest, ft3= Sub alpine Forest)

After clubbing the Age categories III and IV, a chi squared test was done.

Table 4.2.4 Age Class distribution across Forest types

Forest Type	Age Class I	Age Class II	Age Class III and IV
1	92	129	35
2	240	642	491
3	27	242	179

Table 4.2.5 Goodness of fit test for testing differences in age class distribution across forest types

Chi2 (Pearson's)	125.3
df	4
P value	0.000

Younger age classes were more abundant in WTF and CTF. *Abies pindrow* and *Picea smithiana*, the main associates of the Himalayan yew in sub alpine forests, are species of the late successional stages. As the life of a *Taxus* tree can reach upto 1000 years or more, it forms associations with several species at different stages of succession. The older forests, therefore, consist of older age classes.

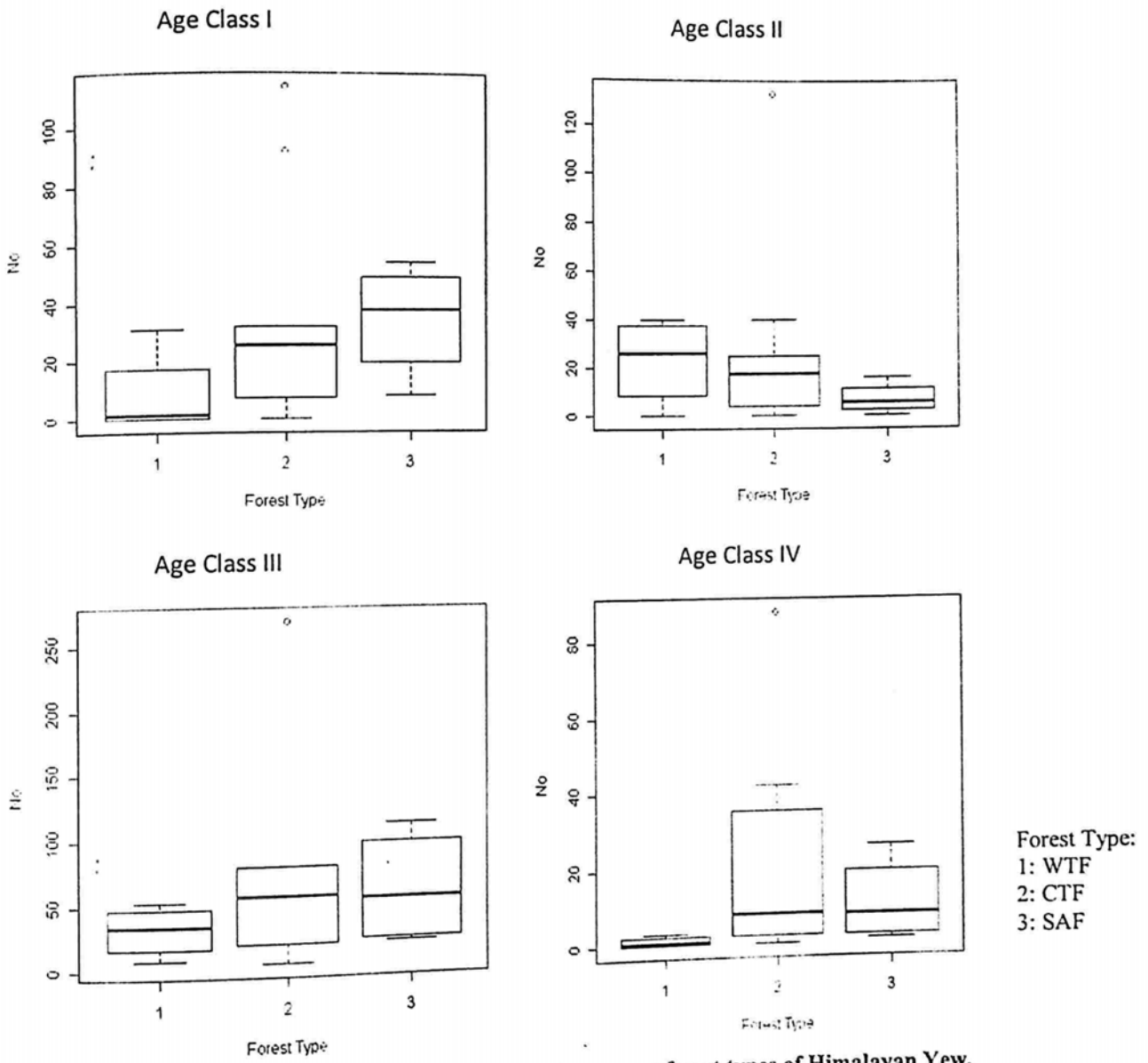


Figure 4.2.2. No of individuals in each age class across forest types of Himalayan Yew.

4.2.2 Effect of habitat on sex ratio

An ANOVA was done to test differences in sex ratio with forest types. The results were significant at $p < 0.0001$. Sex ratio varied according to the habitat type it was present in. On the whole, sex ratio was biased towards females.

Table 4.2.6 Testing for difference in sex ratio across habitat types in *Taxus* in Uttarkashi

Source of variation	df	SS	MS	F	P-value
Among groups	1	21.27	21.27	53.8	1.1E-08
Within groups	36	14.21	0.39		
Total	37	35.48			

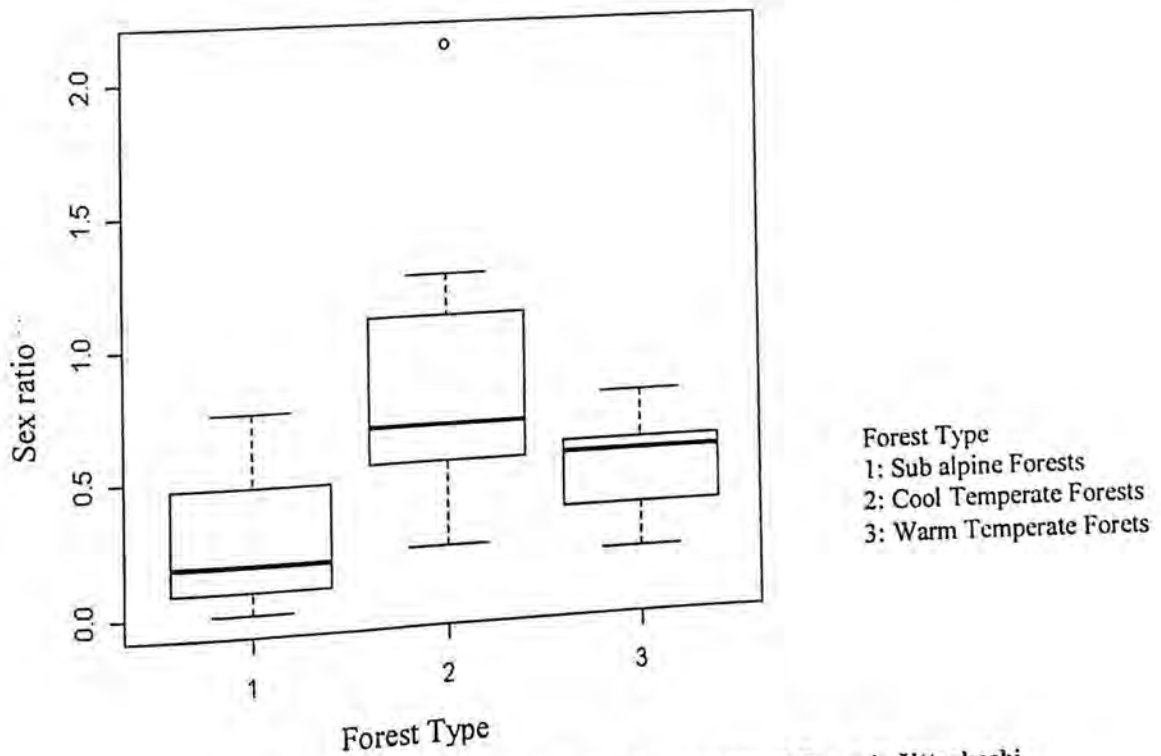


Figure. 4.2. 3 Comparing sex ratio across forest types of *Taxus* in Uttarkashi

Female biased sex ratio across all habitat types would indicate that females are more of generalists as compared to males. The sex ratio at seed stage is not known and studies on this aspect would reveal at what stage the bias creeps in. Are the populations biased at seed stage? Or is the female more hardy so as to achieve greater success in establishment? Another factor which needs to be looked into is, for how many years does a female remain reproductively viable and at what age the female achieves reproductive maturity. It must be mentioned here that determination of sex of the plants in sub alpine areas (sampled first), was difficult. With experience, the determination of sex was done with more ease and accuracy. This could have had some effect on the final results obtained.

4.2.3 What factors affect the population structure of *Taxus* across habitats?

Taking disturbance as a factor, differences in sex ratio, average height and age class distribution were tested for. Patches were grouped according to the level of disturbance (Appendix IV). Disturbance here would be defined as any anthropogenic factor which leads to the opening up of the canopy. This includes fire, lopping and grazing.

Age class distribution was seen to vary significantly with disturbance levels. A G test yielded a p-value of <0.001.

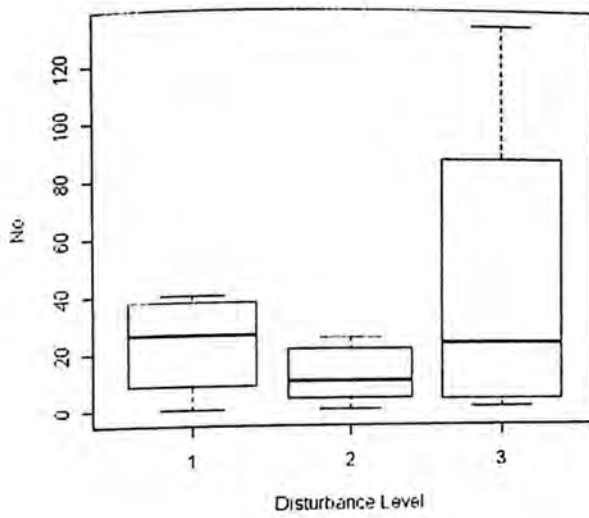
Table 4.2.7 Age class distribution across disturbance gradients of *Taxus* in Uttarkashi

Disturbance	AC1	AC2	AC3	AC4
Low	128	132	4	1
Medium	112	550	308	146
High	180	395	172	57

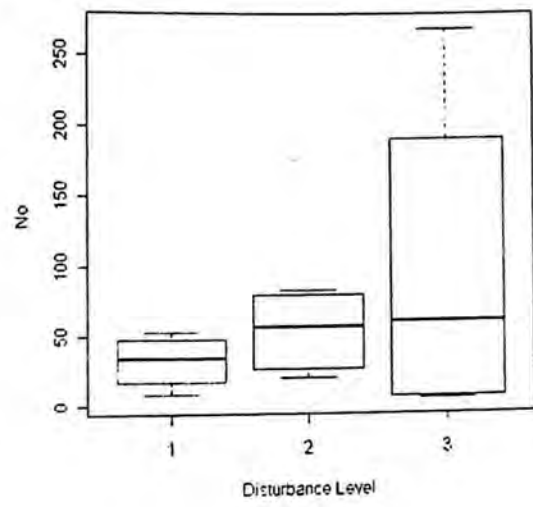
Table 4.2.7 G test for significance (testing differences in age structure across disturbance gradients)

G (adj)	306.90
df	6
P value	0.000
G(crit)	12.59

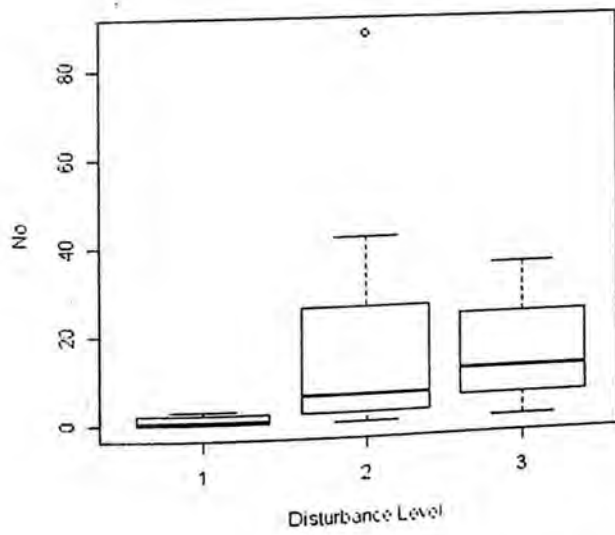
Age Class I



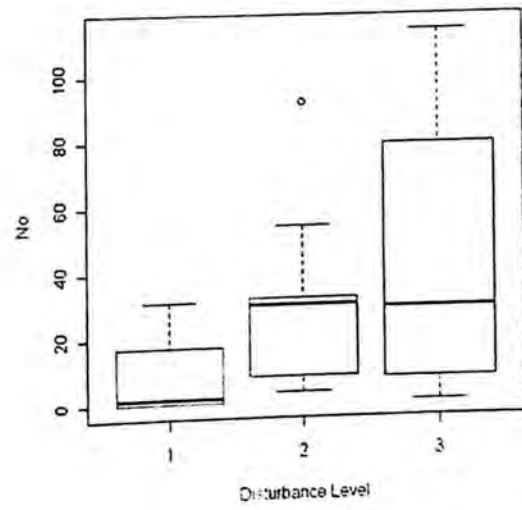
Age Class II



Age Class III



Age Class IV



Disturbance level

1:Low

2: Medium

3: High

Figure 4.2.4 Age class distribution across disturbance gradients in *Taxus* in Uttarkashi

A more even age class distribution is seen with intermediate levels of disturbance. Younger age classes were observed in less disturbed areas. Older age classes were less affected by the disturbances. The intermediate disturbance area saw the most balanced distribution of age classes.

4.2.4 Effect on regeneration by changes in sex-ratio, disturbance levels, and forest types?

Using regeneration as a response variable, a model was created under logistic regression framework. At first, disturbance, forest type, average height of crop and sex ratio were taken individually and tested for. None of the factors were significant. When the collective effect of all the mentioned factors were tested for, the results were not significant. This may have been due to the small sample size of 19 patches.

Sex ratio was the only variable which seemed to influence the presence of regeneration (significant at $p \leq 0.1$). Higher sex ratio was positively correlated with regeneration, the population being biased towards females.

Final Model: $rg \sim \text{sex ratio}$

Deviance Residuals:

Table 4.2.8 Deviance residuals for Final Model (blm4) for Taxus to explain effect of sex ratio on presence or absence of regeneration

Min	1Q	Median	3Q	Max
-1.4494	-0.871	-0.5934	0.935	1.8

Coefficients:

Table 4.2.9 Model summary for Final Model (blm4) created to explain the response of regeneration to changes in sex ratio

	Estimate	Std.Error	z value	Pr(> z)
(Intercept)	-2.067	1.06	-1.951	0.05
Sex ratio	2.465	1.513	1.629	0.10

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 25.008 on 18 degrees of freedom

Residual deviance: 20.870 on 17 degrees of freedom

AIC: 24.87

Table 4. 2.10 AIC values of all models tested for determining key factors responsible for the abundance and presence of Taxus

Model	df	AIC
blm1 = rg~ db	2	26.7478
blm2 = rg~ f.ft	3	28.27072
blm3 = rg~ db+ah	3	27.61604
blm4 = rg~ sr	2	24.87001
blm5= db+res.sr	3	26.4058
blm6 = rg~ db+res.sr+ah	4	26.31236

4.3 Microhabitat preferences and associates of the species

4.3.1 What habitat factors influence the presence of Taxus in any given area?

Parameters such as slope(Slp), aspect(C.Asp), soil temperature(Temp), litter depth(Ld), canopy cover(Can), soil pH(pH), elevation(Elev), associates(C.Asc) were used to define the microhabitat of the species. Each of these variables was tested for individually and then their cumulative effects were taken into account (null model). This was followed by a process called model simplification. Variable combinations that made ecological sense were tested for one by one. The final model with the lowest AIC value was selected. Here, the response variable was number of Taxus present. The data followed a negative binomial distribution so a logistic regression framework was opted for.

Final model: No ~ Slp + C.Asp * Temp + Ld (theta = 0.9659740168, link = log)

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.8205	-0.9521	-0.5940	0.1722	2.2123

Coefficients:

Table 4.2.11 Model summary for the Final model (mod 29) selected to explain factors affecting abundance of Taxus in a given microhabitat

	Estimate	Std. Error	z value	Pr(> z)	
(Intercept)	-1.31	0.399	-3.3	0.000968	***
Slp	0.02	0.007	3.375	0.000739	***
C.Asp2	-1.16	0.257	-4.521	6.17E-06	***
Temp	-0.06	0.056	-1.168	0.242953	
Ld	0.07	0.022	3.233	0.001223	**
C.Asp2:Temp	-0.16	0.098	-1.641	0.100774	

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for Negative Binomial (0.966) family taken to be 1)

Null deviance: 233.55 on 180 degrees of freedom

Residual deviance: 152.23 on 175 degrees of freedom

AIC: 442.7

Number of Fisher Scoring iterations: 1

Theta: 0.966

Std. Err.: 0.262

The final model which took into account, the effect of slope, aspect, and temperature and litter depth gave the best fit and the lowest AIC value.(other models which were tried out have been mentioned in Appendix II). This was the most parsimonious model. Although temperature and aspect as factors alone did not significantly affect the number of *Taxus* found in an area, their interaction played a significant role. Slope and litter depth also significantly affect the number of *Taxus* present on any site. Therefore, it was found that any one variable did not exercise complete control over the number of *Taxus* present in an area. It is a complex of factors which include degree of slope, which is positively correlated; litter depth, which again is positively correlated, and negatively correlated with the interaction of temperature and aspect 2(south eastern to north western aspects). So, microhabitats with steeper slopes, greater litter depth and preferably not on the warmer aspects are the places that the species would prefer to occupy. It should be noted that the main associates of *Taxus*, *Abies pindrow* and *Picea smithiana* are conifers whose needle leaves do not decompose easily. This affords a lot of leaf litter on the ground. Moreover, they are located on slopes which can be steep to gentle.

4.3.2 What are the associate species of *Taxus*?

The main aim kept in mind for this objective was to find out the most likely neighbours of *Taxus* given any particular forest type. *Taxus* is known to occur in three main forest types in Uttarkashi. But, the kind of preferences that it makes with regards to its immediate neighbours is not known. Within each of the forest types in which *Taxus* is known to occur, there are certain species along with which, the probability of finding a *Taxus* individual increases. As indicated in the dendrogram below, the chances of finding *Abies pindrow* and a *Taxus* together is much higher than finding two *Taxus* individuals together themselves. Similarly, *Quercus semecarpifolia* or Kharsu is more likely to be associated with *Taxus* in any given patch rather than another individual of *Taxus*. So, in the West Himalayan sub alpine birch/fir forest type, *Taxus* individuals would be expected in close proximity to Fir individuals. In Upper Western Himalayan Temperate forests, Fir, *Quercus semecarpifolia*, Spruce and Moru(*Q floribunda*), are its most likely neighbours. It has also been observed that in terms of regeneration, *Taxus* seedlings and saplings tend to establish better with one of the above species as associates. Pure *Taxus* patches were encountered with the absence of any overhead canopy. The canopy species

in such patches seems to have failed. Regeneration in a *Taxus* dominant patch was not recorded from any of the 19 patches visited. The dendrogram (Figure 4.3.2) summarizes these finer associations of *Taxus*, given any forest type. The scientific names and codes of species is given in Appendix V.

Abies pindrow is a common associate of both *Taxus* and Deodar. However, it must be noticed that Deodar does not have an affinity to *Taxus*. Few *Taxus* individuals grow in association with Deodar.

Dendrogram using Average Linkage (Between Groups)

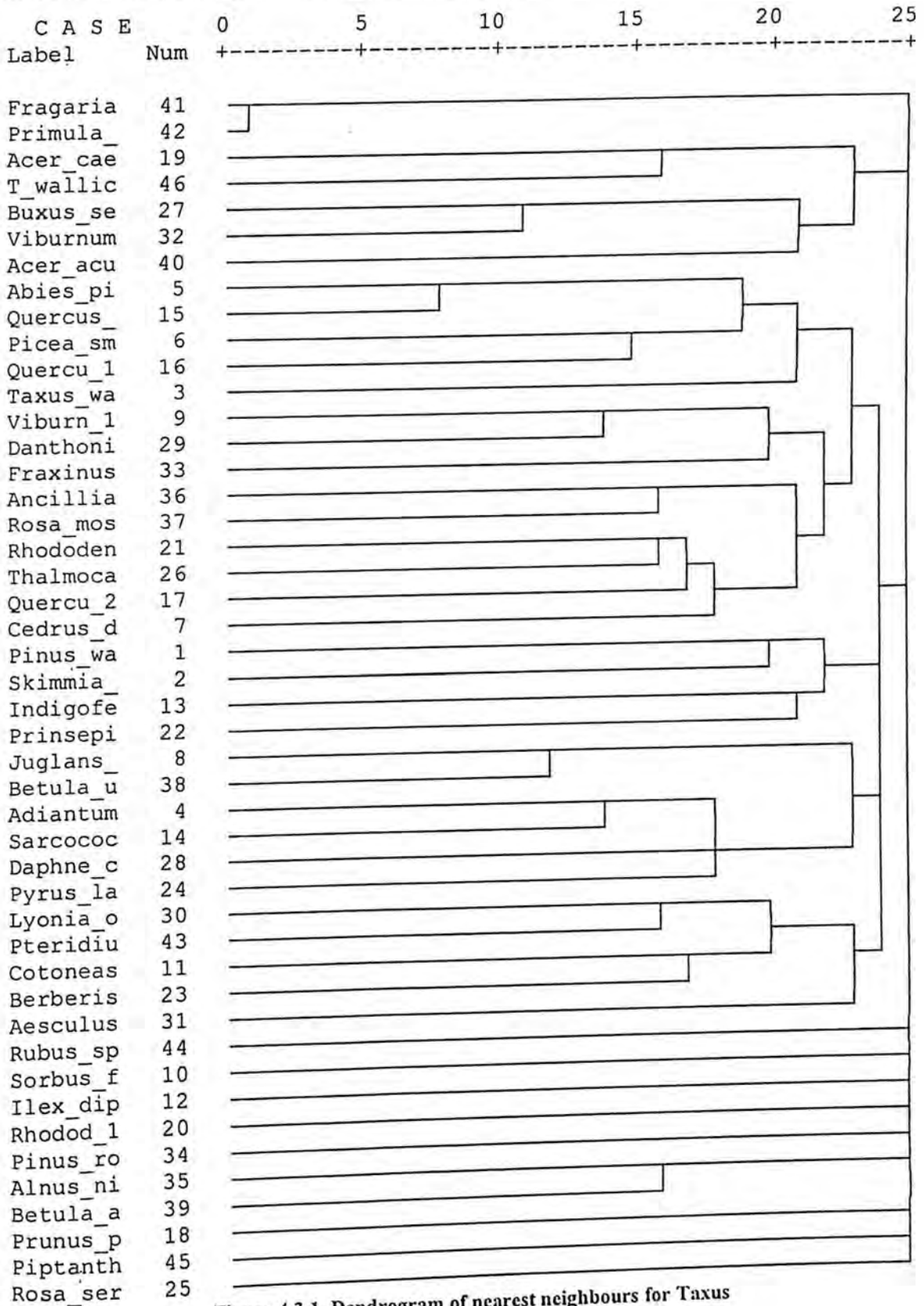


Figure 4.3.1. Dendrogram of nearest neighbours for Taxus

5.1.1 Predicting potential distribution of *Taxus* in Uttarkashi

The predictive distribution model obtained for *Taxus* presence shows interesting patterns as the probability of *Taxus* individuals seems to be highest near the two main river courses running through the area. *Taxus* has been described as a riverine species by (Cusick 1986, Collins and Montgomery 2001). Modelling for *Taxus* presence has been done by Bahera in 2000 and more recently by Saqib in 2006. Whereas Bahera's work is more Clementsian in approach, he has used models which simulate species as community assemblages, the present study is more Gleasonian in nature. Here, the model simulates species individually. As discussed by (Huntley et al. 1995, Birks 1996), modelling species is closer to reality as compared to modelling communities as communities are unlikely to respond as one under changing climatic conditions. The map produced gives sufficient insight into the potential *Taxus* habitats. Ground truthing or verification will actually tell us about the predictive capabilities of this model.

5.1.2 Population structure across habitat types of *Taxus wallichiana*

The age class across habitat (forest) types of *Taxus* varies significantly. Older forests are present in the sub alpine regions in associations with Fir, Spruce. Populations of *Taxus* in sub alpine forests were found to be in a declining state as it reached the climax (Watt 1926). As a species which lasts through several successional stages, *Taxus* forms a variety of associations. Some of these are linked to the earlier life stages, while others to later. Associations with Fir and Spruce in the sub alpine regions are an example of one of its later associations. Watt in 1926 observed that yew populations tended to stagnate and decline after they reached maturity. Moreover, regeneration of yew populations declined as yew woodlands developed. This phenomenon could explain the absence of lower girth classes in the sub alpine birch/ fir forest. Younger yew populations which have not totally dominated the scrublands show an increasing trend in populations.

The sex ratio according to habitat type also varies significantly. The population was also seen to be female biased as reported by (Allison 1990, Svenning and Magård 1999, Garcia et al. 2000,

Hilfiker et al. 2004) Whether the bias is perpetuated by environmental factors or is an inherent quality is a question which is yet unanswered.

Disturbances have a significant effect on age structure of populations irrespective of forest types. However, presence of lower age classes on disturbed sites and even distribution of age classes in areas of intermediate disturbances reveal that restocking programmes on disturbed sites can be met with some degree of success.

5.1.3 Microhabitat preferences and associates of *Taxus wallichiana*

Microhabitat of *Taxus* is chiefly governed by terrain and topographic factors like slope, litter depth. Aspect and temperature together have a significant effect on the presence and abundance of *Taxus*. A requirement of a complex set of microhabitat factors is another hurdle the species has to grapple with. Suitable microhabitats seem to be the limiting factor for the establishment of new yew populations as observed by (Hulme 1996).

5.2 Questions and Conservation and Management Implications

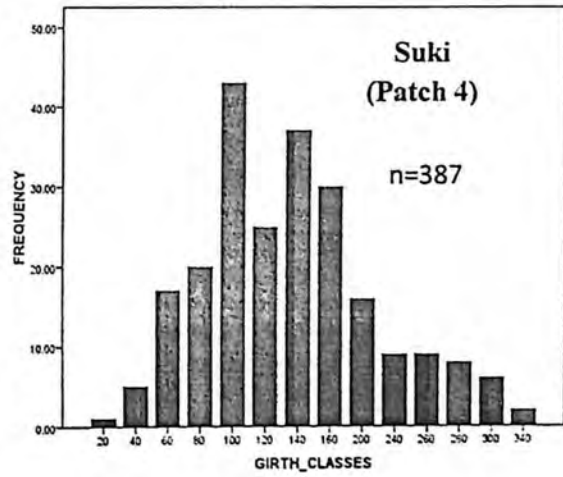
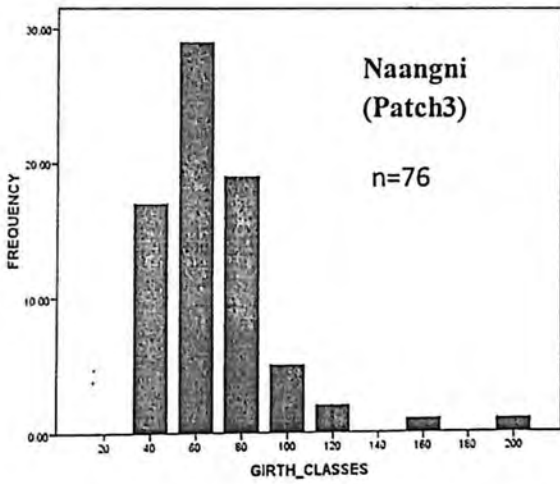
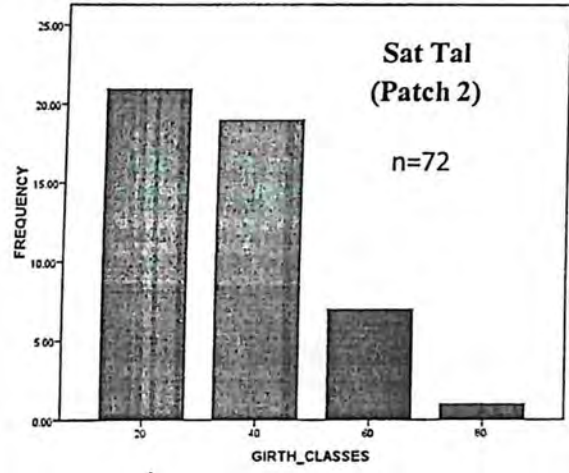
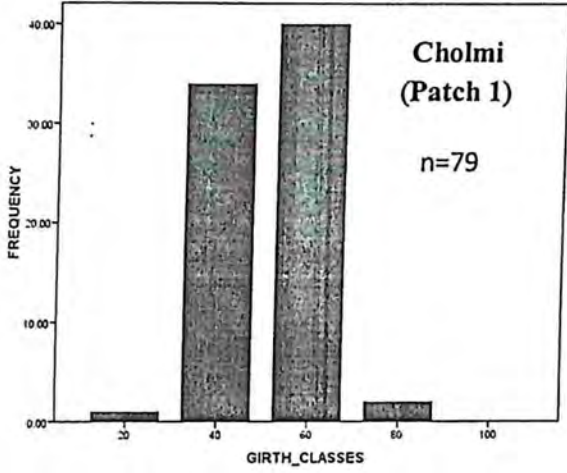
Is the Himalayan Yew fated to stagnate and decline like its sister species? Can the introduction of Yew to suitable marginal shrub lands see recolonisation of the species?

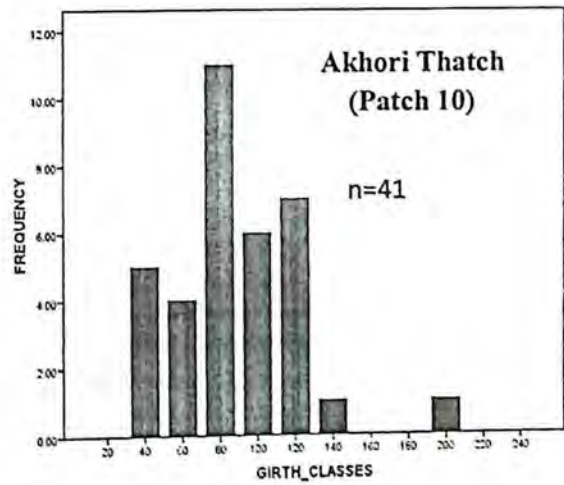
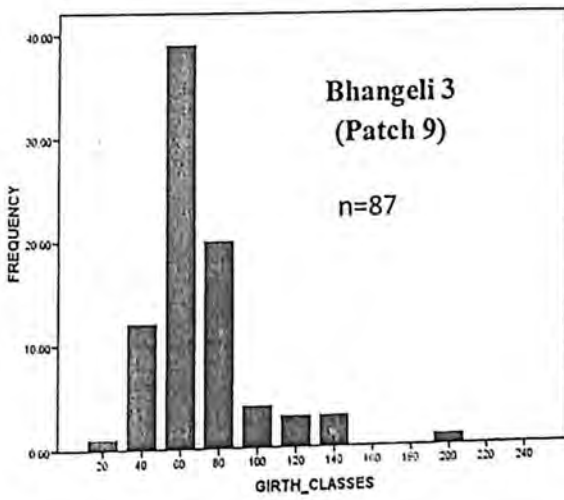
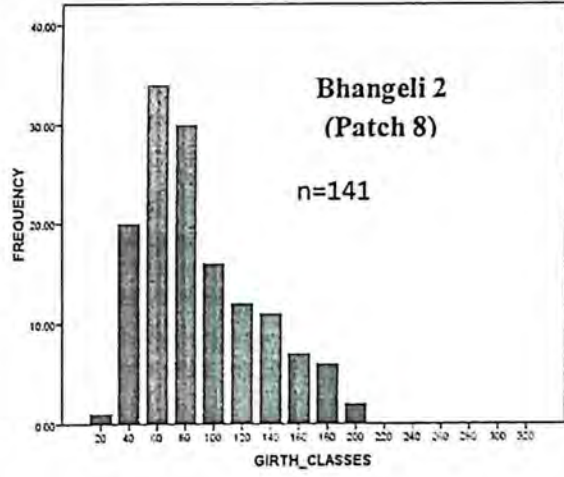
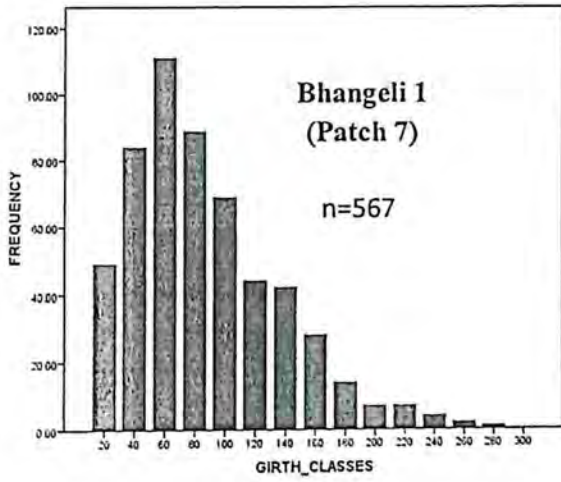
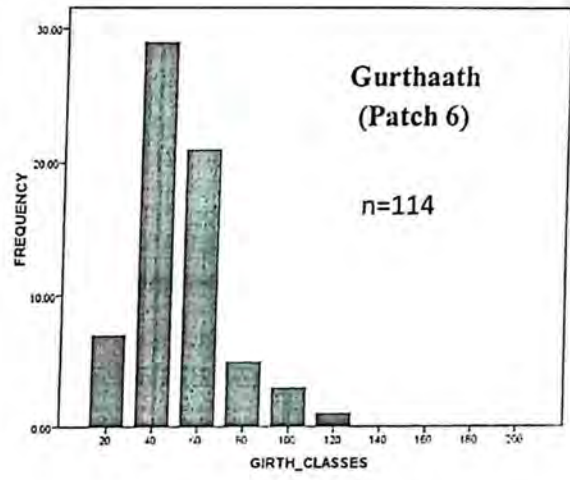
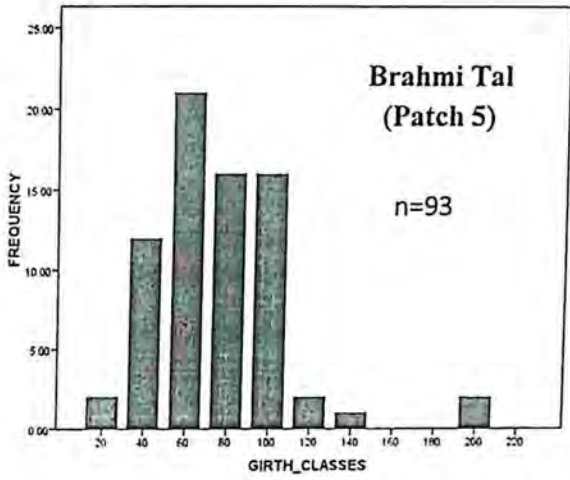
Artificial regeneration has not yet been successful for the species. The requirement of the species is often judged by the requirements of already established adults. Are the requirements of a sapling different from those of the adult? And given that the nearest neighbours of *Taxus* are *Abies pindrow* and *Quercus semecarpifolia* would artificial regeneration stand a better chance under these associates rather than the mother tree?

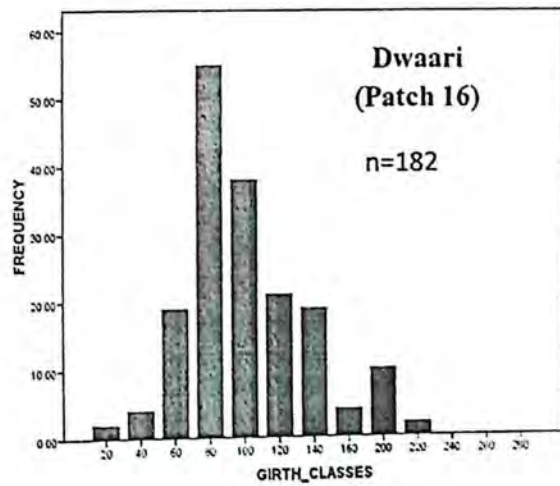
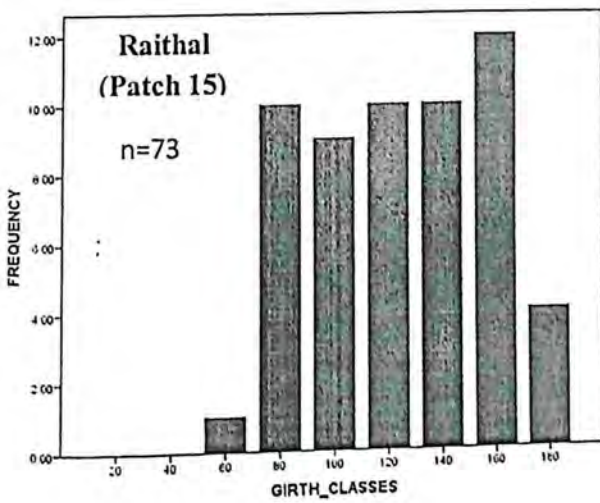
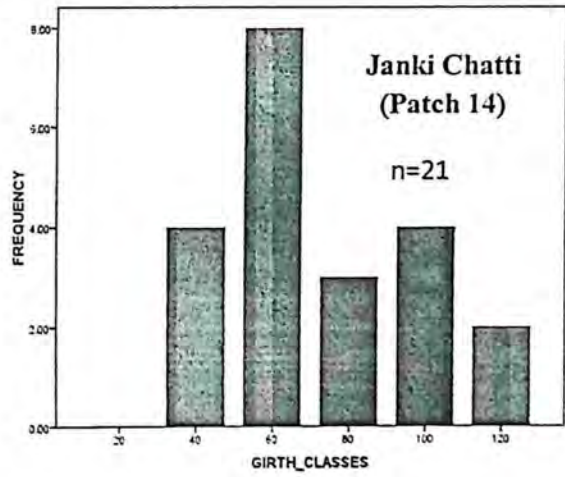
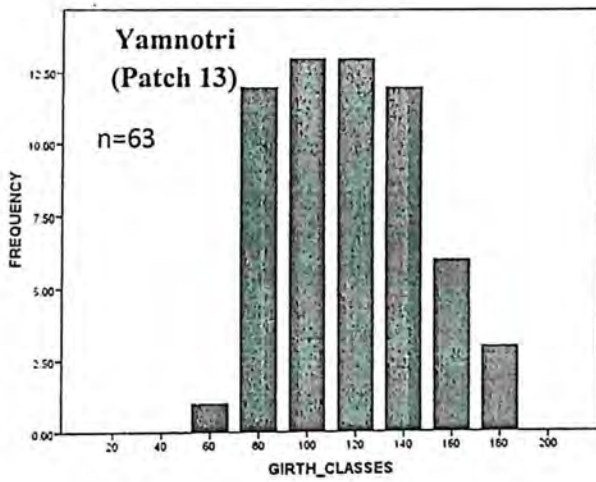
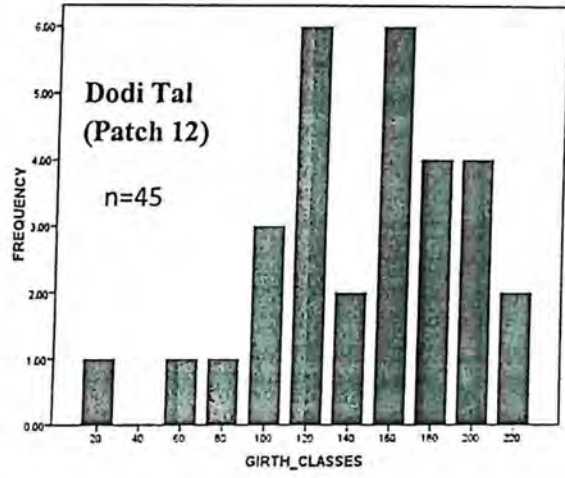
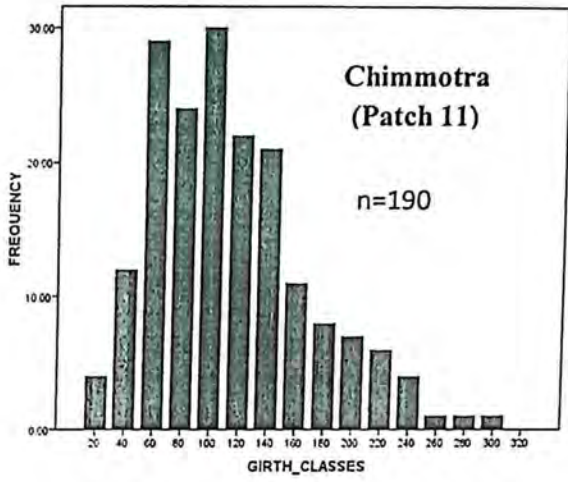
Other interesting aspects are, do male and female individuals differ in their habitat selection? What is the cause for the bias in sex ratio is towards females? Are females less choosy about their habitats? What are the main factors for poor regeneration? Is it non availability of suitable habitats, pressures from grazing, inability of the male and female to flower synchronously (heterocarpy), lack of dispersing agents, and lack of adequate perch sites or allelopathic associations under the mother plant? These questions need to be further investigated to get a better understanding of the species.

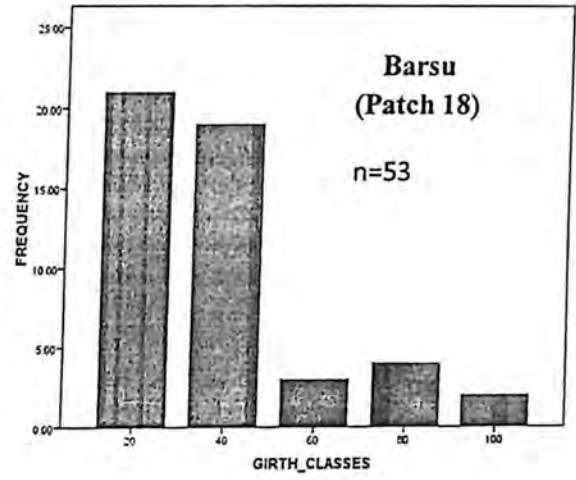
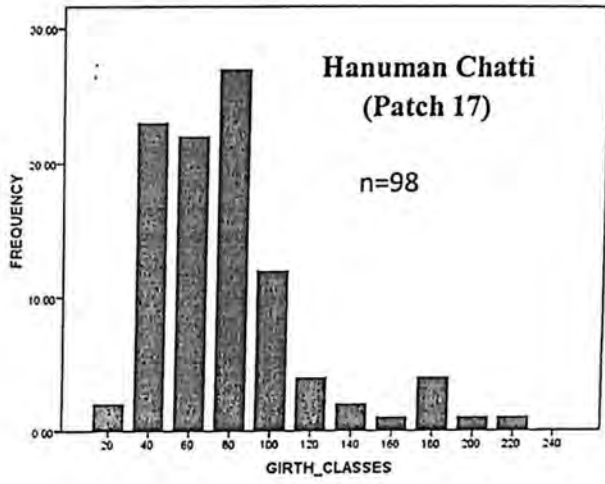
Yew wood is hardy and used by locals for making implements and beams for houses. Care should be taken that reproductively mature trees are not exploited as growth rates are very slow. Would give an insight into probable Taxus patches and help the managers to monitor them. Microhabitat studies can Marking of seed bearing or mother trees would help to manage the Taxus stands judiciously. Distribution maps The study is not exhaustive but very preliminary. Further studies are required to understand the species better and its processes. It is a stepping stone to further insights into mechanisms of nature.

Girth class distribution for individual patches









Model selection for testing for microhabitat preferences

Model name	Model definition	df	AIC
mo	No~Elev+Slp+C.Asp+Temp+pH+Ld+Can	9	446.77
m1	No~Elev	3	491.8972
mod2	No~Slp	3	486.9333
mod3	No~Temp	3	481.208
mod4	No~pH	3	490.533
mod5	No~Ld	3	479.6237
mod6	No~Can	3	495.6121
mod7	No~Can*Slp	5	487.9647
mod8	No~pH*Temp	5	481.6011
mod9	No~Slp*Ld	5	472.6047
mod10	No~Slp*Temp	5	468.7494
mod11	No~pH*Ld	5	479.7801
mod12	No~pH*Elev	5	491.331
mod13	No~Can*Elev	5	495.2554
mod14	No~C.Asp*Temp	5	458.3081
mod15	No~C.Asp*Ld	5	459.3243
mod16	No~C.Asp*Temp+Elev	6	460.2809
mod17	No~C.Asp*Temp+Slp	6	450.8812
mod18	No~C.Asp*Temp+Can	6	459.6701
mod19	No~C.Asp*Temp+Slp+Can	7	451.4983
mod20	No~C.Asp*Temp+Elev*Can	8	463.1865
mod21	No~C.Asp*Elev	5	463.1516
mod22	No~C.Asp*Slp	5	460.0214
mod23	No~C.Asp*pH	5	467.4325
mod24	No~C.Asp*Temp+pH	6	460.1402
mod25	No~C.Asp*Ld	5	459.3243
mod26	No~C.Asp*Temp+pH	6	460.1402
mod27	No~C.Asp*pH+Temp	6	460.6708
mod28	No~C.Asp*Temp	5	458.3081
mod29	No~C.Asp*Can+Ld	6	460.1101

mo

No~Elev+Slp+C.Asp+Temp+pH+Ld+Can

Deviance	Residuals:				
	Min	1Q	Median	3Q	Max
	-1.8209	-0.8687	-0.6196	0.145	2.271
Coefficients:					
	Estimate	Std.	Error	z value	Pr(> z)
(Intercept)	0.5956965	6.4247344	0.093	0.92613	
Elev	-0.0002153	0.0003946	-0.546	0.58533	
Slp	0.0248314	0.0076297	3.255	0.00114	**
C.Asp2	-1.1591655	0.2656819	-4.363	1.28E-05	***
Temp	-0.1444219	0.0470911	-3.067	0.00216	**
pH	-0.1470601	0.9052267	-0.162	0.87095	
Ld	0.0748287	0.0229908	3.255	0.00114	**
Can	-0.00996	0.0058255	-1.71	0.08732	.

mod17

No~C.Asp*Temp+Slp

df=6 AIC=450.8812

Coefficients:					
	Estimate	Std.	Error	z value	Pr(> z)
(Intercept)	-0.478922	0.341423	-1.403	0.1607	
C.Asp2	-1.379346	0.260639	-5.292	1.21E-07	***
Temp	-0.068435	0.057349	-1.193	0.23275	
Slp	0.025108	0.007932	3.165	0.00155	**
C.Asp2:Temp	-0.14939	0.096277	-1.552	0.12074	

Bio- climatic variables (bioclim) for predictive distribution modeling using maxent

BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Disrturbance

Disturbance	Score (Low)	Score (Medium)	Score (High)
Grazing	1	2	3
Fire	1	2	3
Lopping	1	2	3

Total score: 9

Overall disturbance:

1-3: Low

4-6: Medium

7-9: High

Appendix V

1	<i>Pinus wallichiana</i>	23	<i>Berberis spp</i>
2	<i>Skimmia laureola</i>	24	<i>Pyrus lanata</i>
3	<i>Taxus wallichiana</i>	25	<i>Rosa sericea</i>
4	<i>Adiantum spp</i>	26	<i>Thalmocalamus spathiflora</i>
5	<i>Abies pindrow</i>	27	<i>Buxus sempervirens</i>
6	<i>Picea smithiana</i>	28	<i>Daphne cannabina</i>
7	<i>Cedrus deodara</i>	29	<i>Danthonia spp</i>
8	<i>Juglans regia</i>	30	<i>Lyonia ovalifolia</i>
9	<i>Viburnum spp</i>	31	<i>Aesculus indica</i>
10	<i>Sorbus foliosa</i>	32	<i>Viburnum spp</i>
11	<i>Cotoneaster acuminata</i>	33	<i>Fraxinus micrantha</i>
12	<i>Ilex dipyrena</i>	34	<i>Pinus roxburghii</i>
13	<i>Indigofera gerardiana</i>	35	<i>Alnus nitida</i>
14	<i>Sarcococa pruniformis</i>	36	<i>Ancillia spp</i>
15	<i>Quercus semecarpifolia</i>	37	<i>Rosa moschata</i>
16	<i>Quercus dilatata</i>	38	<i>Betula utilis</i>
17	<i>Quercus leucotrichophora</i>	39	<i>Betula alnoides</i>
18	<i>Prunus padus</i>	40	<i>Acer acuminatum</i>
19	<i>Acer caesium</i>	41	<i>Fragaria spp</i>
20	<i>Rhododendron campanulatum</i>	42	<i>Primula spp</i>
21	<i>Rhododendron arboreum</i>	43	<i>Pteridium spp</i>
22	<i>Prinsepia utilis</i>	44	<i>Rubus spp</i>
23	<i>Berberis spp</i>	45	<i>Piptanthes nepalensis</i>
24	<i>Pyrus lanata</i>	46	<i>Taxus wallichiana</i>

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