POPULATION STRUCTURE AND NATURAL REGENERATION OF HIMALAYAN YEW (*Taxus wallichiana* Zucc.) IN SUBTROPICAL FORESTS OF MEGHALAYA

By

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DECLARATION

I, Ms. Mildonna Swer, do hereby declare that the thesis entitled "**Population structure and natural regeneration of Himalayan yew (*Taxus wallichiana* Zucc.) in subtropical forests of Meghalaya**" embodies a record of original and independent research work carried out by me in the Department of Botany, North- Eastern Hill University, Shillong. The work is original and no part of the thesis forms the basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree or diploma in any University / Institute.

The thesis is being submitted to the North- Eastern Hill University for the award of the degree of Doctor of Philosophy in Botany.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

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INTRODUCTION

The vascular plants under the group "Gymnosperm" represent ancient plants having roots of origin in the Carboniferous Period of Palaeozoic Era nearly 360 million years ago and they peak-flourished during Triassic, Jurassic and Cretaceous Periods of Mesozoic Era, i.e., 260 to 50 million years ago (Beck 1966, Gifford and Foster 1989). In fact, the distribution of gymnosperms in the distant past was much more extensive than at present. The Jurassic period, known for Dinosaurs, is also known as age of cycads when Cycads were distributed throughout the world and concentrated in equatorial regions. Due to changes in the environment, topography and biological competition, many gymnosperms became extinct. Consequently, modern day gymnosperms are dominated by conifers (Larches, Pines, Firs and Spruce etc.) and are less diverse. Among these, *Cycas* and *Ginkgo* are categorised as living fossils, whereas *Gnetum*, *Ephedra* and *Welwitschia* have restricted distribution (Singh *et al.* 1999).

The Scottish botanist Robert Brown first distinguished gymnosperms from angiosperms in 1825. Gymnosperms are characterized by naked seeds (ovules not enclosed in an ovary). They are, by and large, evergreen trees with soft woods and mostly bear cones. Currently, we have 1088 accepted gymnosperm species belonging to 88 genera and 14 families (The Plant List, accessed on March 23, 2013). Although gymnosperms have been gradually displaced and outnumbered by the more recently evolved angiosperms (GBO 2001), they are still dominant in many parts of the world and occupy large areas of the Earth's surface. Conifer forests, for example, cover vast regions of northern temperate lands in North America and Eurasia, mostly as boreal (taiga) forests or temperate rain forests. In fact, they grow in more northerly latitudes than do angiosperms and are known for their larger size. Some of them are more than 3,000 years old. Vascular plants that occur at the highest altitudes are the gnetophyte *Ephedra*. Land in the Southern Hemisphere is rich in conifer forests, which tend to be more abundant at higher altitudes. Gymnosperms that occupy areas of the world with severe climatic conditions are adapted to conserving water; leaves are covered with a heavy, waxy cuticle, and pores (stomata) are sunken below the leaf surface to decrease the rate of evaporation. 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. The genus name *Taxus* is from the Greek word 'taxos' for yew. Currently, Taxaceae has five genera, viz., *Amentotaxus, Austrotaxus, Psedotaxus, Taxus* and *Torreya* (The Plant List, accessed on March 23, 2013). The Plant List includes 73 scientific plant names of species rank for the genus *Taxus*. Of these 9 are accepted species names, 61 synonyms, 2 unplaced and 1 unassessed (Table 1.1). The classification of *Taxus* is given below:

Kingdom	*Plantae* – Plants
Subkingdom	*Tracheobionta* – Vascular plants
Superdivision	*Spermatophyta* – Seed plants
Division	*Coniferophyta* – Conifers
Class	*Pinopsida*
Order	*Taxales*
Family	*Taxaceae* – Yew family
Genus	*Taxus* L. – yew

Table 1.1. The accepted names of species in the genus *Taxus* and their conservation status.

Species	Conservation Status
Taxus baccata L.	Lower Risk/least concern ver 2.3
Taxus brevifolia Nutt.	Lower Risk/near threatened ver 2.3
Taxus canadensis Marshall	Lower Risk/least concern ver 2.3
Taxus cuspidata Siebold & Zucc.	Lower Risk/least concern ver 2.3
Taxus floridana Nuttall ex Chapman	Critically Endangered B1ab(iii,v) ver 3.1
Taxus fuana Nan Li & R.R.Mill	Not available in IUCN redlist
Taxus globosa Schlectendahl	Lower Risk/near threatened ver 2.3
Taxus sumatrana (Miq.) de Laub.	Lower Risk/least concern ver 2.3
Taxus wallichiana Zucc. (Himalayan yew)	Endangered A2acd ver 3.1
*Taxus wallichiana*_var._*chinensis*_(Pilg.) Florin*	Lower Risk/least concern ver 2.3

Compiled from: The Plant List (accessed March 23, 2013), *, from GRIN (accessed March 23, 2013),; Farr (2008) CITES Scientific Authority, Natural Resources Canada, Canadian Forest Service, Canada. Threatened Status determined from IUCN 2012. IUCN Red List of Threatened Species. Version 2012.2. <www.iucnredlist.org>. Downloaded on 23 March 2013.

The genus *Taxus* is predominantly confined to the mid-latitudes of the northern Hemisphere with some intrusion to tropical highlands, i.e., between Norway and Indonesia. The genus range includes, in Europe: Britain to northern Iran; in Asia: Russia, Korea, Japan, China, Taiwan, Himal, India, Burma, Vietnam, Philippines; in North America: southeast Alaska to California, southeast Canada to northeast USA, Florida, Mexico, Guatemala, El Salvador (Earle 2008).

Fig.1.1. Global distribution of the genus *Taxus* (Earle 2008).

In India, Taxaceae is represented by two genera, namely *Taxus* and *Amentotaxus* (Sahni 1990). *Taxus baccata* L. subsp. *wallichiana* (Zucc.) Pilger is the only member of *Taxus* found in India which is indigenous to the Himalayan region (Troup 1921, CSIR 1976, Singh and Singh 1992, Samant 1993, Rikhari *et al.* 1998, Kaul 2008, Pant and Samant 2008, Ganguli *et al.* 2011). It is now known as *Taxus wallichiana* Zucc. var. *wallichiana* or simply *Taxus wallichiana* Zucc. In literature, the conservation status of this species has been varying over time and across regions (Table 1.2).

Table 1.2. Global conservation status of *Taxus wallichiana* Zucc.

Region/Country	Status	Source
World	Lower Risk	World List of threatened trees (Oldfield *et al.* 1998)
World	Endangered (A2acd)	IUCN (2012)
World	Not threatened	Farjon (1998)
China	Vulnerable	Xiang (2004)
China	Endangered	Fu and Jin (1992)
China	Critically low, greatly restricted and threatened	Khan (2005)
Northern India	Critically Endangered	Molur and walker (1998)
Arunachal Pradesh, Sikkim, Jammu & Kashmir, Himachal Pradesh and Uttaranchal	Endangered	Ved *et al.* (2003a, 2003b)
Meghalaya (India)	Critically Endangered	Ved *et al.* (2003a, 2003b)
Nepal	Endangered	Anonymous (2001)
Nepal	Threatened	Sharma (2006)
Northern Vietnam	Vulnerable	Thomas and Duc (2004)
Southern Vietnam	Endangered	Thomas and Duc (2004)
Bhutan	Rare	Pradhan (1993)

Source: Review of the Status, Harvest, Trade and Management of Seven Asian CITES-listed Medicinal and Aromatic Plant Species. TRAFFIC, 2008.

The species of the yew family are known as the source of "taxol", an anti-cancer drug. In the 1950's the American Cancer Institute initiated a widespread screening program of substances and extracts from various origins in the hope that they would find antineoplastic agents. Over 110,000 extracts from plant species were tested over a 21 year period (1960-1981), and the findings showed that an extract from the bark of the pacific yew, *Taxus brevifolia* was the most promising antineoplastic agent. Subsequently, other widespread species of *Taxus* were also in demand for taxol. These were *T. baccata* (European yew), *T. cuspidata* (Japanese yew) and *T. wallichiana* (Himalayan yew).

The yew is also known as the "tree of death". The name *Taxus* comes from the Greek 'toxin', which translate to poison or toxin. It's poisonous nature has been mentioned in many cultures. Some examples are:

- In ancient Roman literature, Julius Caesar, wrote that, Catuvolcus, who was king of the Eburones, poisoned himself with the yew because he was old and weak and didn't want endure another war.
- Pliny the Elder (Gaius Plinius Secundus) noted that people died after consuming wine stored in barrels made out of the yew tree.
- In Celtic culture the yew is a sacred tree and is used to carve out religious objects such as the duric staff.
- Dioscorides (Greek physician) observed that the yew emitted poisonous fumes (pollen).
- Shakespeare also used the poisonous nature of yew in Macbeth and Hamlet.
- In the Unani system of medicine, the extract from the bark and leaves of *T. baccata* was the source of a drug *Zarnab*, used for the treatment of various disorders (Anonymous 1976).
- The extract from the bark and leaves is also used for the treatment of various diseases like bronchitis, asthma, poisonous insect bites and also as an aphrodisiac (Beckstrom-Sternberg and Duke 1993).

Monroe E. Wall and Mansukh C. Wani isolated a drug from the bark of the Pacific yew tree, *Taxus brevifolia* and named it "**taxol**" for the first time in 1967. When it was developed commercially by Bristol-Myers Squibb (BMS), the generic name was changed to **paclitaxel** and the BMS compound is sold under the trademark **Taxol**. In this formulation, paclitaxel is dissolved in Cremophor EL and ethanol, as a delivery agent. **Paclitaxel** is a mitotic inhibitor used in cancer chemotherapy. Paclitaxel is used to treat patients with lung, ovarian, breast, head and neck cancer, and advanced forms of Kaposi's sarcoma. Paclitaxel is also used for the prevention of restenosis. A newer formulation, in which paclitaxel is bound to albumin, is sold under the trademark **Abraxane**.

From 1967 to 1993, almost all paclitaxel produced was derived from bark from the Pacific yew, the harvesting of which kills the tree in the process. In 1993, taxol was discovered to be produced in a newly described endophytic fungus living in the yew tree (Stierle *et al.* 1993). It has since been found in a number of other endophytic fungi, including *Nodulisporium sylviforme* (Zhao *et al.* 2004), *Alternaria taxi*, *Cladosporium cladosporioides MD2*, *Metarhizium anisopliae*, *Aspergillus candidus MD3*, *Mucor rouxianus sp.*, *Chaetomellaraphigera*, *Phyllosticta tabernaemontanae*, *Phomopsis*, *Pestalotiopsispauciseta*, *Phyllosticta citricarpa*, *Podocarpus*, *Fusarium solani*, *Pestalotiopsis terminaliae*, *Pestalotiopsis breviseta*, *Botryodiplodia theobromae Pat.*, *Gliocladium sp.*, *Alternaria alternata var. monosporus*, *Cladosporium cladosporioides*, *Nigrospora sp.*, *Pestalotiopsis versicolor*, and *Taxomyces andreanae*.

The lack of a sustainable source of supply of the bark of *Taxus brevifolia* has been a great concern. To extract 1 kg taxol, about 9,000 dried inner bark is required which can be 9kn obtained from 2,000 to 3,000 yew trees. A bio-renewable source of the drug has been found in the form of 10-deacetyl baccatin III, which has led to the discovery of **Taxotere**.

The stating material, 10- Deacetyl baccatin III can be isolated in yields approaching 0.3% from *Taxus baccata* needles, without hampering tree growth. The tree continues to grow after the leaves have been harvested, hence *Taxus baccata* provides a renewable source of the precursor. 10-deacetyl baccatin III can be coupled with a synthetic side chain to give taxol. Intense research is being carried out to produce a viable total synthesis of taxol which would alleviate the supply problem. Also derivatives are being synthesised to find analogues which exhibit a better anticancer effect than taxol. Biotechnologists have obtained taxol from cultivated callus cell of *Taxus brevifolia.* This area of research hopes to cultivate the taxol producing cells and speed up their production. On a large scale taxol could be produced in tanks to supply the huge demand for the drug. A garden variety of the yew tree, *Taxus* media Hicksii, has a high taxol extraction coefficient and is currently being investigated for commercial viability.

Objectives

The information on the populations and regeneration of *Taxus wallichiana* is not available from northeastern region of India to complement those from central Himalayan region and other parts of the world. Further, studies on seed traits, germination and early growth of seedlings in natural habitats have not been undertaken to understand its seed ecology. Hence this study was undertaken with the following objectives:

1. To assess the population structure of *Taxus wallichiana* in subtropical forests containing *Taxus* as an important element, and
2. To study natural regeneration and seedling dynamics of *Taxus wallichiana.*

CHAPTER II

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Taxus wallichiana Zucc. (synonym *Taxus baccata* L. subspecies. *wallichiana* Zucc.) Pilger, is a threatened tree belonging to the family 'Taxaceae'. It is commonly known as 'Himalayan Yew'. Locally, *T. wallichiana* is known as *Tesiang* or *Tesing* in Arunachal Pradesh (Nimachow *et al.* 2010), 'Thuner' in various parts of Western Himalaya (Purohit *et al.* 2001), and 'Rakhal' in Himachal Pradesh (Pant and Samant 2008). The tree came to eminence in 1990s due to large scale injudicious exploitation from the wild due to its anti-cancer medicinal property.

The threat to this species has been recognized at the beginning of the 20th century (Gamble 1922). Degradation of forests sites, extensive clear cutting of old growth forest trees for commercial purpose and grazing are the main identified threats to this species (Bugala 1978, Tittensor 1980, Jahn 1991, Allison 1993, Rikhari *et al.* 1998, 2000, Purohit *et al.* 2001). The extent of canopy damage has been projected to lead to serious consequences on biomass yield, plant survival and natural regeneration by affecting the seed output (Rikhari *et al.* 1998).

2.1. *T. wallichiana* communities

Generally, yews are long-lived trees. The yew (*T. baccata* L.) is believed to have a longevity for more than a millennium (Bebber and Corona 1986, Larson *et al.* 2000), although in reality dendrochronological studies to date have proved a maximum longevity of about five centuries (Biondi 1992). In a first study of its kind in India, the ring-width chronology of the Himalayan yew (*T. wallichiana*) from Western Himalaya has yielded a 345-year chronology (Yadav and Singh 2002).

According to Leuthold (1998), yew occupies a peculiar role of 'triple intermediate species'. In a typical ecological succession, yew is intermediate between pioneer and climax species; in a sociological sense, yew is mostly co-dominant in the lower canopy, half-way between the overstory and the understory; in a morphophysiological sense it is intermediate between broadleaf and needle species.

Information on spatial distribution and mapping of *T. wallichiana* has been generated in recent years from the Hindu-Kush Himalayan region: from Palas Valley in Pakistan (Saqib *et al.* 2006), Uttarkashi in Central Himalaya (Ganguly 2011) and Talle Valley in Arunachal Pradesh (Behera *et al.* 2000). These studies on predictive modeling of distribution of *T. wallichiana* with the help of GIS techniques have confirmed patchy distribution of the species in its range. *T. wallichiana* grows as under canopy tree and is highly clumped in distribution within most forests. It never forms extensive stretches despite wide elevational distribution (1770-3400 m) (Rikhari *et al.* 2000). Further additions to this matrix of data are required especially from the regions where *T. wallichiana* occurs, but not spatially mapped.

The Himalayan yew is found associated with broadleaved as well as conifer tree species. It forms associations with different species at different stages of succession. In the Indian Himalayan Region (IHR), it is generally found as an understorey species in most forest communities. Abundance of yew is low as compared to its associated species (Dhar *et al.* 1997, Rikhari *et al.* 2000, Samant *et al.* 2002, Joshi 2002, Pant and Samant 2005, 2008).

In Arunachal Pradesh, Himalayan yew is associated with coniferous and broadleaved species depending upon the elevation. At high altitudes in temperate and subalpine regions (between 2800 and 3600 m) in Subansiri district, *Pinus wallichiana*, *Tsuga dumosa* and *Abies densa* predominate with a collective IVI of about 210. *T. wallichiana* occurs in these forests sparsely and commands an IVI of only 7.2 (Behera *et al.* 2002). At lower altitudes in Talle Valley (between 2000 and 2500 m), species such as *Quercus lamellosa*, *Q. elegans*, *Rhododendron arboreum*, *R. grande*, *Ilex griffithii*, *Betula alnoides*, *Acer* spp., *Sorbus* spp., and conifers such as *Abies densa*, *Tsuga dumosa*, *Larix* sp., *Cupressus* sp. are the main associates of *T. wallichiana* (Behera *et al.* 2000).The associates vary in their proportional abundances with places (Shukla *et al.* 1994).

At Jageshwar in Kumaon Himalaya, *T. wallichiana* occurs in small groups of 5-10 individuals in two associations between 1810 and 2050 m altitude (Rikhari *et al.* 2000). First, in a cedar forest characterized by the dominance of *Cedrus deodara* in canopy and a low occurrence of undercanopy associate, *Neolitsea pallens*. Second, in a mixed broadleaf forest characterized by co-dominance of tree species in the canopy (*Juglens regia*, *Aesculus indica*, *Q. leucotrichophora* and *Q. floribunda*).

In Nanda Devi Biosphere Reserve (NDBR) of Garhwal region of Central Himalaya, *T. wallichiana* is widely but sparsely distributed along the cool temperate belt between 2600 and 3300 m (Purohit *et al.* 2001). Here, *T. wallichiana* is a late successional species and is closely associated with *Betula utiliz*, *Abies pindrow*, *Acer caesium*, and *Pinus wallichiana*, and also found in small patches under the *Quercus semecarpifolia* and *Rhododendron arboreum* association in other parts of Himalaya (Singh and Singh 1992).

In Uttarkashi in Garhwal Himalaya, *Abies pindrow* is a common associate of both *T. wallichiana* and *Cedrus deodara* (Ganguly 2011). However, it must be noticed that Deodar does not have an affinity to *Taxus*. Few *Taxus* individuals grow in association with Deodar. Hence, *T. wallichiana* shows a strong association with *Abies pindrow*.The chances of finding *A. pindrow* and a *Taxus* together is much higher than finding two *Taxus* individuals together. Similarly, *Quercus semecarpifolia* (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, *Q. semecarpifolia*, Spruce and Moru (*Q. floribunda),* are 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, where canopy species seems to have failed (Ganguly 2011).

In Khokan Wildlife Sanctuary in North Western Himalaya (Himachal Pradesh), Himalayan Yew was found only in six out of sixty-five sites sampled spanning an altitude between 1600 and 3000 m (Pant and Samant 2008). The associate species of *T. wallichiana* varied with altitude (Table 2.1).

Table 2.1. Associates of *T. wallichiana* in six communities in Khokan Wildlife Sanctuary in north-western Himalaya (Source: Pant and Samant 2008).

Site	Altitude (m)	Habitat	Slope (°)	Community type	Associates
1	2380	SM	10	*Abies pindrow*	*Persea odoratissima, Picea smithiana, Qercus floribunda*
2	2220	SM	35	*Abies pindrow-Cedrus deodara* mixed	*Quercus floribunda, Picea smithiana, Aesculus indica*
3	2320	R	60	*Cedrus deodara*	*A. pindrow, Cornus macrophylla, Pinus wallichiana*
4	1800	SM	35	*Picea smithiana*	*A. pindrow, Prunus cornuta, Q. leucotrichophora, Q. floribunda*
5	1790	SM	35	*Q. floribunda*	*P. wallichiana, Q. leucotricophora*
6	2340	SM	15	*Q. semecarpifolia*	*Q. floribunda, P. odoratissima, Aesculus indica, Juglens regia*

2.2. Population structure

The population structure (age structure) of *T. wallichiana* is affected by the level of disturbance irrespective of the forest type. Younger dbh/age classes occur both in less disturbed as well as disturbed forests, older age classes were less affected by the disturbance, while there is a balance in the distribution of age classes in areas of intermediate disturbance.

The population structure of *T. wallichiana* has been studied from Jageshwar, Almora in Central Himalaya from disturbed and undisturbed sites (Rikhari *et al.* 1998). The disturbed plots had a population structure with a lower number of individuals both towards the lower and higher size classes and a higher number of individuals in intermediate size classes. The undisturbed plots also showed a similar population structure, with seedlings being more abundant than individuals of other size classes. However, the conversion of seedlings to saplings was still very poor.

In a subsequent study, Rikhari *et al.* (2000) found a clear effect of disturbance level on population structure of *T. wallichiana*. Along the disturbance gradient, least disturbed mixed broadleaf forest association showed stable population of *T. wallichiana* as evident by greater number of small individuals than large individuals. In contrast, in moderately disturbed sites, saplings and some of the subsequent size classes were not found. At highest disturbed sites, only the oldest tree category was present with more individuals in higher than in lower size classes, indicating failure of regeneration in the past. A similar pattern was observed in the cedar forest.

The ageing of a population of *T. baccata* was studied over 25-year period (1976 to 2001) in Knyazhdvir Nature Reserve, West Ukraine (Iszkulo *et al.* 2005). The age structure was different in various parts of the Nature Reserve. The individuals were vigorous and there was no interaction between the number of individuals per hectare and vitality in three various places in the Nature Reserve. Individuals with bi- or tri-furcate trunks (polycormic) were significantly thicker than those with single trunks (monocormic). The latter were most numerous in the whole population. The changes that occurred during 25 years indicate the tendency towards population ageing, but with relatively numerous young individuals and seedlings.

In a study on the comparison of the natural population of two gene conservation forests from different geographic location in Austria, there were considerable differences between the two populations (Dhar *et al.* 2007). In respect of health condition, the site Stiwollgraben showed 79% of the total yew population vital in comparison to only 49% at the site Leininger Riese.

A study on population structure of *T. wallichiana* from Khokan Wildlife Sanctuary in Kullu, Himachal Pradesh showed an aged population with lack of recruitment (Pant and Samant 2008). The size class distribution showed that over 42% individuals were >90 cm in CBH, nearly 18% were between 70 and 90 cm, almost 11% were between 50 and 70 cm and almost 30% were between 30 and 50 cm. The saplings and seedlings were very less in number.

Piovesan *et al.* (2009) analyzed three populations of *T. baccata* in Apennines, Italy. Here, yew grows in European Beech (*Fagus sylvatica* L.) stands. The beech stands that included yew exhibited a DBH distribution typical of uneven-aged forests and reflected the different management histories at the three study sites. Pettorano, where beechwoods were mostly managed in the past as coppice with standards, differed from the other two study areas, formerly managed as high forest. In all stands, yew occupied the forest understory, growing beneath beech trees. Yew accounted for 21% of tree density at Morino and for 32% at Pettorano as well as Femmina Morta.

Ruprecht *et al.* (2010) studied three gene conservation forests in Austria in order to analyze the relationship between vitality and competition. The three study areas showed significant differences (P = 0.05%) in respect to the DBH distribution of the English yews (DBH >5.0 cm). Reserves A and B had a wider range of the DBH distribution compared to reserve C. In reserves A and B about 40% of the yews had a DBH below 15.0 cm while in reserve C the percentage was 97%.

2.3. Natural regeneration

Natural regeneration plays an important role in conservation of a species. *T. wallichiana* reproduces naturally through seeds but does not regenerate well (Anonymous 1976, Shukla *et al.* 1994, Pant and Samant 2008). The life strategy of *T. wallichiana* has been described as "stress-tolerant". The reproductive activity and recruitment of seedlings is good, but establishment is poor. The lack of regeneration can be due to a number of reasons. For example, clipping of foliage for taxol extraction may reduce seed set even in relatively unharvested yew trees (Allison 1993). Browsing and bark-stripping by wild animals may also be responsible for low regeneration and seedling recruitment (Minore *et al.* 1996, Purohit *et al.* 2001). Frugivory may be another possible reason in which the birds and monkeys consume seeds along with aril and disperse to unfavorable sites. The fallen seeds may be destroyed by field rats rodents resulting in poor seed germination (Rikhari *et al.* 1998).

Besides poor germination, survivability of *T. wallichiana* is also poor and if ~~seedlings~~ seed successfully germinate they grow very slowly (Shukla *et al.* 1994, Nandi *et al.* 1994, Rikhari *et al.* 1998). The survival may be enhanced by better light availability in canopy openings (Svenning and Magard 1999, Dovciak 2002, Ruprecht *et al.* 2010).

Presence of established saplings and adult trees determines the future composition of a community while the age structure of a population predicts its regeneration status (Pokhriyal *et al.* 2010). Moreover, annual variation in seedling abundance and distribution could be a direct indication of future changes in upper treeline stability (Germino *et al.* 2002).

Populations of *Taxus baccata* in sub alpine forests were reported to be in a declining state as they reached the climax stage (Watt 1926). In general, seedlings and saplings were either absent or found in small numbers. Moreover the seedlings found are not younger than 3 to 4 years since the number of seedlings is reported to decline with an increased in the age (Rikhari *et al.* 1998, Pant and Samant 2008, Ganguly 2011, Farris 2012).

In recent years, several studies have expanded our knowledge of yew biology and ecology, but the circumstances under which this species develops from being an occasional component of woodland to becoming the dominant canopy species remain poorly understood (Thomas and Polwart 2003). Previous research indicated that yew recruitment was driven by factors at the micro-habitat scale (100 m^2), but sapling establishment differed considerably between sites, suggesting that landscape factors such as topography (altitude, aspect, and slope), vegetation (canopy cover), and disturbance caused differences in germination and survival (Garcı´a *et al.* 2005b). On the other hand, some studies have suggested that mature yew trees can prevent successful yew regeneration (Hulme 1996, Iszkulo and Boratynski 2006, Watt 1926). Hence, ecological pathways leading to the formation of pure yew forest stands are not well understood, and the limited number of such stands still remaining makes this task even more difficult.

2.4. Morphometric variation in fruit and seed characteristics

Studies on variation in fruit and seed characteristics of tree species in response to varied climatic conditions are few (Harper 1977, Uma Shankar 2006, Ghosh 2007, Uma Shankar 2012, Uma Shankar and Synrem 2012, Nongrum 2012). Within-species variation in respect of seed weight, speed of germination, rate of germination and seedling vigour of yew (*Taxus baccata*) were first studied in England by Melzack and Watts (1982). Six provenances were selected from the widest possible geographic area. Significant variation occurred in all the characters, but only seed weight variation displayed a clinal pattern. Relationships between the characters were not statistically significant. Unlike some other conifers, seed weight in the yew in England is not an indicator of germination rate of seedling vigour.

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is avail
on these
aspects

Within-species variation in fruit and seed characteristics of *T. wallichiana* has not been studied earlier. This study collected data on 2677 fruits and seeds of *T. wallichiana* from different trees and analyzed these data to find the effect of individual trees, provenances and tree vigour on following parameters: fruit weight, fruit length, fruit width, fruit thickness, seed weight, seed length, seed width, and seed thickness (Chapter VI).

2.5. Seed germination and seedling dynamics

Germination of yew seeds in natural condition is very slow and it rarely occurs in the first year. Most germination occurs in the second or third year (Melzack 1979, Melzack and

Watts 1982). After seeds fall they remain dormant for several months. The dormancy is reported from 1.5 to 2 years (Chee 1995, Nasr *et al.* 2007). However, Minore *et al.* (1994, 1996) reported that yew seeds are capable of surviving in the soil seed bank for more than three years. Seed viability is high (USDA 1948) and can remain viable for up to 4 years (Suszka 1978) with germination rate of 50-70% (USDA 1974). Heit (1969) achieved 95% germination over a three year period. The viability of *T. baccata* seeds can be maintained artificially for up to 4 years by storing in damp sand or peat at 'low temperatures' (USDA 1974). Yew seed can also be stored for 5-6 years by drying at room temp to c. 10% moisture content and then storing at 1-2 °C (Heit 1968, 1969) or even lower at -3 °C (Suszka 1985, Thomas and Polwart 2003).

Concerns to overcome yew seed dormancy were revealed in the early 1970s by Le Page-Degivry (1968, 1973) and Le Page-Degivry and Garello 1973). She found that the dormancy of yew embryos was caused by two things: the immaturity of embryos and the occurrence of endogenous inhibitors (abscisic acid, ABA). The immaturity could be overcome by maintaining isolated embryos on a proper medium under in vitro conditions. The removal of inhibitors requires the soaking of seeds in water and using gibberellins, or the soaking of seeds in water and treating them with low temperature. However, using these methods was not enough to obtain a germination ratio higher than 28% in the best case. Attempts were also made to use liquid Heller's medium to leach inhibitors and nourish isolated embryos at the same time (Heller 1953). Research activities were restarted in the field during the early 1990s. Flores and Sgrignoli (1991) paid attention to the significance of the maturity level of yew seeds as a factor affecting the germination of isolated embryos. Their first studies were performed on *Taxus* x media (var. Hicksii, var. Wardi, var. Citation, and var. Sunburst) and *T. brevifolia*, and were continued on *T.*

baccata and *T. cuspidata* (Flores *et al.* 1993). They divided the seeds into five groups according to seed maturity: LG, pale green seeds without arils; G, dark green seeds; EA, seeds with developing, pink aril; RG, green seeds and completely developed aril; and RD, dark brown seeds and completely developed red aril.

Seeds from the G group were the best for germination. These seeds germinated at about 70% efficiency. Higher maturity levels resulted in worse germination frequency (below 10%). On the other hand, seeds from the LG group had embryos too small for isolation, and culturing them together with the embryo sack did not give positive results. Another classification was proposed by Chee (1994). She distinguished three development stages depending on seed color and aril development: stage I, seeds about 2-mm length, pale green, aril green, and not swelled; stage II, seeds about 4-mm length, dark green or pale brown, aril a little swelled, pale pink; stage III, seeds about 6-mm length, brown, aril swelled, and red. In opposition to other authors, she recognized that more mature seeds in stage II and III were the best for in vitro germination. Frequency of germinated embryos were 21 and 52%, respectively.

The effect of low temperatures on isolated embryo germination was also investigated. Flores and Sgrignoli (1991) reported that a short freezing (-20°C) of fully matured seeds could break dormancy, but the germination ratio was lower than in younger seeds. Both Flores *et al.* (1993) and Deyu and Zhongchen (1999) reported that storing seeds at +4°C for about 30–40 d improved the germination ability of isolated embryos from 27 to 70%.

Conditions for obtaining an efficient mass propagation procedure to overcome isolated *Taxus baccata* embryo dormancy were investigated by Zarek (2007). The protocol herein described was efficient for overcoming the dormancy of *T. baccata* isolated embryos under in vitro conditions, enabling the conservation and propagation of this species. *T.*

baccata seeds were unable to germinate directly after collection under in vitro conditions. Very good sterility and germination was achieved by soaking seeds in distilled water at a low temperature (+4°C) at least for 48 h instead of leaching them for 7 d under running water, followed by maintaining isolated embryos on the Murashige and Skoog medium (MS) supplemented with 5 g l-1 activated charcoal. That treatment allowed one to shorten the time of the experiment and gave almost 100% sterility. The best germination was observed in darkness, but to obtain worthy seedlings, it was necessary to place cultures in a 16-h photoperiod after a 2-wk incubation. There was no significant difference in germination between seeds collected from different populations of Southern Poland.

Discrepancies among the reported data require further investigations to optimize the method of breaking *Taxus* seeds dormancy. In this context, we investigated conditions for obtaining an efficient mass propagation procedure to overcome isolated *T. baccata* embryo dormancy.

Seed germination of *Taxus* is very low in respect of percentage. The methods to speed up germination have also been helpful in increasing germination percentage in many instances. Artificial scarification with sulphuric acid, alternating temperatures, short periods of moist pre-chilling (20-30 days) are some good examples. It is also reported that a warm moist period (15-20° C for 90 to 210 days) before a chilling period (60-120 days at 2-5° C) is helpful in increasing the size of the embryo. There is also a recommendation that a fluctuating temperature in the pre-chilling warm period is essential for high subsequent germination (Mitiska 1954, Heit 1968, 1969, Suszka 1985, Thomas and Polwart 2003). But so far literature reveals only limited success. In fact, it is believed that germination of *Taxus* seeds is more difficult than the other coniferous species (Pilz 1996a,b, Datta *et al.* 2006).

Vegetative propagation through stem cuttings and tissue culture methods offer the possible alternative for quick regeneration and faster multiplication of *T. wallichiana* (Khali 2001, Khali and Sharma 2003, Khali *et al.* 2004).

CHAPTER III

THE SPECIES, ITS DISTRIBUTION AND STUDY SITES

CHAPTER III

THE SPECIES, ITS DISTRIBUTION AND STUDY SITES

3.1. The species (*Taxus wallichiana* Zucc.)

Taxus wallichiana Zucc. (synonym *Taxus baccata* L. subspecies. *wallichiana* (Zucc.) Pilger, belonging to the family Taxaceae is commonly known as 'Himalayan Yew', It is a slow growing, long-lived, medium-sized, shade-loving, evergreen tree usually attaining a height up to 20 m (Sahni 1990, Shukla *et al.* 1994) and a gbh (girth at breast height) up to 1.5 m (Sahni 1990) or up to 1.8 m (Hynniewta and Singh 1996). However, higher values of girth and height have been reported from other countries (Busgen *et al.* 1929, Paule *et al.* 1993, Lesani 1999, Earle 2001, Thomas and Polwart 2003, Piovesan *et al.* 2009). The tree has spreading branchlets and leaves arranged in two whorls that are 2.5 to 3.5 cm long and linear. The leaves are glossy green above and pale beneath. *T. wallichiana* can be easily confused with *Cephalotaxus* and *Tsuga*, but the latter have leaves that are white beneath (Uma Shankar 2005).

T. wallichiana has a short, thick and fluted stem (Fig. 3.1). It bears spreading branches which are surrounded by scales at the base. The bark is thin and peels of easily. It is reddish-grey in external appearance and light pink inside with thin fibrous plates (Ganguli *et al.* 2011). The bark of Himalayan Yew is thinner than other yew species, making it susceptible to fire (Pant and Samant 2008). In Sikkim Himalaya, the bark of *T. wallichiana* is used to prepare a beverage locally called as 'Namkin Chay' and also for medicines. The bark stripping in this area has impacted the populations of *T. wallichiana* (Purohit *et al.* 2001). The shoots bear green foliage which are arranged in a fairly close spiral but becomes spread in two ranks by the twisting and curving of the petioles. The leaves are 2.5 - 3.8 cm long, linear, flattened, arranged in two opposite vertical rows, dark glossy green above and pale beneath.

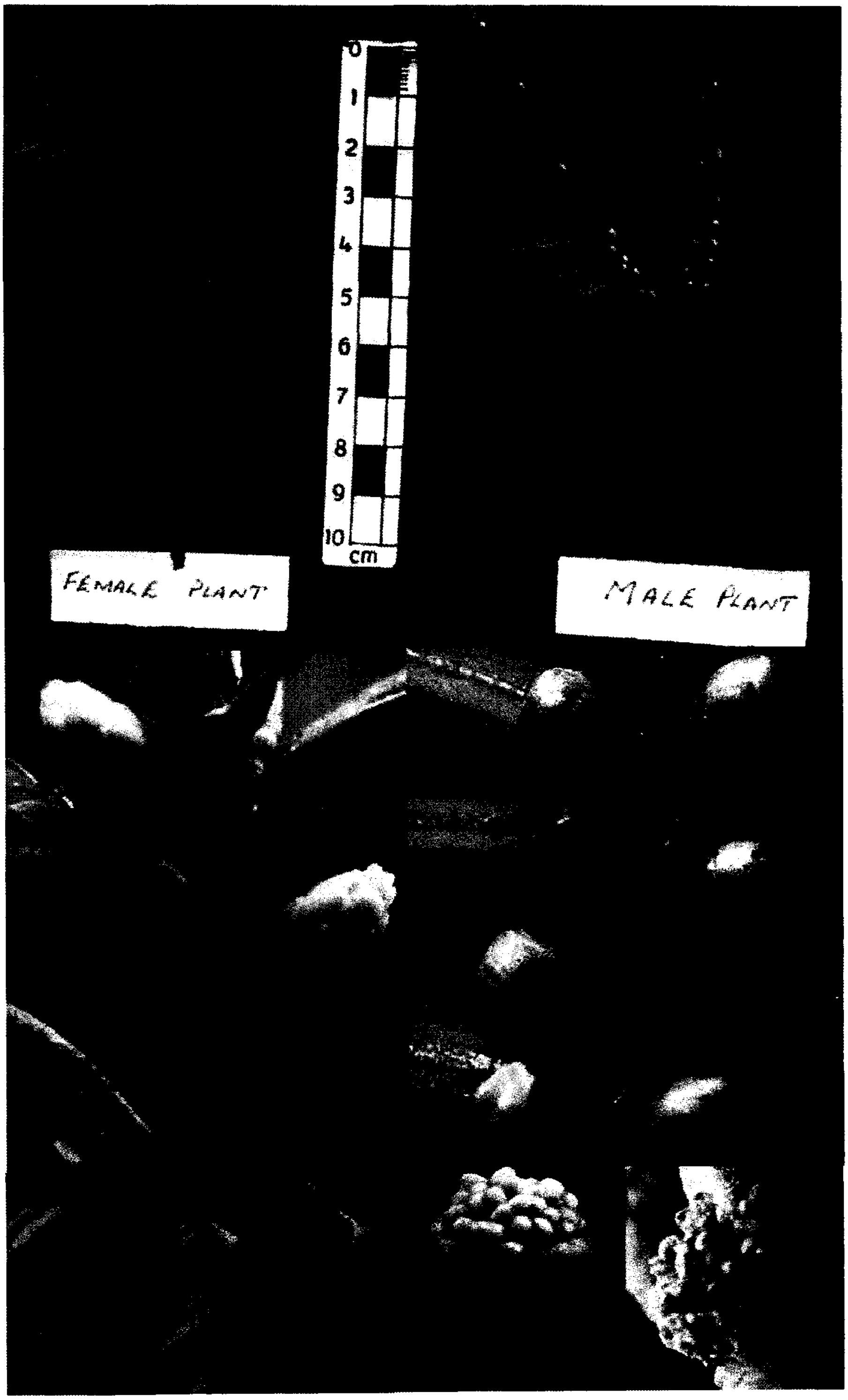


Fig. 3.1. Female (left) and male (right) parts of *T. wallichiana* (Photo: Dr. Uma Shankar).

T. wallichiana is dioecious, i.e., bearing male and female cones on separate trees. The young male and female trees are morphologically alike and cannot be distinguished until they bear reproductive structures, i.e., male and female strobili. Male cones are green, turning yellow in leaf axils. The female cones are solitary in axils (Shukla *et al.* 1994). The fruit is marked by a single seed encapsulated within a succulent, bring-red arillate cup (Haridasan, 1996, Iszkulo 2001, Uma Shankar 2005). The aril (pulp) is edible by birds.

The leaf flush and flowering are synchronous and occur in spring season, from March to April. The leaf senescence occurs during May to June. The seeds are produced in ensuing October-November. However, the fruits may last on the mother tree till late December depending on weather condition (Troup 1921, Sahni 1990).

The ovule is unitegmic, crassinucellate, orthotropous and sessile. The single integument is free from the nucellus except at the base. In a young ovule a ring like outgrowth, the aril, develops at the base of the integument which later, covers the entire ovule. At first it is green saucer- shaped structure but eventually it takes the form of a large, fleshy red cup enclosing the hard bony seed. The seeds surrounded by red, fleshy edible aril are dispersed by birds, monkeys and humans (Purohit *et al.* 2001).

3.2. Distribution of *Taxus wallichiana*

In Indian sub-continent, *Taxus wallichiana* occurs in subtropical, temperate and sub-alpine regions of the Hindu-Kush Himalaya (Yadav and Singh 2002). *T. wallichiana* prefers an altitude between 1,500 and 3,400 m and is distributed from Afganistan through Arunachal Pradesh in the Himalayan ranges and in Khasi and Jaintia Hills of Meghalaya, Naga Hills and Manipur in the sub-Himalayan tracts (Haridasan 1996, Rikhari *et al.* 2000, Yadav and Singh 2002). In Pakistan, *T. wallichiana* is scanty and patchy in Palas Valley (Saqib *et al.* 2006).

In Arunachal Pradesh, the ideal altitudinal zone where *T. wallichiana* occurs is between 2000 and 2500 m, i.e., in the temperate forests of Bomdila, Shergaon, Eagle's Nest, Dirang, Thungri, Tawang, Mago and Zimithang in West Kameng and Tawang districts; Tale Valley in Lower Subansiri district; Anini, Mayodiya in Dibang Valley district; Mechuka in Siang district; and Melinja and Hotspring areas of Lohit district (Beniwal and Haridasan 1992, Shukla *et al.* 1994). In West Kameng district of Arunachal Pradesh, large scale exploitation of leaves of *T. wallichiana* occurred in 1990s, especially from the populations in Domkho, Morshing, Sanglem, Khelang, Phuding, Mandela and Dirang as a result of which the species has fast depleted (Nimachow *et al.* 2010).

In Manipur it occurs in temperate forests (Singh *et al.* 2000). The occurrence of *T. baccata* has been reported by Hooker (1886-90) in Flora of British India, Volume V from Khasi Hills in Meghalaya. In his description of the species, Hooker has mentioned *T. wallichiana* Zucc. as a synonym. Brandis (1906) also mentions the occurrence of this tree as *T. baccata* in his book, 'Indian Trees' and reports from Khasi Hills, presumably based on Hooker's description. Kanjilal (1940) also mentioned the occurrence of *T. baccata* in 'Flora of Assam' from Khasi Hills, Mishmi Hills and Balipara Frontier Tract. The present survey has shown that *T. wallichiana* occurs in the following districts of Meghalaya: East Khasi Hills, West Khasi Hills and Jaintia Hills.

Champion and Seth (1968) in their monumental treatise on "The Revised Survey of Forests of India" observed the presence of *T. wallichiana* in Himalayan moist temperate forests and Subalpine forests (Table 3.1).

Table 3.1. An inventory of forest habitats of *T. wallichiana* in India as per Champion and Seth (1968).

Sl. #	Forest type	Page
1	Group 12. Himalayan Moist Temperate Forests	
	CI. Lower Western Himalayan Temperate Forest	296
	a. Moru oak forests (*Quercus dilatata*)	299-300
	b. Western mixed coniferous forests (Spruce, blue pine, silver fir)	305
	c. Moist temperate deciduous forests	307
	CII. Upper Western Himalayan Temperate Forest	310
	a. Kharsu oak forest (*Quercus semecarpifolia*)	311
	b. West Himalayan upper oak/fir forest	313
	c. Moist temperate deciduous forests	314
2	Group 14. Sub Alpine Forests	
	CI. West Himalayan sub-alpine birch/ fir forests (Betula/Abies)	334
	a. West Himalayan sub-alpine fir forest	335

3.3. Study sites

A reconnaissance survey was undertaken to explore the forest sites harbouring *T. wallichiana* in Meghalaya. The first hand information on the distribution of *T. wallichiana* was collected from published floras of the region (Hooker 1886-90, Kanjilal 1940, Anonymous 1976, Haridasan 1987, Balakrishnan 1984). The documents of the State Forest Department were also consulted. The village headmen were contacted to gather information on the populations of *T. wallichiana* from the local people such as traditional medicine practitioners and NTFP collectors. Six natural populations of *T. wallichiana* could be marked in Meghalaya (Table 3.1, Fig. 3.2). The geographical attributes of these sites were recorded using a Garmin GPS (Table 3.2). In four of these sites, viz., Nongmawlum Pyrda, Phudjaut Rangthong, Mawlieh-Rambrai and Pyrden-Riangdo, extremely rare occurrence of *T. wallichiana* was noted due to harvesting in 1990s.

Table 3.2. The potential sites of occurrence of natural populations of *T. wallichiana* in Meghalaya.

Site	Elevation (m)	Latitude (N)	Longitude (E)
1. Mawphlang East Khasi Hills	1788	25°26’34.70”	91°44’27.00”
2. Nongmawlum Pyrda East Khasi Hills	1715	25°30’08.60”	91°03’44.25”
3. Phudjaut Rangthong West Khasi Hills	1283	25°21’57.90”	91°23’17.00”
4. Mawlieh-Rambrai West Khasi Hills	1446	25°35’25.11”	91°18’08.05”
5. Pyrden-Riangdo West Khasi Hills	1002	25°40’08.97”	91°03’10.63”
6. Moodymmai Jaintia Hills	1154	25°30’48.72”	92°03’06.44”

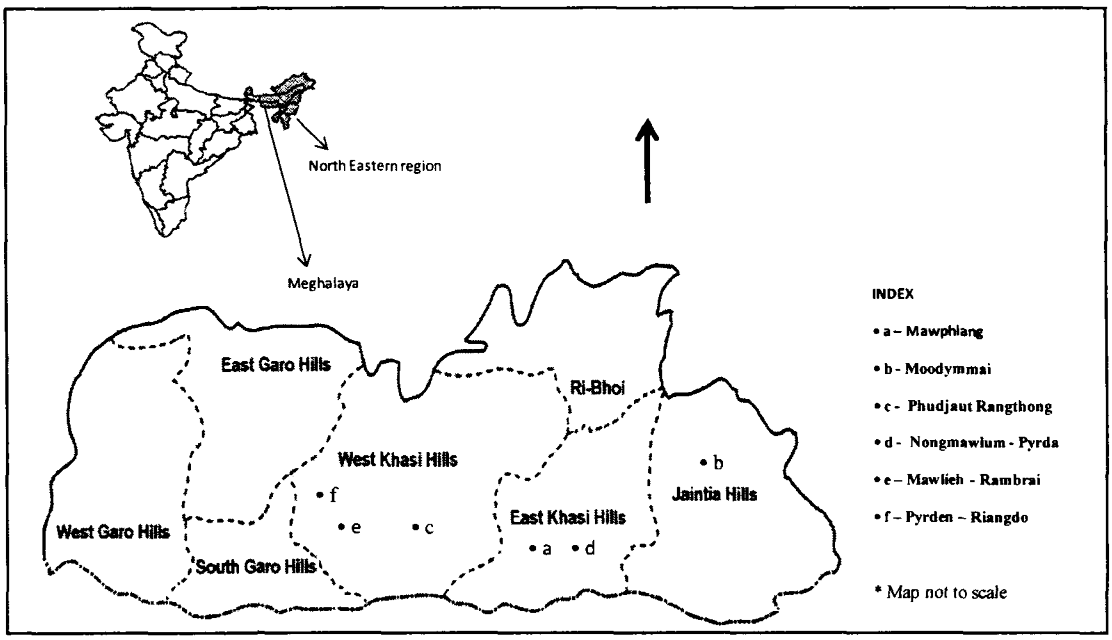
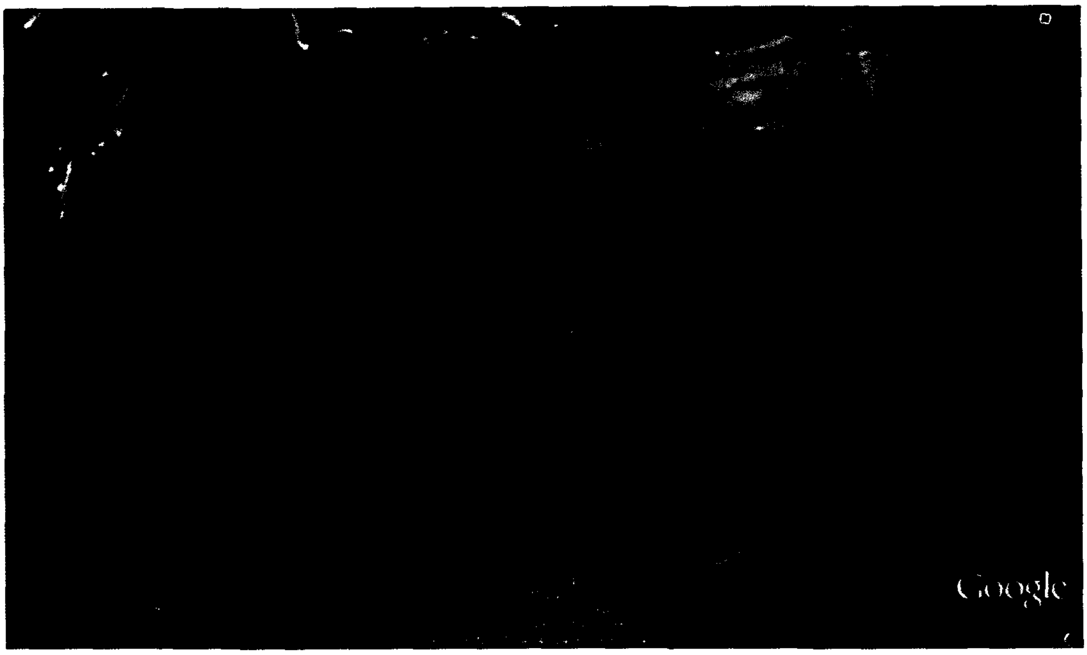


Fig. 3.2. Map of India showing the location of northeastern states (shaded area) and map of Meghalaya showing the sites of occurrence of *Taxus wallichiana*: a, Mawphlang; b, Moodymmai; c, Phudjaut-Rangthong; d, Nongmawlum-Pyrda; e, Mawlieh-Rambrai; f, Pyrden-Riangdo.

Only two sites, viz., Mawphlang and Moodymmai were selected for detailed study (Fig. 3.3). Mawphlang is about 30 km from the state capital, Shillong. The forest stand at Mawphlang is relatively undisturbed, dense and evergreen with broad-leaved trees not exceeding 20 m in height. It represents a relic of the climax vegetation which has been left undisturbed due to religious beliefs of the local tribals (Fig. 3.3).



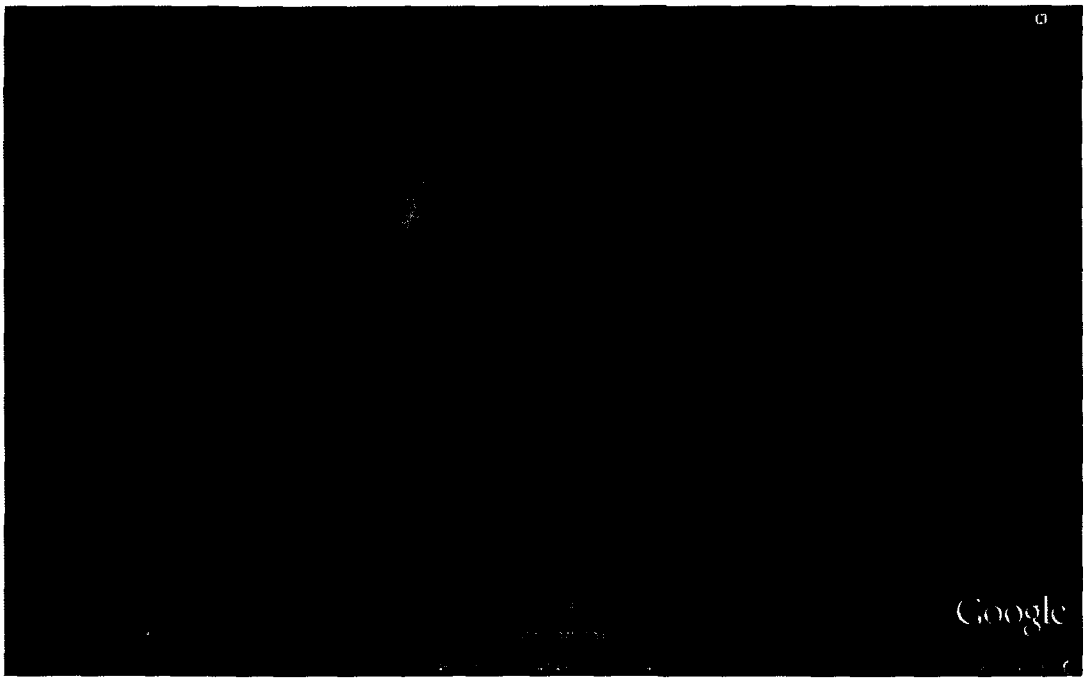


Fig. 3.3. The location of sample quadrats (red squares) in Mawphlang (above) and Moodymmai (below) forests in Meghalaya.

The dominant tree species are *Quercus dealbata, Quercus griffithii, Schima khasiana, Myrica esculenta, Rhododendron arboreum* and *Manglietia insignis* (Hazra 1977). The understorey with predominance of *Symplocus chinensis, Daphne shillong* and *Eurya japonica* is hardly distinguishable. There is a heavy growth of epiphytic orchids, mosses, ferns and woody climbers in the forest. The stand shows poor under-canopy growth. The climate is monsoonic with an average annual rainfall of 2500 mm, 85% of which occurs between May and September. The winter (November to February) is characterized by low temperature (mean minimum -3 °C, mean maximum 16 °C) and occasional rain. The period during April-mid-May is usually dry. The mean annual maximum and minimum temperatures are 22 °C and 16 °C respectively. The soil is lateritic, loam to loamy silt with acidic reaction (pH 5.0 - 5.7). The organic matter and nitrogen content vary between 3.2 - 6.4% and 0.17 - 0.28% respectively. The canopy cover is almost 100% and the average light intensity on the forest floor is 20% of the illumination outside the forest (Rao *et al.* 1990).

Moodymmai is situated in Jaintia Hills district, about 65 km from Shillong. The forest stand at Moodymmai is experiences anthropogenic disturbance in the form of firewood collection, grazing and collection of NTFPs (Fig. 3.2). The dominant species here include *Pinus kesiya* and *Castanopsis* sp.

The climate of Moodymmai is monsoonic with distinct wet and dry seasons (Fig. 3.4). The wet season extends from April to October, followed by a dry period from November to March. During wet season, monthly rainfall ranges from 131 mm to 1557 mm, while in dry period it is usually <50 mm per month. The annual rainfall as high as 6,539 mm was recorded in year 2000. The mean monthly temperature varies from a minimum of 5 °C in January to a maximum of 26 °C in April (Upadhaya *et al.* 2003, 2004).

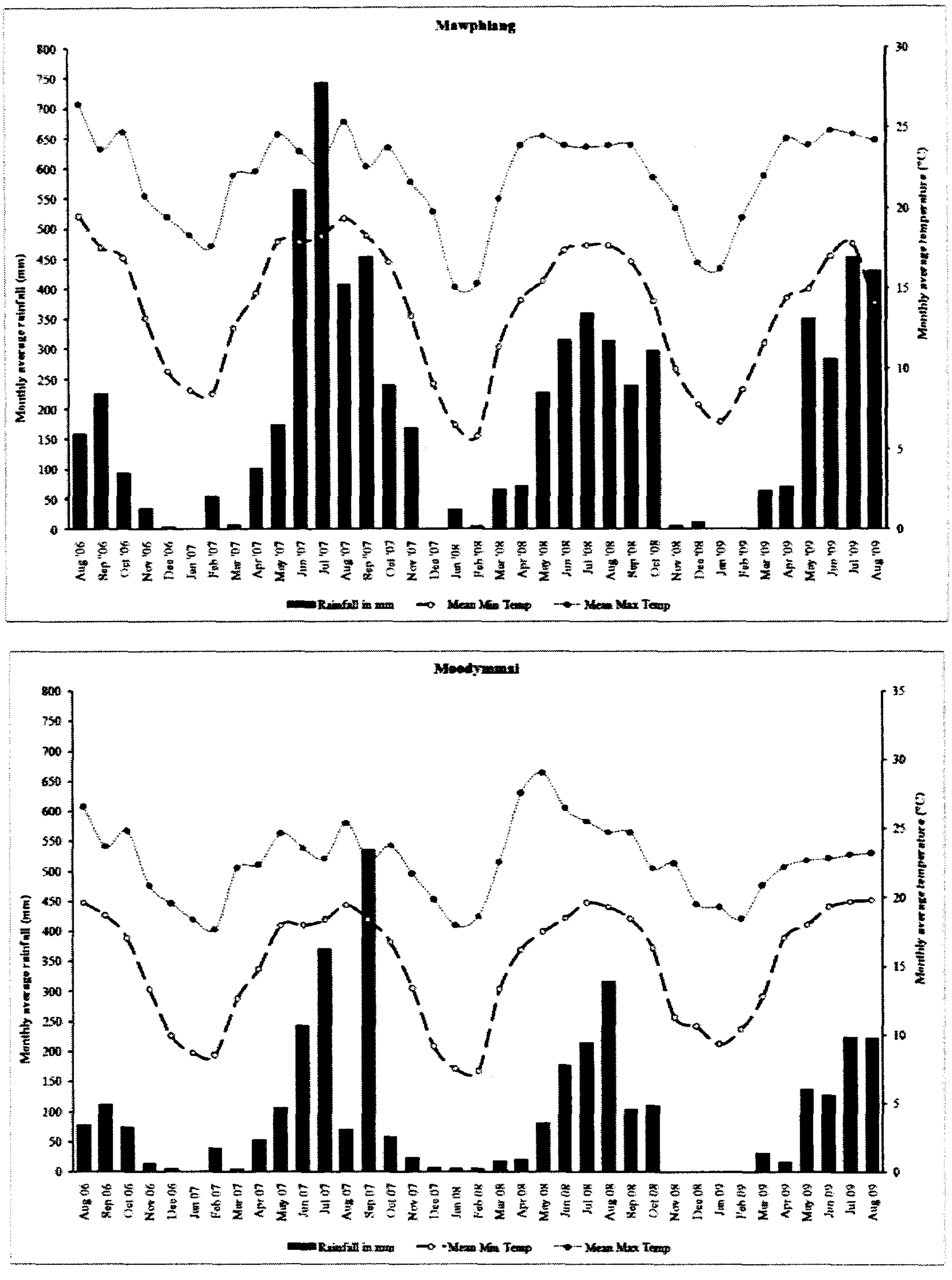


Fig. 3.4. Climatic diagrams of Mawphlang and Moodymmai. (Source: Meteorological Center, Upper Shillong and District Local Research Station and Laboratory of Jowai)

Sampling of vegetation at Mawphlang and Moodymmai was done following quadrat method. At each site, 8 quadrats of 25 x 25 m were sampled, yielding a total sampling area of 5,000 m^2. The geographical attributes of the quadrats are given in Table 3.2.

Table 2.3. Geographical attributes of quadrats sampled at Mawphlang and Moodymmai.

Quadrat #	Corner	Mawphlang			Moodymmai		
		Latitude (N)	Longitude (E)	Elevation (m)	Latitude	Longitude	Elevation (m)
1	NE	25°26'43.2"	91°44'47.7"	1814	25°30'51.6"	92°06'44.7"	1158
	NW	25°26'43.5"	91°44'47.1"	1810	25°30'51.37"	92°06'43.88"	1157
	SW	25°26'43.1"	91°44'46.5"	1820	25°30'50.59"	92°06'43.85"	1151
	SE	25°26'42.4"	91°44'47.2"	1811	25°30'50.80"	92°06'44.62"	1152
2	NE	25°26'44.0"	91°44'56.9"	1825	25°30'50.80"	92°06'44.62"	1157
	NW	25°26'43.8"	91°44'56.2"	1826	25°30'50.59"	92°06'43.85"	1158
	SW	25°26'43.2"	91°44'56.6"	1819	25°30'49.93"	92°06'44.24"	1163
	SE	25°26'43.3"	91°44'57.2"	1823	25°30'50.10"	92°06'44.90"	1162
3	NE	25°26'39.5"	91°44'42.7"	1806	25°30'49.9"	92°06'45.10"	1164
	NW	25°26'39.3"	91°44'42.1"	1813	25°30'49.82"	92°06'44.21"	1164
	SW	25°26'38.7"	91°44'42.2"	1814	25°30'49.10"	92°06'44.07"	1170
	SE	25°26'38.8"	91°44'42.9"	1800	25°30'49.10"	92°06'44.94"	1170
4	NE	25°26'38.3"	91°44'42.8"	1812	25°30'49.04"	92°06'45.22"	1170
	NW	25°26'38.6"	91°44'42.4"	1819	25°30'49.09"	92°06'44.22"	1170
	SW	25°26'37.9"	91°44'42.2"	1808	25°30'48.25"	92°06'44.12"	1176
	SE	25°26'37.7"	91°44'42.9"	1815	25°30'48.26"	92°06'44.99"	1177
5	NE	25°26'38.7"	91°44'38.3"	1819	25°30'47.7"	92°06'45.0"	1160
	NW	25°26'38.3"	91°44'37.6"	1822	25°30'47.9"	92°06'44.2"	1159
	SW	25°26'37.8"	91°44'37.8"	1823	25°30'47.3"	92°06'44.2"	1185
	SE	25°26'38.2"	91°44'38.4"	1818	25°30'47.2"	92°06'44.9"	1173
6	NE	25°26'39.6"	91°44'37.3"	1811	25°30'46.5"	92°06'45.6"	1171
	NW	25°26'39.7"	91°44'36.4"	1833	25°30'46.1"	92°06'45.1"	1163
	SW	25°26'39.1"	91°44'36.3"	1821	25°30'45.7"	92°06'45.3"	1175
	SE	25°26'39.0"	91°44'37.0"	1814	25°30'46.2"	92°06'45.9"	1179
7	NE	25°26'42.1"	91°44'40.3"	1826	25°30'45.2"	92°06'45.6"	1187
	NW	25°26'42.1"	91°44'39.3"	1827	25°30'45.4"	92°06'45.0"	1177
	SW	25°26'41.4"	91°44'39.3"	1829	25°30'44.8"	92°06'44.7"	1182
	SE	25°26'41.5"	91°44'40.1"	1830	25°30'44.7"	92°06'45.1"	1185
8	NE	25°26'45.5"	91°44'59.5"	1807	25°30'44.0"	92°06'46.5"	1214
	NW	25°26'45.6"	91°44'58.7"	1818	25°30'43.8"	92°06'45.9"	1203
	SW	25°26'44.7"	91°44'58.9"	1803	25°30'43.2"	92°06'45.8"	1202
	SE	25°26'44.8"	91°44'59.6"	1805	25°30'43.4"	92°06'46.8"	1209

CHAPTER IV

COMMUNITY STRUCTURE OF TAXUS WALLICHIANA HABITATS

CHAPTER IV

COMMUNITY STRUCTURE OF *Taxus wallichiana* HABITATS

4.1. Introduction

The Himalayan yew, *Taxus wallichiana*, is known to occur throughout Himalayan ranges between 1800 and 3300 m elevation, from Jammu & Kashmir (Khan *et al.* 2006) and Himachal Pradesh (Kaul 2008, Pant and Samant 2008) in the western reaches through Garhwal hills (Purohit *et al.* 2001), Kumaon hills (Rikhari *et al.* 1998, 2000), Nepal, Sikkim and Darjeeling (Datta *et al.* 2006), and Bhutan Himalayan ranges to Arunachal Pradesh (Beniwal and Haridasan 1992, Chatterjee and Dey 1997, Behera *et al.* 2000, Nimchaow *et al.* 2010) in the eastern reaches. In sub-Himalayan tracts, *T. wallichiana* occurs at lower altitudes (<2000 m) in Manipur and Meghalaya. The wide distribution of *T. wallichiana* in the Himalayas has rendered it ample niche breadth, enabling it to grow in fairly large variations of habitats, altitudes and vegetation types.

Generally, Himalayan Yew is a slow growing species which prefers undercanopy in many forest communities of the Indian Himalayan region. *T. wallichiana* forms undercanopy associations with several species (Yadav and Singh 2002, Ganguly *et al.* 2011). The associations vary from place to place depending upon the local conditions (Shukla *et al.* 1994, Nimachow *et al.* 2010). The associations of *T. wallichiana* are known with broadleaved as well as conifer tree species. The dominance of *T. wallichiana* in the communities in which it occurs varies widely. In temperate regions, *T. wallichiana* is abundant in the community and forms association with conifers such as spruce (*Abies pindrow*), acer (*Acer caesium*), and rhododendrons (*Rhododendron arboreum*). In sub-temperate to tropical regions, *T. wallichiana* is closely associated with oaks (*Quercus* *semecarpifolia*, *Q. floribunda*, *Q. leucotrichophora*), birch (*Betula alnoides*, *Betula utilis*), and blue pine (*Pinus wallichiana*) (Singh and Singh 1992, Dhar *et al.* 1997, Samant *et al.* 2002, Joshi 2002, Pant 2005, Pant and Samant 2008).

In northeastern India, the status of habitats of *T. wallichiana* in the wild is not well known. A report from West Kameng district of Arunachal Pradesh mentioned merciless mass exploitation has converted the area into a 'death valley' of *T. wallichiana* as 105 trees out of 145 trees discovered were found dead (Nimchow *et al.* 2010). In a RAPD analysis of 24 trees, Saikia *et al.* (2000) found low level of polymorphism and close clustering with small molecular distances indicating a narrow genetic base among the trees growing in northeastern region.

Hence, the objectives of this study were to: a) ascertain floristic composition of different habitats of *T. wallichiana*, b) determine the associates of *T. wallichiana*, and c) assess the regeneration status of *T. wallichiana*.

4.2. Methods

The habitats of *Taxus wallichiana* were explored in the East Khasi Hills, West Khasi Hills and Jaintia Hills of Meghalaya by undertaking a reconnaissance survey (Table 3.2). Of the six habitats explored, only two (Mawphlang and Moodymmai) were selected for the detailed phytosociological analysis (Fig. 4.1).

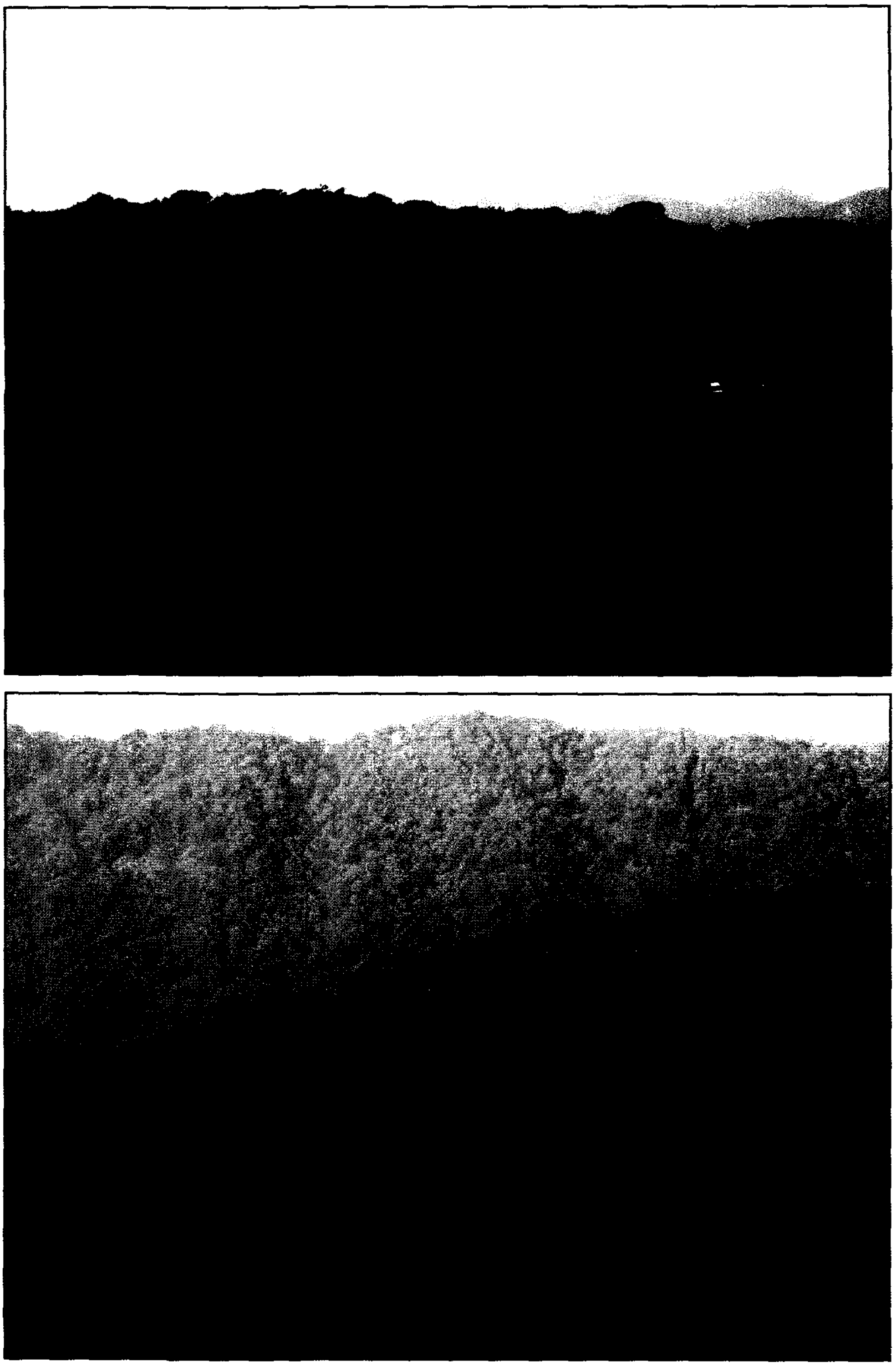


Fig. 4.1. The sampled habitats of *Taxus wallichiana* in Meghalaya: (a) Mawphlang, and (b) Moodymmai.

The phytosociology was worked out using standard methods as outlined by Misra (1968), Mueller-Dombois and Ellenberg (1974), Murali *et al.* (1996) and Uma Shankar (2001). The vegetation was sampled by quadrat method. The quadrats were laid randomly in the habitat, but were partially adjusted in such a way as to include at least one individual of *Taxus wallichiana* in each quadrat. A total of 8 quadrats of 25 m x 25 m size were laid at both the sites (Mawphlang and Moodymmai). The four corners of each quadrat were marked and their physical parameters (latitude, longitude and altitude) were recorded by a GPS. These parameters are already given in the description of the study sites in previous chapter (Table 3.2).

The geographical location of each stem≥ 10 cm in girth (GBH) was recorded in terms of X and Y coordinates. The X coordinate corresponds to the north-south direction and Y coordinate to the east-west direction (Alder and Synnot 1992). Spatial distribution of the stems within each quadrat was plotted using PASSAGE Ver. 2.0 software.

The gender of the trees was determined by observing the presence or absence of seeds/fruits during the fruiting season. The remains of seeds at the base of the tree, remnants of the fruit on the female tree and presence of seedlings in the vicinity also helped in determining the female trees. This was done following the method of Iszkulo (2001).

The girth and height of all stems were measured using a meter tape. The girth was measured at breast height (1.37 m above the ground level) to the nearest millimetre graduation, and the height was visually estimated using a bamboo stick. Similarly, the individuals of *T. wallichiana* occurring in the quadrats were enumerated and their girth (cm) and height (m) were measured. Voucher specimens of the plant species were collected for identification. The identification of the plant specimens was done in the lab at the Department of Botany, North-Eastern Hill University (NEHU), Shillong and also at the herbarium of the Botanical Survey of India, Eastern circle, Shillong. The nomenclature of the species was studied by following the regional floras, e.g., Flora of Assam (Kanjilal *et al.* 1940), Flora of Jowai (Balakrishnan 1981-1983), and the Forest Flora of Meghalaya (Haridasan and Rao 1985-1987).

The importance of a woody species in a forest community is generally characterized by a measure called 'Importance Value Index' or IVI. The measure IVI is a composite of three parameters, viz., relative frequency, relative density and relative dominance. These three relative values of a species are reckoned after calculation of frequency, density and dominance values of all the species. The frequency is obtained from the number of occurrences of a species in sample plots. The density is obtained from the number of individuals of a species in sample plots. The dominance is obtained from the basal area of a species in sample plots. The calculation of various parameters to obtain IVI are based on standard methods given by Misra (1968), Müller-Dumbois and Ellenberg (1974), Uma Shankar (2001) and Magurran (2004).

The formulae are given below:

Whitford's index:

A/F ratio = abundance of the species / per cent frequency of the species

where, abundance is the number of individuals divided by the number of quadrats in which species occurred, and frequency is the ratio of the number of quadrats in which species occurred divided by the number of all quadrats in which species was studied.

Index of association:

$IA = c + d / (a + b + c + d)$

where, a = number of plots having both the species A and B b = number of plots having only species A

c = number of plots having only species B

d = number of plots having both the species absent

Phi coefficient of association:

ϕ = ad - bc / √ (ab · cd · ac · bd)

where, a = number of plots having both the species A and B

b = number of plots having only species A

c = number of plots having only species B

d = number of plots having both the species absent

Chi-square value:

$\chi^2 = \phi^2 \cdot (a + b + c + d)$

Sørensen's similarity index:

= 2 C x 100 / (A+B)

where, A = number of species in stand A

B = number of species in stand B

C = number of species common to both stands, A and B

Species richness index:

= S-1 / $\log_{10}$ N

where, S = number of species

N = number of individuals

Shannon's diversity index:

$H' = -\sum \{(n_i)/N \times \log_{10} (n_i)/N\}$

where, n_i = importance value or number of individuals of i^{th} species

N = sum of importance values or number of individuals of all species

Simpson's dominance Index (λ):

$$Cd = \Sigma(n_i / N) \times (n_i / N)$$

where, n_i = importance value or number of individuals of i^{th} species

N = sum of importance values or number of individuals of all species

Pielou's evenness index:

$$e = -\Sigma \{(n_i)/N \times \log (n_i)/N\} / \log S$$

Where, n_i = importance value or number of individuals of i^{th} species

N = sum of importance values or number of individuals of all species

S = number of species

The population structure of *T. wallichiana* was studied following the methods outlined by Rao *et al.* (1990), Rikhari *et al.* (2000) and Uma Shankar (2001). The individuals of *T. wallichiana* were classified into nine girth classes: 1 (<10 cm), 2 (10-30 cm), 3 (30-60 cm), 4 (60-90 cm), 5 (90-120 cm), 6 (120-150 cm), 7 (150-180 cm), 8 (180-210 cm) and 9 (>210 cm).

The vertical height structure of *T. wallichiana* was studied following the methods outlined by Rikhari *et al.* (2000) and Uma Shankar (2001). The individuals of *T. wallichiana* were classified into six height classes: 1 (<4 m), 2 (4-8 m), 3 (8-12 m), 4 (12-16 m), 5 (16-20 m) and 6 (>20 m).

4.3. Results

4.3.1. Phytosociology of *T. wallichiana* community at Mawphlang

The floristic composition of *Taxus wallichiana* habitat in Mawphlang is given in Table 4.1. At this site, a total of 945 individual≥10 cm gbh belonged to 61 species. *Quercus dealbata* and *Rhododendron arboretum* were the two most dominant species.

[illegible]

Table 4.1. Floristic composition, occurrences (number of plots of species occurrence), frequency (%), density (ha^{-1}), basal area (cm^2 ha^{-1}), importance value index (IVI) and abundance-to-frequency ratio (A/F) of Mawphlang site.

Sl. #	Species	Family	Occurrences	Frequency	Density	Basal area	IVI	A/F ratio
1	*Quercus dealbata*	Fagaceae	6	75.0	340.0	107,605	47.7	0.378
2	*Rhododendron arboreum*	Ericaceae	7	87.5	192.0	64,758	30.6	0.157
3	*Quercus lanceaefolia*	Fagaceae	6	75.0	66.0	22,744	13.3	0.073
4	*Quercus fenestrata*	Fagaceae	4	50.0	58.0	28,586	12.8	0.145
5	*Taxus wallichiana*	Taxaceae	7	87.5	36.0	22,918	12.5	0.029
6	*Castanopsis* sp2	Fagaceae	7	87.5	44.0	18,355	11.9	0.036
7	*Symplocos* sp2	Symplocaceae	3	37.5	134.0	10,114	11.7	0.596
8	*Viburnum simonsii*	Caprifoliaceae	3	37.5	116.0	9,896	10.7	0.516
9	*Ficus nemoralis*	Moraceae	5	62.5	72.0	12,377	10.4	0.115
10	*Symplocos spicata*	Symplocaceae	4	50.0	114.0	5,470	10.3	0.285
11	*Neolitsea zeylanicum*	Lauraceae	5	62.5	70.0	9,531	9.7	0.112
12	*Castanopsis indica*	Fagaceae	1	12.5	108.0	12,888	9.5	4.320
13	*Myrica esculenta*	Myricaceae	5	62.5	42.0	9,829	8.3	0.067
14	*Schima khasiana*	Theaceae	3	37.5	36.0	17,333	8.2	0.160
15	*Erythroxylum kunthianum*	Erythroxylaceae	4	50.0	38.0	6,406	6.5	0.095
16	*Coffea* sp1	Rubiaceae	3	37.5	38.0	4,740	5.4	0.169
17	*Eurya japonica*	Theaceae	3	37.5	34.0	3,350	4.8	0.151
18	*Daphne papyracea*	Thymelaeceae	4	50.0	16.0	2,580	4.4	0.040
19	*Photinia integrifolia*	Rosaceae	2	25.0	26.0	5,559	4.2	0.260
20	K1T49 with thorns	Rosaceae	3	37.5	24.0	2,088	4.0	0.107
21	*Quercus grifithii*	Fagaceae	2	25.0	34.0	2,999	4.0	0.340
22	*Schima* like	Unidentified	1	12.5	6.0	10,700	3.6	0.240
23	*Schima wallichii*	Theaceae	2	25.0	6.0	4,371	2.8	0.060
24	*Glochidion* sp1	Phyllanthaceae	2	25.0	16.0	1,837	2.8	0.160
25	*Persea odoratissima*	Lauraceae	2	25.0	10.0	2,91	2.5	0.100
26	*Symplocos glomerata*	Symplocaceae	2	25.0	14.0	941	2.5	0.140

[illegible]

27	hairy	Unidentified	2	25.0	8.0	874	2.1	0.080
28	*Myrsine semiserrata*	Myrsinaceae	2	25.0	10.0	378	2.1	0.100
29	*Docynia indica*	Rosaceae	1	12.5	14.0	2,369	2.0	0.560
30	*Michelia* sp1	Magnoliaceae	2	25.0	8.0	512	2.0	0.080
31	K3T2 Bark peeling shrub	Unidentified	1	12.5	20.0	631	2.0	0.800
32	*Photinia notoniana*	Rosaceae	1	12.5	6.0	3,346	1.8	0.240
33	*Tupidanthes calyptratus*	Araliaceae	1	12.5	2.0	4,017	1.8	0.080
34	*Pyrus* sp2	Rosaceae	1	12.5	16.0	367	1.7	0.640
35	*Pinus kesiya*	Pinaceae	1	12.5	8.0	2,148	1.7	0.320
36	*Quercus semiserreta*	Fagaceae	1	12.5	10.0	813	1.5	0.400
37	*Ardisia* sp	Primulaceae	1	12.5	12.0	353	1.5	0.480
38	Climber sp1	Unidentified	1	12.5	10.0	274	1.3	0.400
39	*Eriobotrya bengalensis*	Rosaceae	1	12.5	6.0	1,097	1.3	0.240
40	bark peeling shrub	Unidentified	1	12.5	6.0	501	1.2	0.240
41	*Exbuklandia populnia*	Hamamelidaceae	1	12.5	4.0	871	1.2	0.160
42	*Engelhardtia spicata*	Juglandaceae	1	12.5	2.0	1,91	1.1	0.080
43	*Symplocos chinensis*	Symplocaceae	1	12.5	2.0	1,021	1.1	0.080
44	*Randia* sp	Rubiaceae	1	12.5	6.0	107	1.1	0.240
45	K7T10 poisonous	Unidentified	1	12.5	4.0	554	1.1	0.160
46	*Corylopsis himalayana*	Hamamelidaceae	1	12.5	6.0	70	1.1	0.240
47	*Helicia erratica*	Proteaceae	1	12.5	2.0	931	1.1	0.080
48	*Myrica nagi*	Myricaceae	1	12.5	4.0	407	1.1	0.160
49	*Pyrus* sp1	Rosaceae	1	12.5	4.0	356	1.0	0.160
50	*Toona ciliata*	Meliaceae	1	12.5	2.0	802	1.0	0.080
51	*Xylosma* sp	Salicaceae	1	12.5	4.0	274	1.0	0.160
52	Rosaceae with thorns	Rosaceae	1	12.5	4.0	208	1.0	0.160
53	K6T4	Rutaceae	1	12.5	4.0	74	1.0	0.160
54	*Litsea* sp	Lauraceae	1	12.5	2.0	435	1.0	0.080
55	*Zanthoxylum ovalifolium*	Rutaceae	1	12.5	2.0	344	0.9	0.080
56	*Michelia* sp2	Magnoliaceae	1	12.5	2.0	251	0.9	0.080
57	K1T42	Unidentified	1	12.5	2.0	66	0.9	0.080
58	*Vernonia volkamariifolia*	Asteraceae	1	12.5	2.0	66	0.9	0.080
59	*Michelia* sp3	Magnoliaceae	1	12.5	2.0	64	0.9	0.080
60	*Camellia* sp1	Theaceae	1	12.5	2.0	31	0.9	0.080
61	*Cinnamomum pauciflorum*	Lauraceae	1	12.5	2.0	17	0.9	0.080
	Total		1675	1,675	1,890.0	425,784	300.0	16.070

A total of ten species exhibited an IVI >10 and together these species accounted for an IVI of 172 which is nearly two-third of the total IVI. *Taxus wallichiana* ranked 5th with an IVI of 12.5 only (Table 4.1). Among the top ten species, 4 species belonged to Fagaceae, rendering this family most important at Mawphlang. In all, 13 species were rare with only 1 individual each. About 25% of stand basal area was due to only one species, *Q. dealbata.* The top 10 species accounted for 72% basal area. The 13 rare species accounted for only 2.1% of stand basal area.

The girth of all individuals at Mawphlang ranged from 10.1 to 201.1 cm with a mean value of 41.7 cm and CV of 1093.2% (Table 4.2). A total of ten species recorded girth between 10 and 30 cm and only nineteen species had maximum girth >100 cm, and among them also only two species had girth >200 cm. The remaining 32 species exhibited girth between 10 and 100 cm. The girth of *Taxus wallichiana* ranged from 11.2 to 196.7 with a mean of 68.6 cm and CV of 3293.4%. The variability (CV) in the girth measurements is zero for only those species that were recorded with only a single individual. It was highest for *Taxus wallichiana* indicating that very small girth and very large girth individuals occurred in this species.

The height of all individuals at Mawphlang ranged from 1.5 to 26.5 m with a mean value of 7.9 m and CV of 19% (Table 4.2). A total of three species recorded a height <5 m and only fourteen species had maximum height >20 m, and among them also only two species had height >25 m. The remaining 44 species exhibited height between 5 and 20 m. The height of *Taxus wallichiana* ranged from 3 to 20 m with a mean of 9.9 m and CV of 25.7%. The variability (CV) in the height measurements is zero for only those species that were recorded with only a single individual. It was highest for *Schima khasiana.*

Table 4.2. Variability in measures of girth at breast height or GBH (cm) and stem height (m) of all recorded species at Mawphlang site as depicted by minimum (Min), maximum (Max), mean and coefficient of variation (CV in %). The species are arranged in order of maximum to minimum values of IVI.

Sl. #	Species	GBH (cm)				Stem height (m)			
		Min	Max	Mean	CV	Min	Max	Mean	CV
1	*Quercus dealbata*	11.6	170.2	55.2	930.9	2.0	23.0	8.6	10.9
2	*Rhododendron arboreum*	10.2	200.5	50.3	1705.5	1.5	22.0	7.5	17.1
3	*Quercus lanceaefolia*	10.1	201.1	52.6	1564.2	3.0	23.6	11.0	31.0
4	*Quercus fenestrata*	12.9	160.1	68.5	1500.9	2.5	22.0	13.4	30.3
5	*Taxus wallichiana*	11.2	196.7	68.6	3293.4	3.0	20.0	9.9	25.7
6	*Castanopsis* sp2	10.1	152.1	58.9	1770.1	2.5	22.3	9.1	20.0
7	*Symplocos* sp2	10.1	93.9	26.4	251.5	1.5	20.9	6.4	13.4
8	*Viburnum simonsii*	10.8	86.1	29.3	212.1	3.0	18.0	8.2	9.3
9	*Ficus nemoralis*	11.0	170.8	34.1	997.0	2.8	22.5	8.3	16.2
10	*Symplocos spicata*	10.7	90.5	21.0	160.9	1.5	11.0	4.3	4.4
11	*Neolitsea zeylanicum*	10.3	130.5	34.3	537.5	3.0	18.0	8.3	6.0
12	*Castanopsis indica*	10.3	81.8	33.8	359.4	1.5	13.0	5.3	6.6
13	*Myrica esculenta*	10.5	111.6	46.1	821.3	3.0	16.0	8.9	16.4
14	*Schima khasiana*	13.5	197.3	63.0	2085.7	4.5	25.4	14.4	47.1
15	*Erythroxylum kunthianum*	10.4	121.6	37.6	704.3	3.0	21.1	8.7	14.7
16	*Coffea* sp1	10.1	149.1	25.8	902.2	1.5	22.0	6.9	28.8
17	*Eurya japonica*	14.6	100.4	27.7	472.3	2.0	12.0	6.3	10.9
18	*Daphne papyracea*	10.5	110.4	32.4	974.8	2.0	12.6	6.8	11.7
19	*Photinia integrifolia*	10.3	139.7	38.1	1237.2	3.5	10.0	6.7	3.1
20	K1T49 with thorns	10.1	51.1	30.6	158.5	4.0	13.0	7.1	6.3
21	*Quercus grifithii*	16.1	53.2	31.5	118.7	3.1	8.5	5.9	3.4
22	*Schima* like	92.4	171.9	145.0	1385.3	23.9	26.5	24.9	1.3
23	*Schima wallichii*	31.5	119.1	87.2	1560.6	4.1	12.5	9.5	14.8
24	*Glochidion* sp1	10.2	65.5	32.1	413.8	4.0	13.0	7.4	8.9
25	*Persea odoratissima*	14.4	80.4	41.1	936.5	4.5	22.0	8.5	46.1
26	*Symplocos glomerata*	15.5	44.6	27.4	92.0	4.5	17.5	9.9	19.3
27	hairy	24.7	52.3	35.6	103.7	4.2	9.0	6.8	2.9
28	*Myrsine semiserrata*	15.1	29.6	21.0	35.8	4.5	8.8	6.0	2.5
29	*Docynia indica*	14.4	71.6	42.1	358.5	3.0	12.0	7.3	11.3
30	*Michelia* sp1	11.9	41.2	25.9	133.3	1.8	6.0	3.8	2.2
31	K3T2 Bark peeling shrub	11.4	30.4	18.9	38.8	2.5	9.5	5.0	5.9

32	*Photinia notoniana*	68.4	105.7	82.0	282.2	9.5	18.5	15.0	15.5
33	*Tupidanthes calyptratus*	158.9	158.9	158.9	0.0	20.2	20.2	20.2	0.0
34	*Pyrus* sp2	10.8	27.3	16.1	29.0	2.1	12.1	5.7	9.4
35	*Pinus kesiya*	28.1	88.9	53.7	492.3	4.1	9.5	7.3	3.9
36	*Quercus semiserreta*	18.5	47.2	30.5	93.8	4.0	11.0	7.4	8.6
37	*Ardisia* sp	11.1	31.6	18.0	46.5	3.9	9.5	6.0	4.2
38	climber sp1	13.4	29.5	17.6	36.6	5.0	12.0	8.0	7.6
39	*Eriobotrya bengalensis*	35.8	65.8	45.8	200.0	6.0	8.0	6.8	0.8
40	bark peeling shrub	28.6	34.5	32.3	6.9	5.0	7.0	6.3	0.9
41	*Exbuklandia populnea*	50.5	54.1	52.3	3.2	9.0	9.0	9.0	0.0
42	*Engelhardtia spicata*	82.8	82.8	82.8	0.0	16.0	16.0	16.0	0.0
43	*Symplocos chinensis*	80.1	80.1	80.1	0.0	14.0	14.0	14.0	0.0
44	*Randia* sp	11.0	20.6	14.3	19.7	5.1	8.0	6.1	1.7
45	K7T10 poisonous	32.7	49.1	40.9	67.2	9.0	9.0	9.0	0.0
46	*Corylopsis himalayana*	11.0	12.8	12.1	0.6	7.0	12.0	10.0	4.7
47	*Helicia erratica*	76.5	76.5	76.5	0.0	7.5	7.5	7.5	0.0
48	*Myrica nagi*	27.9	42.2	35.1	51.1	5.0	7.2	6.1	1.2
49	Pyrus sp1	18.8	43.4	31.1	151.3	2.5	3.5	3.0	0.3
50	*Toona ciliata*	71.0	71.0	71.0	0.0	12.5	12.5	12.5	0.0
51	*Xylosma* sp	10.4	40.2	25.3	222.0	3.0	5.5	4.2	1.5
52	Rosaceae with thorns	21.1	29.4	25.3	17.2	6.0	7.0	6.5	0.3
53	K6T4	12.5	17.5	15.0	6.3	3.5	8.0	5.8	5.1
54	*Litsea* sp	52.3	52.3	52.3	0.0	15.0	15.0	15.0	0.0
55	*Zanthoxylum ovalifolium*	46.5	46.5	46.5	0.0	12.0	12.0	12.0	0.0
56	*Michelia* sp2	39.7	39.7	39.7	0.0	9.0	9.0	9.0	0.0
57	K1T42	20.4	20.4	20.4	0.0	7.6	7.6	7.6	0.0
58	*Vernonia volkamariifolia*	20.4	20.4	20.4	0.0	6.3	6.3	6.3	0.0
59	*Michelia* sp3	20.0	20.0	20.0	0.0	7.1	7.1	7.1	0.0
60	*Camellia* sp1	13.9	13.9	13.9	0.0	4.5	4.5	4.5	0.0
61	*Cinnamomum pauciflorum*	10.3	10.3	10.3	0.0	4.0	4.0	4.0	0.0
	Total	10.1	201.1	41.7	1093.2	1.5	26.5	7.9	19.0

The population structure of all species recorded at Mawphlang is presented in Table 4.3. The frequency of occurrences of stems is shown in nine girth classes, viz., 10-30, 30-50, 50-70, 70-90, 90-120, 120-150, 150-180, 180-210 and >210 cm.

Table 4.3. Population structure of all recorded species at Mawphlang site. The frequency of occurrences of stems in different GBH (girth at breast height) classes is shown for eight sampled plots. The species are arranged in order of maximum to minimum values of IVI.

		GBH Class (cm)									
Sl. #	Species	10-30	30-50	50-70	70-90	90-120	120-150	150-180	180-210	> 210	Total
1	*Quercus dealbata*	45	42	31	28	18	5	1	0	0	170
2	*Rhododendron arboreum*	48	15	8	8	7	8	0	2	0	96
3	*Quercus lanceaefolia*	12	5	8	3	3	1	0	1	0	33
4	*Quercus fenestrata*	4	8	4	6	4	2	1	0	0	29
5	*Taxus wallichiana*	4	7	1	2	1	0	1	2	0	18
6	*Castanopsis* sp2	10	2	1	2	4	2	1	0	0	22
7	*Symplocos* sp2	48	13	5	0	1	0	0	0	0	67
8	*Viburnum simonsii*	35	18	3	2	0	0	0	0	0	58
9	*Ficus nemoralis*	24	3	6	1	1	0	1	0	0	36
10	*Symplocos spicata*	49	7	0	0	1	0	0	0	0	57
11	*Neolitsea zeylanicum*	19	10	4	1	0	1	0	0	0	35
12	*Castanopsis indica*	28	17	5	4	0	0	0	0	0	54
13	*Myrica esculenta*	7	6	3	4	1	0	0	0	0	21
14	*Schima khasiana*	4	4	4	3	0	2	0	1	0	18
15	*Erythroxylum kunthianum*	10	5	2	1	0	1	0	0	0	19
16	*Coffea* sp1	16	2	0	0	0	1	0	0	0	19
17	*Eurya japonica*	13	2	1	0	1	0	0	0	0	17
18	*Daphne papyracea*	6	1	0	0	1	0	0	0	0	8
19	*Photinia integrifolia*	6	4	1	1	0	1	0	0	0	13
20	K1T49 with thorns	6	5	1	0	0	0	0	0	0	12
21	*Quercus grifithii*	8	8	1	0	0	0	0	0	0	17
22	*Schima* like	0	0	0	0	1	0	2	0	0	3
23	*Schima wallichii*	0	1	0	0	2	0	0	0	0	3
24	*Glochidion* sp1	4	2	2	0	0	0	0	0	0	8
25	*Persea odoratissima*	3	0	0	2	0	0	0	0	0	5
26	*Symplocos glomerata*	5	2	0	0	0	0	0	0	0	7
27	hairy	1	2	1	0	0	0	0	0	0	4

28	*Myrsine semiserrata*	5	0	0	0	0	0	0	0	0	5
29	*Docynia indica*	3	1	2	1	0	0	0	0	0	7
30	*Michelia* sp1	2	2	0	0	0	0	0	0	0	4
31	K3T2 Bark peeling shrub	9	1	0	0	0	0	0	0	0	10
32	*Photinia notoniana*	0	0	1	1	1	0	0	0	0	3
33	*Tupidanthes calyptratus*	0	0	0	0	0	0	1	0	0	1
34	*Pyrus sp2*	8	0	0	0	0	0	0	0	0	8
35	*Pinus kesiya*	1	1	1	1	0	0	0	0	0	4
36	*Quercus semiserreta*	3	2	0	0	0	0	0	0	0	5
37	*Ardisia* sp	5	1	0	0	0	0	0	0	0	6
38	*climber* sp1	5	0	0	0	0	0	0	0	0	5
39	*Eriobotrya bengalensis*	0	2	1	0	0	0	0	0	0	3
40	*bark peeling shrub*	1	2	0	0	0	0	0	0	0	3
41	*Exbuklandia populnia*	0	0	2	0	0	0	0	0	0	2
42	*Engelhardtia spicata*	0	0	0	1	0	0	0	0	0	1
43	*Symplocos chinensis*	0	0	0	1	0	0	0	0	0	1
44	*Randia* sp	3	0	0	0	0	0	0	0	0	3
45	*K7T10 poisonous*	0	2	0	0	0	0	0	0	0	2
46	*Corylopsis himalayana*	3	0	0	0	0	0	0	0	0	3
47	*Helicia erratica*	0	0	0	1	0	0	0	0	0	1
48	*Myrica nagi*	1	1	0	0	0	0	0	0	0	2
49	*Pyrus* sp1	1	1	0	0	0	0	0	0	0	2
50	*Toona ciliata*	0	0	0	1	0	0	0	0	0	1
51	*Xylosma* sp	1	1	0	0	0	0	0	0	0	2
52	*Rosaceae with thorns*	2	0	0	0	0	0	0	0	0	2
53	K6T4	2	0	0	0	0	0	0	0	0	2
54	*Litsea* sp	0	0	1	0	0	0	0	0	0	1
55	*Zanthoxylum ovalifolium*	0	1	0	0	0	0	0	0	0	1
56	*Michelia* sp2	0	1	0	0	0	0	0	0	0	1
57	K1T42	1	0	0	0	0	0	0	0	0	1
58	*Vernonia volkamariifolia*	1	0	0	0	0	0	0	0	0	1
59	*Michelia* sp3	1	0	0	0	0	0	0	0	0	1
60	*Camellia* sp1	1	0	0	0	0	0	0	0	0	1
61	*Cinnamomum pauciflorum*	1	0	0	0	0	0	0	0	0	1
	Total for all species	475	210	100	75	47	24	8	6	0	945

The population structure of individuals at Mawphlang showed a successive decline in number of individuals from a lower to the next higher class (Fig. 4.2). Hence, the regeneration at the stand level was good. The number of species represented in a girth class also showed a successive decline from a lower to the next higher class (Fig. 4.3). Of all species together, more than one-half of the individuals occurred in 10-30 cm girth class and only 14 individuals exceeded a girth of 150 cm (Table 4.3). About one-half of the individuals occurred between 30 and 150 cm.

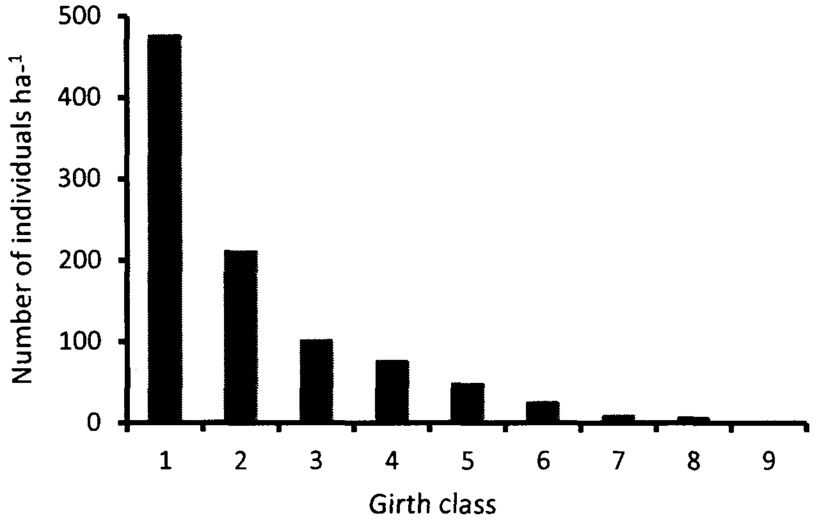


Fig. 4.2. Population structure of individuals of all species at Mawphlang in nine girth classes, viz., 1 (10-30 cm), 2 (30-50 cm), 3 (50-70 cm), 4 (70-90 cm), 5 (90-120 cm), 6 (120-150 cm), 7 (150-180 cm), 8 (180-210 cm) and 9 (>210 cm).

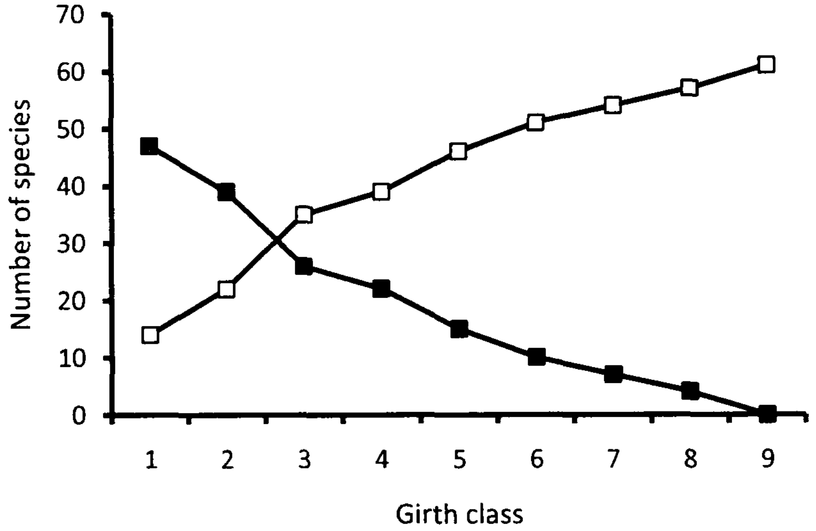


Fig. 4.3. Number of species present (filled squares) and absent (open squares) at Mawphlang in nine girth classes, viz., 1 (10-30 cm), 2 (30-50 cm), 3 (50-70 cm), 4 (70-90 cm), 5 (90-120 cm), 6 (120-150 cm), 7 (150-180 cm), 8 (180-210 cm) and 9 (>210 cm).

The vertical (height) structure of all species recorded at Mawphlang is presented in ~~T~~table 4.4. The frequency of occurrences of stems is shown in six height classes, viz., 0-4, 4-8, 8-12, 12-16, 16-20, and >20 m. The vertical height structure of individuals at Mawphlang showed a successive decline in number of individuals from a lower to the next higher class from 4-8 m class onwards (Fig. 4.4). The number of individuals in 0-4 m class was lesser than that in 4-8 m class. The number of species represented in a height class also showed a successive decline from a lower to the next higher class from 4-8 m class onwards (Fig. 4.5). Of all species together, more than two-third of the individuals were between 4 and 12 m height and only 25 individuals (2.6%) exceeded a height of 20 cm (Table. 4.4). Most species exhibited more individuals in 4-8 m height class than the individuals in 0-4 m height class.

Table 4.4. Vertical height structure of all reccorded species at Mawphlang site. The frequency of occurrences of stems in different height classes is shown for eight sampled plots. The species are arranged in order of maximum to minimum values of IVI.

Sl. #	Species	Height class (m)						
		0-4	4-8	8-12	12-16	16-20	>20	Total
1	*Quercus dealbata*	8	57	66	35	3	1	170
2	*Rhododendron arboreum*	15	40	24	11	5	1	96
3	*Quercus lanceaefolia*	1	12	5	9	3	3	33
4	*Quercus fenestrata*	1	2	11	3	8	4	29
5	*Taxus wallichiana*	1	6	5	2	3	1	18
6	*Castanopsis* sp2	3	6	8	3	1	1	22
7	*Symplocos* sp2	16	30	14	5	1	1	67
8	*Viburnum simonsii*	3	22	24	7	2	0	58
9	*Ficus nemoralis*	4	14	12	4	1	1	36
10	*Symplocos spicata*	24	28	5	0	0	0	57
11	*Neolitsea zeylanicum*	1	11	20	2	1	0	35
12	*Castanopsis indica*	18	27	7	2	0	0	54
13	*Myrica esculenta*	2	7	3	8	1	0	21
14	*Schima khasiana*	0	3	5	3	2	5	18
15	*Erythroxylum kunthianum*	1	7	8	2	0	1	19
16	*Coffea* sp1	4	9	3	1	1	1	19
17	*Eurya japonica*	5	5	6	1	0	0	17
18	*Daphne papyracea*	2	3	2	1	0	0	8
19	*Photinia integrifolia*	1	7	5	0	0	0	13
20	K1T49 with thorns	0	8	3	1	0	0	12
21	*Quercus grifithii*	2	9	6	0	0	0	17
22	*Schima* like	0	0	0	0	0	3	3
23	*Schima wallichii*	0	1	0	2	0	0	3
24	*Glochidion* sp1	0	6	1	1	0	0	8
25	*Persea odoratissima*	0	4	0	0	0	1	5
26	*Symplocos glomerata*	0	3	2	1	1	0	7
27	hairy	0	3	1	0	0	0	4
28	*Myrsine semiserrata*	0	4	1	0	0	0	5
29	*Docynia indica*	1	2	3	1	0	0	7
30	*Michelia* sp1	2	2	0	0	0	0	4
31	K3T2 Bark peeling shrub	5	3	2	0	0	0	10
32	*Photinia notoniana*	0	0	1	0	2	0	3

33	*Tupidanthes calyptratus*	0	0	0	0	0	1	1
34	*Pyrus* sp2	3	3	1	1	0	0	8
35	*Pinus kesiya*	0	2	2	0	0	0	4
36	*Quercus semiserreta*	0	2	3	0	0	0	5
37	*Ardisia* sp	1	4	1	0	0	0	6
38	*climber* sp1	0	2	2	1	0	0	5
39	*Eriobotrya bengalensis*	0	2	1	0	0	0	3
40	*bark peeling shrub*	0	3	0	0	0	0	3
41	*Exbuklandia populnia*	0	0	2	0	0	0	2
42	*Engelhardtia spicata*	0	0	0	0	1	0	1
43	*Symplocos chinensis*	0	0	0	1	0	0	1
44	*Randia* sp	0	2	1	0	0	0	3
45	K7T10 poisonous	0	0	2	0	0	0	2
46	*Corylopsis himalayana*	0	1	1	1	0	0	3
47	*Helicia erratica*	0	1	0	0	0	0	1
48	*Myrica nagi*	0	2	0	0	0	0	2
49	*Pyrus* sp1	2	0	0	0	0	0	2
50	*Toona ciliata*	0	0	0	1	0	0	1
51	*Xylosma* sp	1	1	0	0	0	0	2
52	*Rosaceae with thorns*	0	2	0	0	0	0	2
53	K6T4	1	0	1	0	0	0	2
54	*Litsea* sp	0	0	0	1	0	0	1
55	*Zanthoxylum ovalifolium*	0	0	0	1	0	0	1
56	*Michelia* sp2	0	0	1	0	0	0	1
57	K1T42	0	1	0	0	0	0	1
58	*Vernonia volkamariifolia*	0	1	0	0	0	0	1
59	*Michelia* sp3	0	1	0	0	0	0	1
60	*Camellia* sp1	0	1	0	0	0	0	1
61	*Cinnamomum pauciflorum*	0	1	0	0	0	0	1
	Total	128	373	271	112	36	25	945

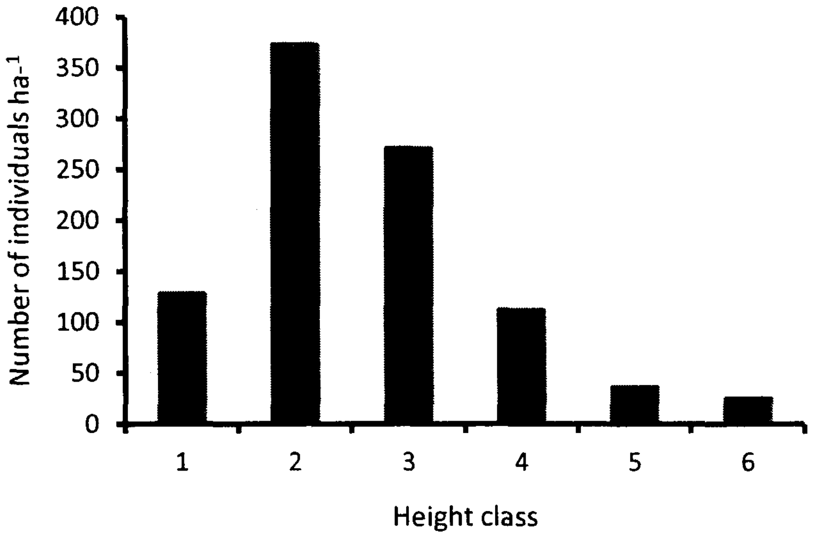


Fig. 4.4. Height structure of individuals of all species at Mawphlang in six height classes, viz., 1 (<4 m), 2 (4-8 m), 3 (8-12 m), 4 (12-16 m), 5 (16-20 m) and 6 (>20 m).

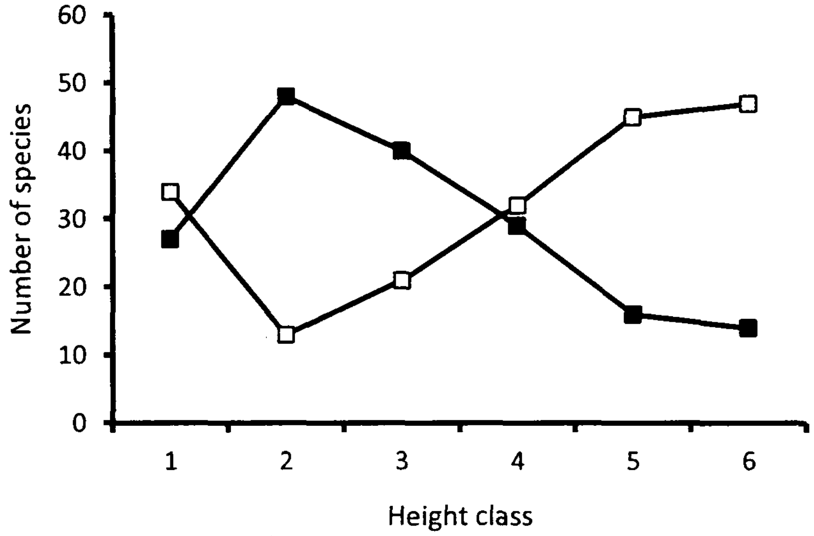


Fig. 4.5. Number of species present (filled squares) and absent (open squares) at Mawphlang in six height classes, viz., 1 (<4 m), 2 (4-8 m), 3 (8-12 m), 4 (12-16 m), 5 (16-20 m) and 6 (>20 m).

The family dominance pattern at Mawphlang was analysed by clubbing the species belonging to each family. All identified species occurred in 26 families and seven unidentified species were placed in a single "unidentified" family (Table 4.5). Rosaceae with 8 species was on top followed by Fagaceae with 7 species, Lauraceae, Symplocaceae and Theaceae with 4 species each, Magnoliaceae with 3 species, Hamamelidaceae, Myricaceae, Rubiaceae and Rutaceae with 2 each each, and the rest with only one species each. Fagaceae was the most dominant family in terms of the number of stems and the basal area (Table 4.5). Ericaceae exhibited the second highest accumulation of basal area. Symplocaceae exhibited the second highest accumulation of the number of stems. Ericaceae exhibited the third highest accumulation of the number of stems.

Among families, mean girth varied from 20.4 cm for Asteraceae to 158.9 cm for Araliaceae (Table 4.5). The mean girth was 41.7 cm for all individuals of all families. A total of 16 families showed a mean girth >30 cm. The mean girth of top four dominant families (in terms of IVI) was: 51.3 cm for Fagaceae, 50.3 cm for Ericaceae, 68.6 cm for Taxaceae and 24.5 cm for Symplocaceae.

Among families, mean height varied from 4.2 m for Salicaceae to 20.2 m for Araliaceae (Table 4.5). The mean height was 7.9 m for all individuals of all families. A total of 12 families showed a mean height >8 m and only 3 families showed a mean height >20 m. The mean height of top four dominant families (in terms of IVI) was: 8.6 m for Fagaceae, 7.5 m for Ericaceae, 9.9 m for Taxaceae and 5.8 m for Symplocaceae.

The family Taxaceae, represented with only *T. Wallichiana*, had 18 individuals, 11,459 mm^2 basal area, 68.6 cm mean girth and 9.9 m mean height of individuals (Table 4.5).

Table 4.5. Species richness, stem abundance, accumulation of basal area and minimum (Min), maximum (Max), mean and coefficient of variation (CV in %) of girth and height in all families at Mawphlang site. The "unidentified" family contains seven species.

Family	Number of species	Number of stems	Basal area (mm^2)	Girth (cm)				Height (m)			
				Min	Max	Mean	CV	Min	Max	Mean	CV
Araliaceae	1	1	2,008	158.9	158.9	158.9	0	20.2	20.2	20.2	0
Caprifoliaceae	1	58	4,948	10.8	86.1	29.3	212	3.0	18.0	8.2	9
Compositae	1	1	33	20.4	20.4	20.4	0	6.3	6.3	6.3	0
Ericaceae	1	96	32,379	10.2	200.5	50.3	1705	1.5	22.0	7.5	17
Erythroxylaceae	1	19	3,203	10.4	121.6	37.6	704	3.0	21.1	8.7	15
Fagaceae	7	330	96,994	10.1	201.1	51.3	1067	1.5	23.6	8.6	19
Hamamelidaceae	2	5	471	11.0	54.1	28.2	390	7.0	12.0	9.6	3
Juglandaceae	1	1	545	82.8	82.8	82.8	0	16.0	16.0	16.0	0
Lauraceae	4	42	6,037	10.3	130.5	34.9	586	3.0	22.0	8.4	12
Magnoliaceae	3	6	413	11.9	41.2	27.2	125	1.8	9.0	5.2	6
Meliaceae	1	1	401	71.0	71.0	71.0	0	12.5	12.5	12.5	0
Moraceae	1	36	6,188	11.0	170.8	34.1	997	2.8	22.5	8.3	16
Myricaceae	2	23	5,118	10.5	111.6	45.1	764	3.0	16.0	8.6	16
Myrsinaceae	1	5	189	15.1	29.6	21.0	36	4.5	8.8	6.0	2
Phyllanthaceae	1	8	919	10.2	65.5	32.1	414	4.0	13.0	7.4	9
Pinaceae	1	4	1,074	28.1	88.9	53.7	492	4.1	9.5	7.3	4
Primulaceae	1	6	177	11.1	31.6	18.0	47	3.9	9.5	6.0	4
Proteaceae	1	1	466	76.5	76.5	76.5	0	7.5	7.5	7.5	0
Rosaceae	8	50	7,695	10.1	139.7	35.6	665	2.1	18.5	7.0	11
Rubiaceae	2	22	2,424	10.1	149.1	24.2	797	1.5	22.0	6.8	25
Rutaceae	2	3	209	12.5	46.5	25.5	225	3.5	12.0	7.8	12
Salicaceae	1	2	137	10.4	40.2	25.3	222	3.0	5.5	4.2	2
Symplocaceae	4	132	8,773	10.1	93.9	24.5	233	1.5	20.9	5.8	12
Taxaceae	1	18	11,459	11.2	196.7	68.6	3293	3.0	20.0	9.9	26
Theaceae	4	42	17,892	13.5	197.3	55.1	2318	2.0	26.5	11.3	54
Thymelaeaceae	1	8	1,290	10.5	110.4	32.4	975	2.0	12.6	6.8	12
Unidentified	7	25	1,450	11.4	52.3	24.7	117	2.5	12.0	6.5	6
All families	61	945	212,892	10.1	201.1	41.7	1093	1.5	26.5	7.9	19

4.3.2 Phytosociology of *T. wallichiana* community at Moodymmai

The floristic composition of *Taxus wallichiana* habitat in Moodymmai is given in ~~T~~table 4.6. At this site, a total of 435 individuals ≥10 cm gbh belonged to 49 species. Incomplete sentence *Castanopsis tribuloides*, *Pinus kesiya* and *Schima wallichii* were the three most dominant species. A total of eight species exhibited IVI >10 and together these species accounted for an IVI of 187.4 which is nearly two-third of the total IVI. *Taxus wallichiana* ranked 4th with an IVI of 18.3 only (Table 4.6). All the top ten dominant species belonged to ~~a~~ different famil~~y~~ies, rendering this site at Moodymmai more diverse at this level. In all, 19 species were rare with only 1 individual each. About 45% of stand basal area was due to only one species, *Castanopsis tribuloides*. The top 10 species accounted for 92% basal area. The 19 rare species accounted for only 2.6% of stand basal area.

Table 4.6. Floristic composition, occurrences (number of plots of species occurrence), frequency (%), density (ha^{-1}), basal area (cm^2 ha^{-1}), importance value index (IVI) and abundance-to-frequency ratio (A/F) of Moodymmai site.

Sl. #	Species	Family	Occurrences	Frequency	Density	Basal area	IVI	A/F ratio
1	*Castanopsis tribuloides*	Fagaceae	8	100	214	129,885	75.3	0.134
2	*Pinus kesiya*	Pinaceae	4	50	52	37,550	21.9	0.130
3	*Schima wallichii*	Theaceae	6	75	76	20,813	20.3	0.084
4	*Taxus wallichiana*	Taxaceae	7	87.5	50	21,388	18.3	0.041
5	*Macropanax dispermus*	Araliaceae	7	87.5	52	14,788	16.2	0.042
6	*Saurauia nepaulensis*	Sauraiaceae	5	62.5	56	10,284	13.7	0.090
7	*Albizzia stipulata*	Fabaceae	5	62.5	12	18,844	11.6	0.019
8	*Cyathea* sp	Cyatheaceae	7	87.5	26	5,749	10.1	0.021
9	*Ficus pomifera*	Moraceae	7	87.5	36	713	9.5	0.029
10	*Betula alnoides*	Betulaceae	6	75	20	4,259	8.2	0.022
11	*Itea macrophylla*	Iteaceae	5	62.5	24	4,820	8.1	0.038
12	*Bischofia javanica*	Bischofiaceae	4	50	22	2,120	6.2	0.055
13	*Viburnum simonsii*	Caprifoliaceae	4	50	26	520	6.1	0.065
14	*Eurya acuminata*	Theaceae	5	62.5	16	701	5.8	0.026
15	*Litsea monopetala*	Lauraceae	2	25	6	4,769	3.8	0.060

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16	*Lyonia ovalifolia*	Ericaceae	3	37.5	10	607	3.6	0.044
17	*Styrax serrulatum*	Styracaceae	3	37.5	8	373	3.3	0.036
18	*Prunus* sp1	Rosaceae	3	37.5	8	196	3.2	0.036
19	*Schefflera hypoleuca*	Araliaceae	3	37.5	8	100	3.2	0.036
20	*Maesa Montana*	Myrsinaceae	2	25	10	1,092	3.0	0.100
21	*Engelhardtia spicata*	Juglandaceae	3	37.5	6	148	2.9	0.027
22	*Lindera caudate*	Lauraceae	2	25	12	149	2.9	0.120
23	*Micromelum integerrimum*	Rutaceae	1	12.5	16	605	2.8	0.640
24	*Macropanax oreophilum*	Araliaceae	2	25	10	427	2.8	0.100
25	*Ficus clavata*	Moraceae	2	25	10	281	2.7	0.100
26	*Wendlandia wallichii*	Rubiaceae	2	25	8	138	2.4	0.080
27	*Helicia erratica*	Proteaceae	2	25	6	422	2.3	0.060
28	*Polyalthia* sp	Annonaceae	2	25	4	716	2.2	0.040
29	J2T42	Unidentified	1	12.5	2	3,030	2.0	0.080
30	*Derris* sp	Fabaceae	2	25	4	217	2.0	0.040
31	*Xylosma longifolia*	Flacourtiaceae	2	25	4	33	1.9	0.040
32	*Viburnum odoratissimum*	Caprifoliaceae	2	25	4	32	1.9	0.040
33	*Rhus* sp1	Anacardiaceae	1	12.5	6	909	1.7	0.240
34	*Citrus* sp1	Rutaceae	1	12.5	6	261	1.5	0.240
35	*Ilex* sp	Aquifoliaceae	1	12.5	6	117	1.5	0.240
36	*Syzygium cuminii*	Myrtaceae	1	12.5	4	749	1.5	0.160
37	*Tupidenthes calyptratus*	Araliaceae	1	12.5	4	176	1.3	0.160
38	J2T16	Unidentified	1	12.5	2	807	1.2	0.080
39	*Ligustrum robustum*	Oleaceae	1	12.5	4	74	1.2	0.160
40	J3T19a	Unidentified	1	12.5	2	297	1.1	0.080
41	*Docynia indica*	Rosaceae	1	12.5	2	135	1.0	0.080
42	*Elaeagnus latifolia*	Elaeagnaceae	1	12.5	2	104	1.0	0.080
43	*Persea odoratissima*	Lauraceae	1	12.5	2	74	1.0	0.080
44	*Cyclea bicristata*	Menispermaceae	1	12.5	2	23	1.0	0.080
45	*Viburnum cylindricum*	Caprifoliaceae	1	12.5	2	21	1.0	0.080
46	*Elaeocarpus* sp	Elaeocarpaceae	1	12.5	2	20	1.0	0.080
47	*Jasminium* sp	Oleaceae	1	12.5	2	19	1.0	0.080
48	*Glochidion* sp	Euphorbiaceae	1	12.5	2	18	1.0	0.080
49	*Dalbergia sericea ?*	Fabaceae	1	12.5	2	16	1.0	0.080
	Total		136	1,700	870	289,586	300.0	4.55

The girth of all individuals at Moodymmai ranged from 10 to 280 cm with a mean value of 46.4 cm and CV of 2028% (Table 4.7). A total of twenty species recorded girth between 10 and 30 cm and only ten species had maximum girth >100 cm, and among them only four species >200 cm. The remaining 19 species exhibited girth between 10 and 100 cm. The girth of *Taxus wallichiana* ranged from 10 to 219 with a mean of 52.6 cm and CV of 2612%. The variability (CV) in the girth measurements is zero for only those species that were recorded with only a single individual. It was highest for *Castanopsis tribuloides* indicating that very small girth and very large girth individuals occurred in this species.

Incomplete sentence.

The height of all individuals at Moodymmai ranged from 1.5 to 26.0 m with a mean value of 8.8 m and CV of 26.9% (Table 4.7). A total of two species recorded a height <5 m and only nine species had maximum height >20 m, and among them only two species >25 m. The remaining 38 species exhibited height between 5 and 20 m. The height of *Taxus wallichiana* ranged from 1.5 to 20 m with a mean of 7.1 m and CV of 24.8%. The variability (CV) in the height measurements is zero for only those species that were recorded with only a single individual. It was highest for *Pinus kesiya* indicating that very short and very tall individuals occurred in this species.

Incomplete sentence.

Table 4.7. Variability in measures of girth at breast height or GBH (cm) and stem height (m) of all recorded species at Moodymmai site as depicted by minimum (Min), maximum (Max), mean and coefficient of variation (CV in %). The species are arranged in order of maximum to minimum values of IVI.

Sl. #	Species	GBH (cm)				Stem height (m)			
		Min	Max	Mean	CV	Min	Max	Mean	CV
1	*Castanopsis tribuloides*	8.7	280.0	65.0	3402.1	2.0	26.0	11.4	35.3
2	*Pinus kesiya*	18.5	200.1	78.9	2859.4	1.5	22.0	11.0	54.1
3	*Schima wallichii*	11.0	150.0	49.5	995.8	1.8	18.0	8.9	15.5
4	*Taxus wallichiana*	9.5	219.0	52.6	2612.0	1.5	20.0	7.1	24.8
5	*Macropanax dispermus*	10.1	190.0	47.9	1278.6	3.0	16.0	8.7	8.2
6	*Saurauia nepaulensis*	10.0	110.0	42.5	506.0	3.0	12.0	8.1	4.8
7	*Albizzia stipulata*	47.5	211.0	129.1	3087.2	9.0	25.0	18.8	33.1
8	*Cyathea* sp	24.2	99.5	49.2	359.3	1.0	7.0	3.6	2.2
9	*Ficus pomifera*	10.0	34.0	14.5	37.7	2.0	8.0	4.7	3.3
10	*Betula alnoides*	12.5	135.0	35.8	1393.4	6.0	22.0	10.0	26.4
11	*Itea macrophylla*	12.2	76.5	46.9	326.5	3.3	12.0	9.2	5.5
12	*Bischofia javanica*	9.3	60.7	30.9	257.5	4.0	18.0	8.0	16.5
13	*Viburnum simonsii*	4.0	36.4	13.9	57.7	1.5	9.0	5.1	3.6
14	*Eurya acuminata*	10.0	49.8	19.7	162.6	4.0	18.0	8.0	17.1
15	*Litsea monopetala*	14.2	124.0	86.1	2585.1	4.8	21.1	12.3	45.1
16	*Lyonia ovalifolia*	9.9	49.1	24.2	175.8	2.0	7.0	5.2	3.8
17	*Styrax serrulatum*	14.4	30.4	23.3	41.5	5.0	8.0	7.0	1.5
18	*Prunus* sp1	14.2	23.6	17.2	14.1	5.5	8.0	6.6	0.9
19	*Schefflera hypoleuca*	10.0	16.6	12.3	7.3	3.0	6.0	5.0	1.5
20	*Maesa montana*	9.9	78.1	26.3	680.5	3.0	12.0	7.0	8.9
21	*Engelhardtia spicata*	16.7	19.0	17.6	1.0	6.0	8.2	7.1	0.8
22	*Lindera caudata*	8.2	15.3	12.2	6.4	6.0	7.5	6.8	0.3
23	*Micromelum integerrimum*	8.8	47.5	18.2	143.5	4.0	8.0	6.3	1.4
24	*Macropanax oreophilum*	10.0	37.6	20.4	120.1	4.0	8.0	5.8	1.8
25	*Ficus clavata*	10.3	25.1	18.0	28.9	4.0	8.0	5.4	2.2
26	*Wendlandia wallichii*	8.9	24.4	13.2	41.8	4.0	9.0	5.3	4.7
27	*Helicia erratica*	13.5	37.5	27.9	107.2	5.0	12.0	9.0	8.7
28	*Polyalthia* sp	10.1	66.3	38.2	789.6	6.0	10.0	8.0	4.0
29	J2T42	138.0	138.0	138.0	0.0	22.0	22.0	22.0	0.0
30	*Derris* sp	10.1	35.5	22.8	161.3	4.0	8.0	6.0	4.0
31	*Xylosma longifolia*	10.1	10.2	10.2	0.0	2.7	5.0	3.9	1.3
32	*Viburnum odoratissimum*	10.0	10.0	10.0	0.0	3.0	5.0	4.0	1.0

33	*Rhus* sp1	36.8	47.3	43.4	22.0	10.5	22.0	15.8	22.4
34	*Citrus* sp1	10.0	37.2	19.9	150.2	6.0	7.0	6.3	0.2
35	*Ilex* sp	11.9	19.2	15.4	8.9	5.0	7.0	6.3	0.9
36	*Syzygium cuminii*	40.2	55.6	47.9	59.3	8.0	8.0	8.0	0.0
37	*Tupidenthes calyptratus*	22.0	25.0	23.5	2.3	5.8	6.0	5.9	0.0
38	J2T16	71.2	71.2	71.2	0.0	12.0	12.0	12.0	0.0
39	*Ligustrum robustum*	13.4	16.9	15.2	3.1	6.0	7.0	6.5	0.3
40	J3T19a	43.2	43.2	43.2	0.0	8.0	8.0	8.0	0.0
41	*Docynia indica*	29.1	29.1	29.1	0.0	10.0	10.0	10.0	0.0
42	*Elaeagnus latifolia*	25.6	25.6	25.6	0.0	20.0	20.0	20.0	0.0
43	*Persea odoratissima*	21.5	21.5	21.5	0.0	9.0	9.0	9.0	0.0
44	*Cyclea bicristata*	12.0	12.0	12.0	0.0	5.0	5.0	5.0	0.0
45	*Viburnum cylindricum*	11.6	11.6	11.6	0.0	4.6	4.6	4.6	0.0
46	*Elaeocarpus* sp	11.2	11.2	11.2	0.0	7.0	7.0	7.0	0.0
47	*Jasminium* sp	10.8	10.8	10.8	0.0	6.0	6.0	6.0	0.0
48	*Glochidion* sp	10.7	10.7	10.7	0.0	5.0	5.0	5.0	0.0
49	*Dalbergia sericea ?*	10.1	10.1	10.1	0.0	4.0	4.0	4.0	0.0
	Total	4.0	280.0	46.4	2028.0	1.5	26.0	8.8	26.9

?
Not correct

The population structure of all species recorded at Moodymmai is presented in Table 4.8. The frequency of occurrences of stems is shown in nine girth classes, viz., 10-30, 30-50, 50-70, 70-90, 90-120, 120-150, 150-180, 180-210 and >210 cm. The population structure of individuals at Moodymmai showed a successive decline in number of individuals from a lower to the next higher class (Fig. 4.6). Hence, the regeneration at the stand level was good. The number of species represented in a girth class also showed a successive decline from a lower to the next higher class (Fig. 4.7). Of all species together, more than one-half of the individuals occurred in 10-30 cm girth class and only 18 individuals exceeded a girth of 150 cm (Table 4.8). About 44% of the individuals occurred between 30 and 150 cm girth.

Table 4.8. Population structure of all recorded species at Moodymmai site. The frequency of occurrences of stems in different GBH (girth at breast height) classes is shown for eight sampled plots. The species are arranged in order of maximum to minimum values of IVI.

		GBH Class (cm)									
Sl. #	Species	10-30	30-50	50-70	70-90	90-120	120-150	150-180	180-210	> 210	Total
1	*Castanopsis tribuloides*	46	8	8	18	7	9	5	1	5	107
2	*Pinus kesiya*	8	3	3	2	3	5	1	1	0	26
3	*Schima wallichii*	14	5	8	9	1	0	1	0	0	38
4	*Taxus wallichiana*	12	3	2	4	1	2	0	0	1	25
5	*Macropanax dispermus*	9	7	6	3	0	0	0	1	0	26
6	*Saurauia nepaulensis*	8	12	6	0	2	0	0	0	0	28
7	*Albizzia stipulata*	0	1	0	1	0	2	1	0	1	6
8	*Cyathea* sp	1	7	4	0	1	0	0	0	0	13
9	*Ficus pomifera*	17	1	0	0	0	0	0	0	0	18
10	*Betula alnoides*	7	1	0	1	0	1	0	0	0	10
11	*Itea macrophylla*	2	5	3	2	0	0	0	0	0	12
12	*Bischofia javanica*	7	2	2	0	0	0	0	0	0	11
13	*Viburnum simonsii*	12	1	0	0	0	0	0	0	0	13
14	*Eurya acuminata*	7	1	0	0	0	0	0	0	0	8
15	*Litsea monopetala*	1	0	0	0	0	2	0	0	0	3
16	*Lyonia ovalifolia*	4	1	0	0	0	0	0	0	0	5
17	*Styrax serrulatum*	3	1	0	0	0	0	0	0	0	4
18	*Prunus* sp1	4	0	0	0	0	0	0	0	0	4
19	*Schefflera hypoleuca*	4	0	0	0	0	0	0	0	0	4
20	*Maesa montana*	4	0	0	1	0	0	0	0	0	5
21	*Engelhardtia spicata*	3	0	0	0	0	0	0	0	0	3
22	*Lindera caudata*	6	0	0	0	0	0	0	0	0	6
23	*Micromelum integerrimum*	7	1	0	0	0	0	0	0	0	8
24	*Macropanax oreophilum*	4	1	0	0	0	0	0	0	0	5
25	*Ficus clavata*	5	0	0	0	0	0	0	0	0	5
26	*Wendlandia wallichii*	4	0	0	0	0	0	0	0	0	4
27	*Helicia erratica*	1	2	0	0	0	0	0	0	0	3
28	*Polyalthia* sp	1	0	1	0	0	0	0	0	0	2
29	J2T42	0	0	0	0	0	1	0	0	0	1
30	*Derris* sp	1	1	0	0	0	0	0	0	0	2
31	*Xylosma longifolia*	2	0	0	0	0	0	0	0	0	2
32	*Viburnum odoratissimum*	2	0	0	0	0	0	0	0	0	2
33	*Rhus* sp1	0	3	0	0	0	0	0	0	0	3

34	*Citrus* sp1	2	1	0	0	0	0	0	0	0	3
35	*Ilex* sp	3	0	0	0	0	0	0	0	0	3
36	*Syzygium cuminii*	0	1	1	0	0	0	0	0	0	2
37	*Tupidenthes calyptratus*	2	0	0	0	0	0	0	0	0	2
38	J2T16	0	0	0	1	0	0	0	0	0	1
39	*Ligustrum robustum*	2	0	0	0	0	0	0	0	0	2
40	J3T19a	0	1	0	0	0	0	0	0	0	1
41	*Docynia indica*	1	0	0	0	0	0	0	0	0	1
42	*Elaeagnus latifolia*	1	0	0	0	0	0	0	0	0	1
43	*Persea odoratissima*	1	0	0	0	0	0	0	0	0	1
44	*Cyclea bicristata*	1	0	0	0	0	0	0	0	0	1
45	*Viburnum cylindricum*	1	0	0	0	0	0	0	0	0	1
46	*Elaeocarpus* sp	1	0	0	0	0	0	0	0	0	1
47	*Jasminium* sp	1	0	0	0	0	0	0	0	0	1
48	*Glochidion* sp	1	0	0	0	0	0	0	0	0	1
49	*Dalbergia sericea ?*	1	0	0	0	0	0	0	0	0	1
	Total for all species	224	70	44	42	15	22	8	3	7	435

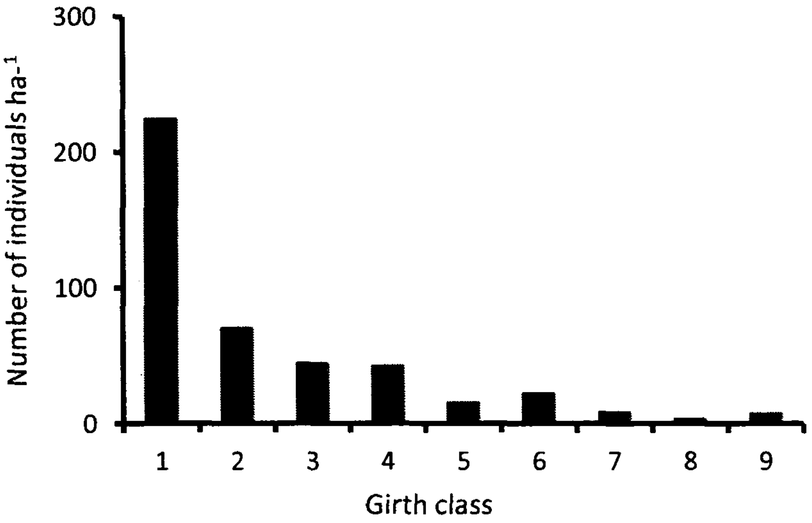


Fig. 4.6. Population structure of individuals of all species at Moodymmai in nine girth classes, viz., 1 (10-30 cm), 2 (30-50 cm), 3 (50-70 cm), 4 (70-90 cm), 5 (90-120 cm), 6 (120-150 cm), 7 (150-180 cm), 8 (180-210 cm) and 9 (>210 cm).

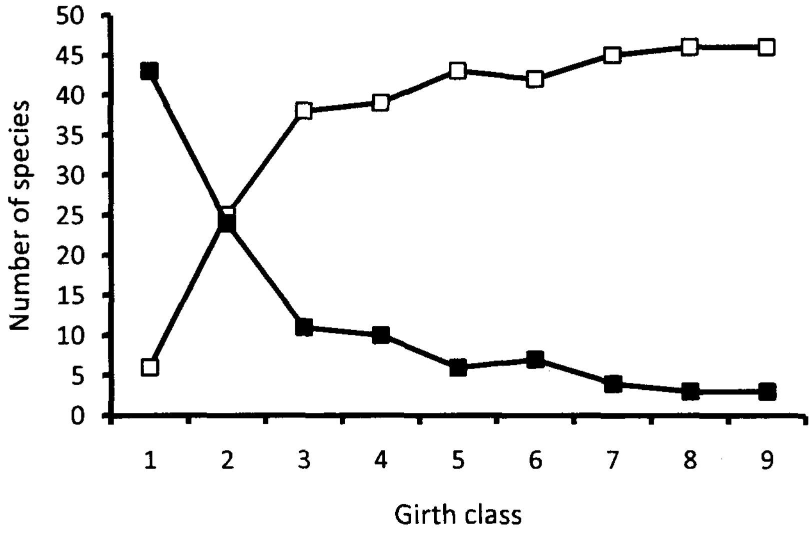


Fig. 4.7. Number of species present (filled squares) and absent (open squares) at Moodymmai in nine girth classes, viz., 1 (10-30 cm), 2 (30-50 cm), 3 (50-70 cm), 4 (70-90 cm). 5 (90-120 cm), 6 (120-150 cm), 7 (150-180 cm), 8 (180-210 cm) and 9 (>210 cm).

The vertical (height) structure of all species recorded at Moodymmai is presented in Table 4.9. The frequency of occurrences of stems is shown in six height classes, viz., 0-4, 4-8, 8-12, 12-16, 16-20, and >20 m. The vertical height structure of individuals at Moodymmai showed a successive decline in number of individuals from a lower to the next higher class from 4-8 m class onwards (Fig. 4.8). The number of individuals in 0-4 m class was lesser than that in 4-8 m class. The number of species represented in a height class also showed a successive decline from a lower to the next higher class from 4-8 m class onwards (Fig. 4.9). Of all species together, 38% of the individuals were between 4 and 12 m height and only 32 individuals (7%) exceeded a height of 20 cm (Table. 4.9). Most species exhibited more individuals in 4-8 m height class than the individuals in 0-4 m height class.

Table 4.9. Vertical height structure of all reccorded species at Moodymmai site. The frequency of occurrences of stems in different height classes is shown for eight sampled plots. The species are arranged in order of maximum to minimum values of IVI.

Sl. #	Species	Height class (m)						
		0-4	4-8	8-12	12-16	16-20	>20	Total
1	*Castanopsis tribuloides*	7	25	31	12	14	18	107
2	*Pinus kesiya*	7	5	2	2	5	5	26
3	*Schima wallichii*	1	15	13	4	5	0	38
4	*Taxus wallichiana*	10	3	6	3	2	1	25
5	*Macropanax dispermus*	1	6	15	3	1	0	26
6	*Saurauia nepaulensis*	2	7	18	1	0	0	28
7	*Albizzia stipulata*	0	0	1	1	0	4	6
8	*Cyathea* sp	8	5	0	0	0	0	13
9	*Ficus pomifera*	6	10	2	0	0	0	18
10	*Betula alnoides*	0	4	4	0	1	1	10
11	*Itea macrophylla*	1	0	8	3	0	0	12
12	*Bischofia javanica*	0	7	2	1	1	0	11
13	*Viburnum simonsii*	3	9	1	0	0	0	13
14	*Eurya acuminata*	0	6	1	0	1	0	8
15	*Litsea monopetala*	0	1	1	0	0	1	3

16	*Lyonia ovalifolia*	1	4	0	0	0	0	5
17	*Styrax serrulatum*	0	2	2	0	0	0	4
18	*Prunus* sp1	0	3	1	0	0	0	4
19	*Schefflera hypoleuca*	1	3	0	0	0	0	4
20	*Maesa montana*	1	2	1	1	0	0	5
21	*Engelhardtia spicata*	0	2	1	0	0	0	3
22	*Lindera caudata*	0	6	0	0	0	0	6
23	*Micromelum integerrimum*	0	7	1	0	0	0	8
24	*Macropanax oreophilum*	0	4	1	0	0	0	5
25	*Ficus clavata*	0	4	1	0	0	0	5
26	*Wendlandia wallichii*	0	3	1	0	0	0	4
27	*Helicia erratica*	0	1	1	1	0	0	3
28	*Polyalthia* sp	0	1	1	0	0	0	2
29	J2T42	0	0	0	0	0	1	1
30	*Derris* sp	0	1	1	0	0	0	2
31	*Xylosma longifolia*	1	1	0	0	0	0	2
32	*Viburnum odoratissimum*	1	1	0	0	0	0	2
33	*Rhus* sp1	0	0	1	1	0	1	3
34	*Citrus* sp1	0	3	0	0	0	0	3
35	*Ilex* sp	0	3	0	0	0	0	3
36	*Syzygium cuminii*	0	0	2	0	0	0	2
37	*Tupidenthes calyptratus*	0	2	0	0	0	0	2
38	J2T16	0	0	0	1	0	0	1
39	*Ligustrum robustum*	0	2	0	0	0	0	2
40	J3T19a	0	0	1	0	0	0	1
41	*Docynia indica*	0	0	1	0	0	0	1
42	*Elaeagnus latifolia*	0	0	1	0	0	0	1
43	*Persea odoratissima*	0	0	1	0	0	0	1
44	*Cyclea bicristata*	0	1	0	0	0	0	1
45	*Viburnum cylindricum*	0	1	0	0	0	0	1
46	*Elaeocarpus* sp	0	1	0	0	0	0	1
47	*Jasminium* sp	0	1	0	0	0	0	1
48	*Glochidion* sp	0	1	0	0	0	0	1
49	*Dalbergia sericea ?*	0	1	0	0	0	0	1
	Total	51	164	124	34	30	32	435

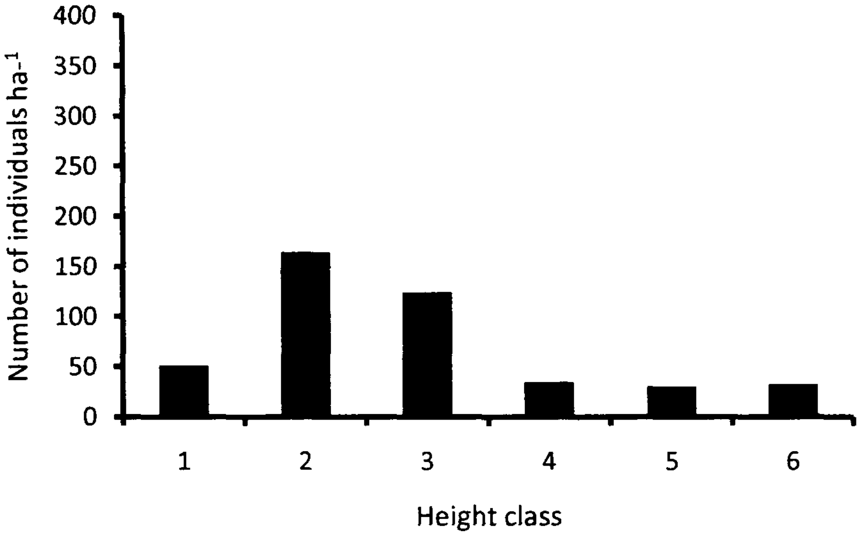


Fig. 4.8. Height structure of individuals of all species at Moodymmai in six height classes, viz., 1 (<4 m), 2 (4-8 m), 3 (8-12 m), 4 (12-16 m), 5 (16-20 m) and 6 (>20).

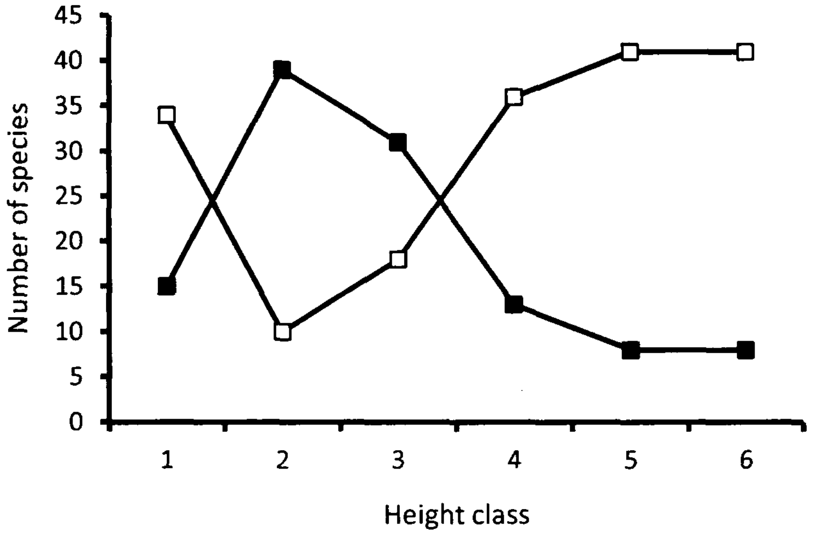


Fig. 4.9. Number of species present (filled squares) and absent (open squares) at Moodymmai in six height classes, viz., 1 (<4 m), 2 (4-8 m), 3 (8-12 m), 4 (12-16 m), 5 (16-20 m) and 6 (>20).

The family dominance pattern at Moodymmai was analysed by clubbing the species belonging to each family. All identified species occurred in 32 families and three unidentified species were placed in a single "unidentified" family (Table 4.9). Araliaceae with 4 species was on top followed by Caprifoliaceae, Fabaceae and Lauraceae with 3 species each, Moraceae, Oleaceae, Rosaceae, Rutaceae and Theaceae with 2 species, and the rest with only one species each. Fagaceae was the most dominant family in terms of the number of stems and the basal area (Table 4.9). Pinaceae exhibited the second highest accumulation of basal area. Theaceae exhibited the second highest accumulation of the number of stems. Araliaceae exhibited the third highest and Pinaceae the fourth highest accumulation of the number of stems.

Among families, mean girth varied from 10.2 cm for Flacourtiaceae to 92.2 cm for Fabaceae (Table 4.9). The mean girth was 46.4 cm for all individuals of all families. A total of 16 families showed a mean girth >30 cm. The mean girth of top four dominant families (in terms of IVI) was: 92.2 cm for Fabaceae, 78.9 cm for Pinaceae, 65.0 cm for Fagaceae and 44.3 cm for Theaceae.

Among families, mean height varied from 3.6 m for Cyatheaceae to 20.0 m for Elaeagnaceae (Table 4.9). The mean height was 8.8 m for all individuals of all families. A total of 15 families showed a mean height >8 m and only 1 family showed a mean height >20 m. The mean height of top four dominant families (in terms of IVI) was: 14.3 m for Fabaceae, 11.0 m for Pinaceae, 11.4 m for Fagaceae and 8.7 m for Theaceae.

The family Taxaceae, represented with only *T. wallichiana*, had 25 individuals, 10694 mm^2 basal area, 52.6 cm mean girth and 7.1 m mean height of individuals (Table 4.9).

Table 4.10. Species richness, stem abundance, accumulation of basal area and minimum (Min), maximum (Max), mean and coefficient of variation (CV in %) of girth and height in all recorded families at Moodymmai site. The "unidentified" family contains three species.

Family	Number of species	Number of stems	Basal area (mm^2)	Girth (cm)				Height (m)			
				Min	Max	Mean	CV	Min	Max	Mean	CV
Anacardiaceae	1	3	455	36.8	47.3	43.4	22	10.5	22.0	15.8	22
Annonaceae	1	2	358	10.1	66.3	38.2	790	6.0	10.0	8.0	4
Aquifoliaceae	1	3	59	11.9	19.2	15.4	9	5.0	7.0	6.3	1
Araliaceae	4	37	7,746	10.0	190.0	39.0	1109	3.0	16.0	7.7	8
Betulaceae	1	10	2,130	12.5	135.0	35.8	1393	6.0	22.0	10.0	26
Bischofiaceae	1	11	1,060	9.3	60.7	30.9	258	4.0	18.0	8.0	16
Caprifoliaceae	3	16	287	4.0	36.4	13.3	49	1.0	9.0	4.9	3
Cyatheaceae	1	13	2,875	24.2	99.5	49.2	359	1.0	7.0	3.6	2
Elaeagnaceae	1	1	52	25.6	25.6	25.6	0	20.0	20.0	20.0	0
Elaeocarpaceae	1	1	10	11.2	11.2	11.2	0	7.0	7.0	7.0	0
Ericaceae	1	5	304	9.9	49.1	24.2	176	2.0	7.0	5.2	4
Euphorbiaceae	1	1	9	10.7	10.7	10.7	0	5.0	5.0	5.0	0
Fabaceae	3	9	9,538	10.1	211.0	92.2	4819	4.0	25.0	14.3	64
Fagaceae	1	107	64,942	8.7	280.0	65.0	3402	2.0	26.0	11.4	35
Flacourtiaceae	1	2	16	10.1	10.2	10.2	0	2.7	5.0	3.9	1
Iteaceae	1	12	2,410	12.2	76.5	46.9	326	3.3	12.0	9.2	5
Juglandaceae	1	3	74	16.7	19.0	17.6	1	6.0	8.2	7.1	1
Lauraceae	3	10	2,496	8.2	124.0	35.3	1891	4.8	21.1	8.6	20
Menispermaceae	1	1	11	12.0	12.0	12.0	0	5.0	5.0	5.0	0
Moraceae	2	23	497	10.0	34.0	15.3	38	2.0	8.0	4.8	3
Myrsinaceae	1	5	546	9.9	78.1	26.3	681	3.0	12.0	7.0	9
Myrtaceae	1	2	374	40.2	55.6	47.9	59	8.0	8.0	8.0	0
Oleaceae	2	3	46	10.8	16.9	13.7	6	6.0	7.0	6.3	0
Pinaceae	1	26	18,775	18.5	200.1	78.9	2859	1.0	22.0	11.0	54
Proteaceae	1	3	211	13.5	37.5	27.9	107	5.0	12.0	9.0	9
Rosaceae	2	5	165	14.2	29.1	19.5	34	5.5	10.0	7.3	3
Rubiaceae	1	4	69	8.9	24.4	13.2	42	4.0	9.0	5.3	5
Rutaceae	2	11	433	8.8	47.5	18.7	146	4.0	8.0	6.3	1
Saurauiaceae	1	28	5,142	10.0	110.0	42.5	506	3.0	12.0	8.1	5
Styracaceae	1	4	186	14.4	30.4	23.3	41	5.0	8.0	7.0	2
Taxaceae	1	25	10,694	9.5	219.0	52.6	2612	1.0	20.0	7.1	25

Theaceae	2	46	10,757	10.0	150.0	44.3	978	1.8	18.0	8.7	16
Unidentified	3	3	2067	43.2	138.0	84.1	1581	8.0	22.0	14.0	35
All families	49	435	144,793	4.0	280.0	46.4	2028	1.0	26.0	8.8	27

4.3.3 Comparison of the two sites, Mawphlang and Moodymmai

The spatial distribution of individuals of all species in eight study plots (quadrats) is shown in Fig. 4.10 for Mawphlang and Fig. 4.11 for Moodymmai. Four different colours are depicted to distinguish the species: '●' for *Taxus wallichiana*, '●' for the dominant *Quercus dealbata* in Mawphlang and *Castanopsis tribuloides* in Moodymmai , '●' for the codominant *Rhododendron arboreum* in Mawphlang and *Pinus kesiya* in Moodymmai and '●' for the rest of the species. All the eight plots at Mawphlang are more populated as compared to all the eight plots at Moodymmai. The plots at Moodymmai show more blank spaces which correspond to the canopy gaps. Hence, the canopy at Mawphlang is continuous and dense whereas the canopy at Moodymmai is discrete and sparse. The green circles representing *Taxus wallichiana* individuals occurred mostly in neighbourhood, signifying non-random dispersion.

The two sites varied with respect to various phytosociological parameters (Table 4.11). The most pronounced variation between the two sites was due to the mean number of stems per quadrat ($p<0.001$) followed by the mean basal area per quadrat ($p<0.03$). The mean number of species per quadrat did not vary significantly between the two sites ($p<0.91$). Similarly, the mean girth of individuals per quadrat did not vary between the two sites ($p<0.60$). Further, the mean height of individuals per quadrat also did not vary between the two sites ($p<0.53$).

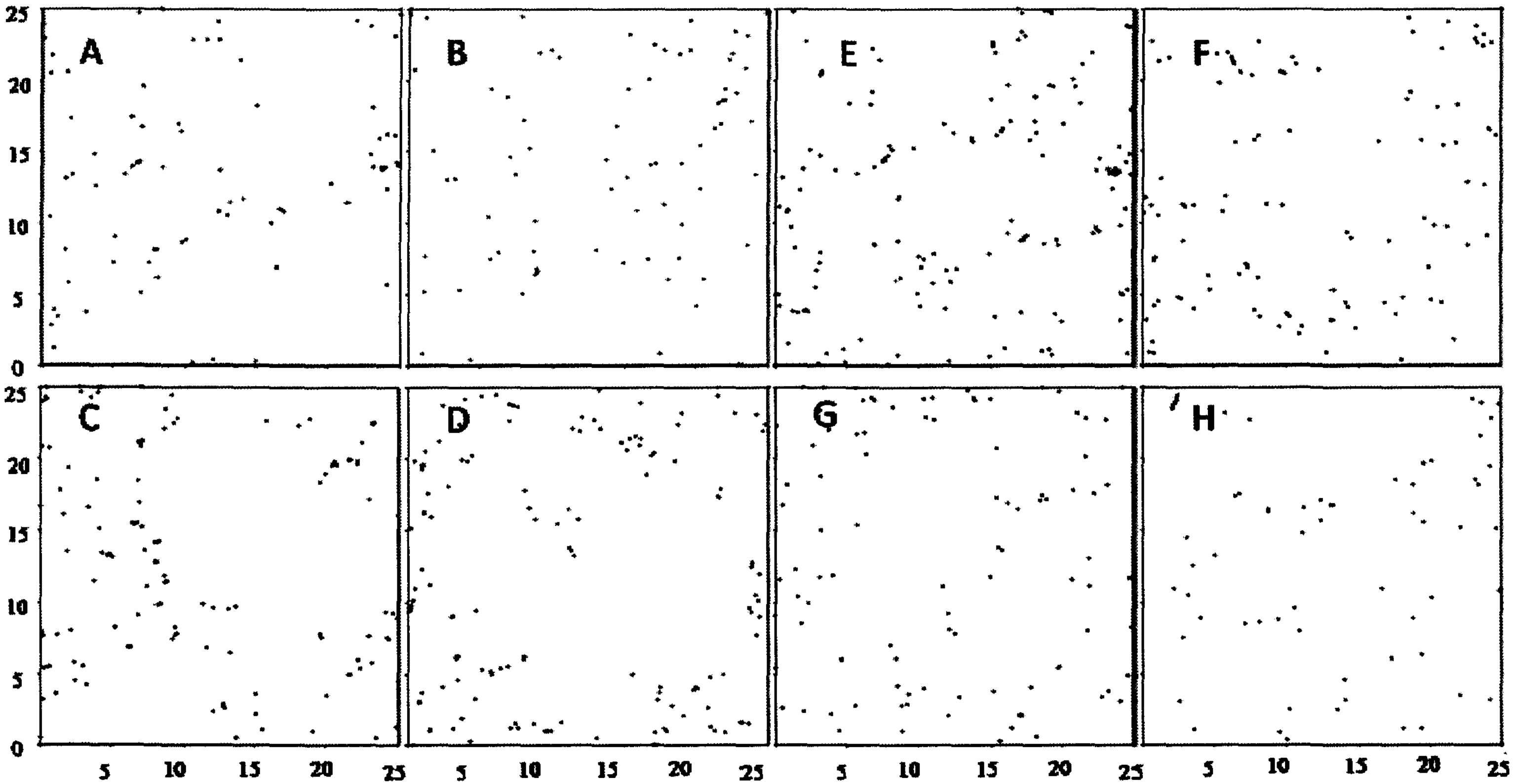


Fig. 4.11. Spatial distribution of tree individuals in the 25x25m^2 8 quadrate (A-H) in Mawphlang showing *Taxus wallichiana* (●), *Quercus dealbata* (●), *Rhododendron arboreum* (●) and other species (●).

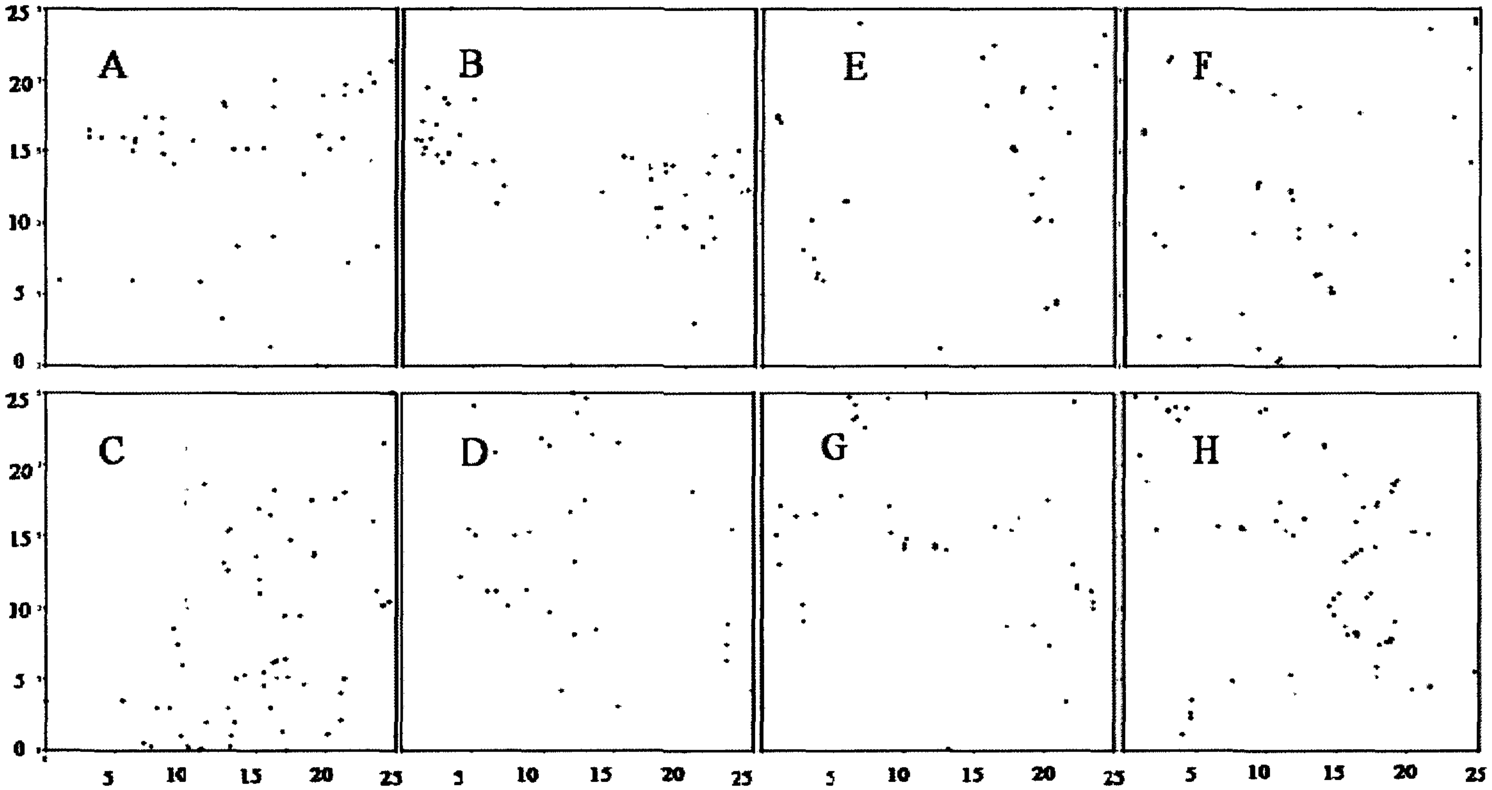


Fig. 4.12. Spatial distribution of tree individuals in the 25x25m^2 8 quadrate (A-H) in Moodymmai showing *Taxus wallichiana* (●), *Quercus dealbata* (●), *Rhododendron arboreum* (●) and other species (●).

Table 4.11. Variability among sample plots at Mawphlang and Moodymmai with respect to species richness, stem abundance, accumulation of basal area and minimum (Min), maximum (Max), mean and coefficient of variation (CV in %) of girth and height.

Plot	Number of species	Number of stems	Basal area (mm^2)	Girth (cm)				Height (m)			
				Min	Max	Mean	CV	Min	Max	Mean	CV
MAWPHLANG											
A	20	105	37770	10.1	200.5	50.8	1940	2.5	25.4	8.7	15
B	19	84	34831	10.5	197.3	52.9	2415	3.0	26.5	10.6	51
C	14	146	22579	10.1	130.5	34.7	742	1.5	19.0	6.4	110
D	15	135	13077	10.3	88.9	30.6	281	1.5	13.0	5.0	5
E	20	175	24445	10.3	139.7	34.2	585	3.0	15.0	7.6	6
F	16	117	21762	10.3	201.1	39.5	777	1.5	15.0	7.0	9
G	15	108	26001	10.5	111.6	48.5	674	3.0	17.0	9.3	12
H	15	75	32428	10.1	160.1	61.1	1705	2.0	22.0	12.5	31
A-H	61	945	212892	10.1	201.1	41.7	1093	1.5	26.5	7.9	19
MOODYMMAI											
A	22	51	14925	9.9	200.1	40.6	2033	1.0	21.1	6.8	18
B	25	53	9819	10.0	138.0	34.8	1115	1.0	22.0	7.3	14
C	21	86	25335	4.0	219.0	42.4	1905	2.0	20.0	8.1	17
D	15	36	15880	10.0	214.0	49.8	3065	1.5	26.0	9.4	42
E	10	35	25681	9.5	211.0	78.1	3126	2.8	23.8	15.0	45
F	12	50	19923	12.2	280.0	55.3	1956	2.8	22.0	10.1	19
G	13	49	21452	10.2	212.0	60.4	1856	1.0	22.0	9.9	26
H	18	75	11779	8.2	145.0	31.8	962	1.0	22.0	7.1	16
A-H	49	435	144793	4.0	280.0	46.4	2028	1.0	26.0	8.8	27
SINGLE FACTOR ANOVA BETWEEN TWO SITES											
$\bar{x}_{\text{Mawp}}$	16.8	118.1	26612			44.0				8.4	
$\bar{x}_{\text{Mood}}$	17.0	54.4	18099			49.1				9.2	
P value	0.91	0.001	0.03			0.60				0.53	

The two sites showed marked variation with respect to the diversity indices (Table 4.12). The species richness index, Shannon's diversity index and Pielou's evenness index was higher at Mawphlang site than at Moodymmai site. On the contrary, Simpson's dominance index was higher at Moodymmai site than at Mawphlang site.

Table 4.12. Diversity indices for two sampled habitats of *Taxus wallichiana* in Meghalaya, viz., Mawphlang and Moodymmai.

Sl. #	Diversity indices	Mawphlang	Moodymmai
1.	Species richness index	61	49
2.	Shannon's diversity index	1.495	1.346
3.	Simpson's dominance index	0.055	0.090
4.	Pielou's evenness index	0.837	0.796

The dominance-diversity curve based on Log_{10} of IVI showed greater equitability at Mawphlang than at Moodymmai (Fig. 4.12). The most dominant species at both sites belonged to Fagaceae, i.e., *Quercus dealbata* (IVI = 47.7) at Mawphlang and *Castanopsis tribuloides* (IVI = 75.3) at Moodymmai. The codominant species were *Rhododendron arboretum* (IVI = 30.6) at Mawphlang and *Pinus kesiya* (IVI = 21.9) at Moodymmai. Although the shape of the curve was more or less similar at both the sites corresponding to a lognormal pattern, the dominance of the top species was more pronounced at Moodymmai than at Mawphlang. *Taxus wallichiana* ranked fifth at Mawphlang, with an IVI of 12.5 and fourth at Moodymmai, with an IVI of 18.3.

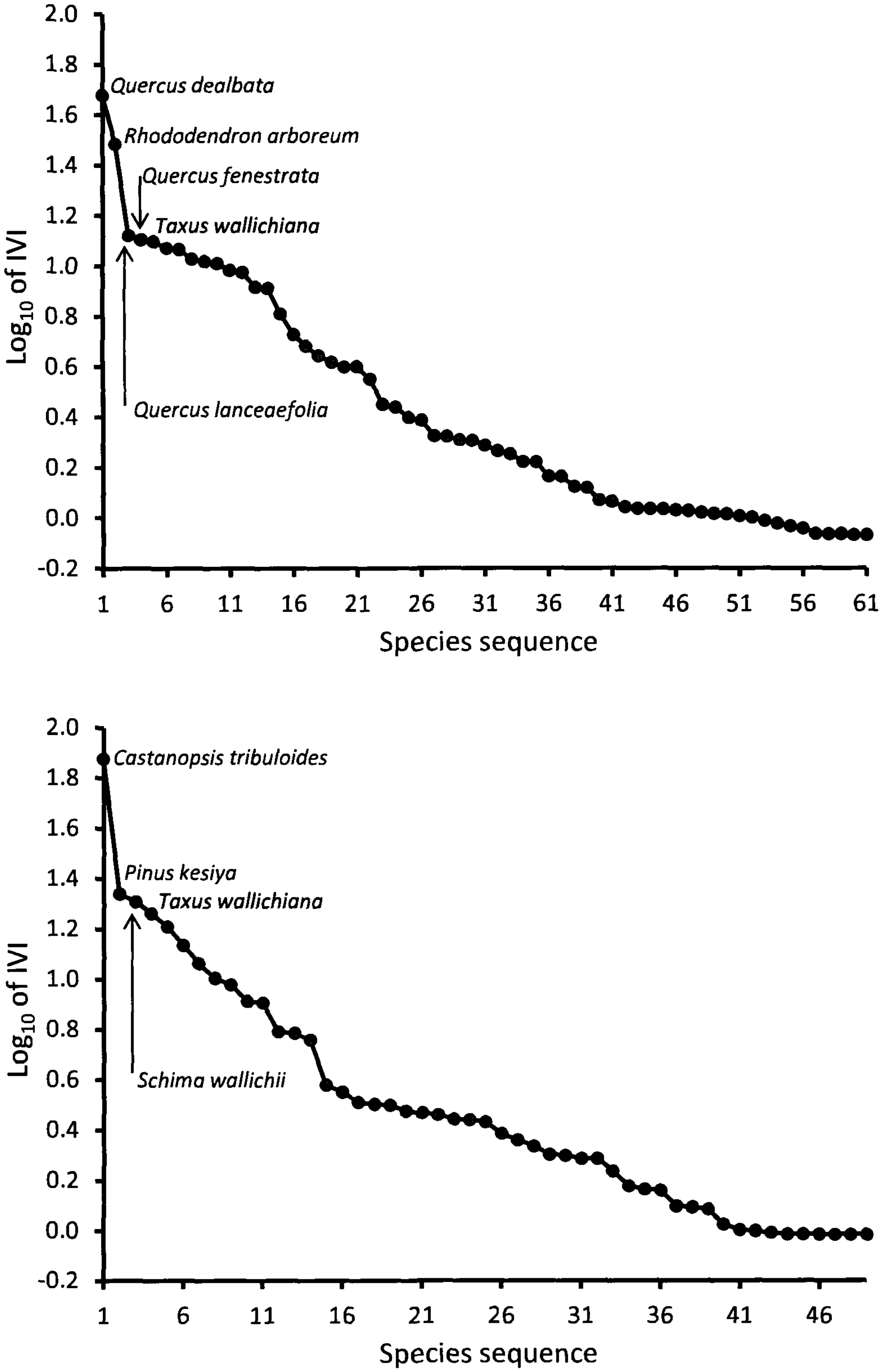


Fig. 4.12. Dominance-diversity curves based on Log_{10} of IVI for Mawphlang (a), and Moodymmai (b).

4.3.4. The population and height structure of *Taxus wallichaina*

The data on population structure of *Taxus wallichiana* are drawn from Mawphlang and Moodymmai sites (Table 4.13). Additionally, the data from two other sites (Phudjaut-Rangthong and Nongmawlum-Pyrda), which were surveyed but were not selected for detailed study due to paucity of *T. wallichiana* individuals, are also shown in Table 4.13. Hence, from these four sites together, 310 individuals of *T. wallichiana* were recorded.

Table 4.13. Population structure of *Taxus wallichiana* in all the sites in Meghalaya.

Site	GBH class (cm)									
	<10	10-30	30-60	60-90	90-120	120-150	150-180	180-210	>210	Total
Mawphlang	39	75	53	21	14	4	2	4	3	215
Moodymmai	24	13	4	5	1	2	0	0	2	51
Phudjaut-Rangthong	0	10	3	2	1	0	0	0	0	16
Nongmawlum-Pyrda	2	22	4	0	0	0	0	0	0	28
Total	65	120	64	28	16	6	2	4	5	310

The distribution of the pooled data of the four sites in nine girth classes showed a successive decline in the number of individuals from a lower to the next higher girth class from 10-30 cm girth class onwards (Table 4.13, Fig. 4.13). The number of individuals in <10 cm girth class was lesser (almost one-half) than the number of individuals in 10-30 cm girth class. The site Moodymmai showed a greater number of individuals in <10 cm girth class than in 10-30 cm girth class (Table 4.13). The individuals in <10 cm girth class represent the seedling stage and indicate that the recruitment of seedlings is poor at all sites (Fig. 4.14). The sites, Phudjaut-Rangthong and Nongmawlum-Pyrda lacked individuals in medium to higher girth classes (Table 4.13) probably due to felling of *T. wallichiana* trees in the past at these sites (Fig. 4.14).

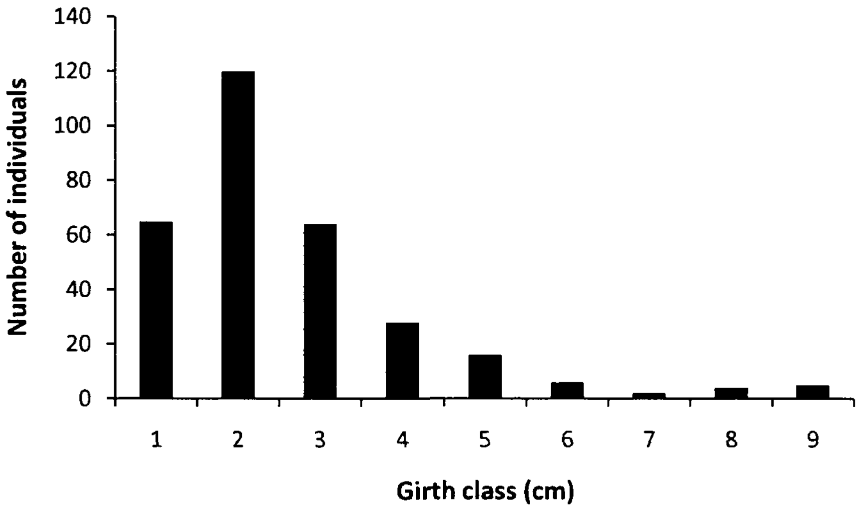


Fig. 4.13. A pooled population structure of *Taxus wallichiana* in nine girth classes, *viz.*, 1 (<10 cm), 2 (10-30 cm), 3 (30-60 cm), 4 (60-90 cm), 5 (90-120 cm), 6 (120-150 cm), 7 (150-180 cm), 8 (180-210 cm) and 9 (>210 cm).

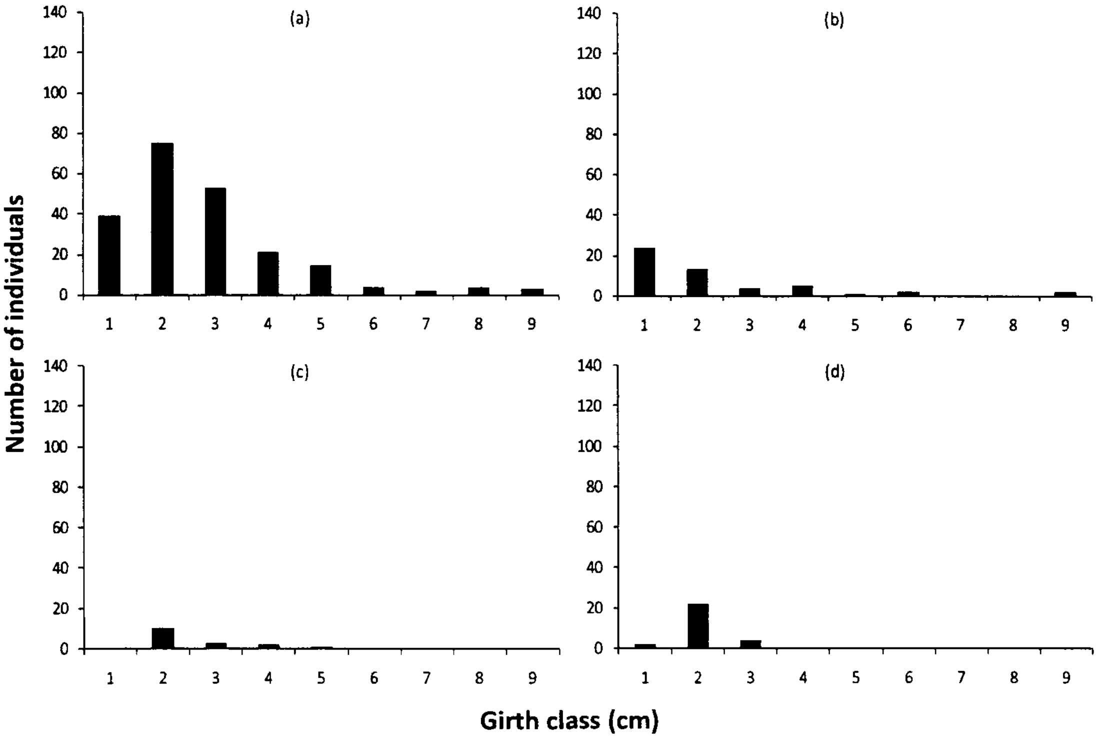


Fig. 4.14. Population structure of *Taxus wallichiana* in nine girth classes, *viz.*, 1 (<10cm), 2 (10-30 cm), 3 (30-60 cm), 4 (60-90 cm), 5 (90-120 cm), 6 (120-150 cm), 7 (150-180 cm), 8 (180-210 cm) and 9 (>210 cm) at four individual sites in Meghalaya (a, Mawphlang; b, Moodymmai; c, Phudjaut Rangthong and d, Nongmawlum Pyrda).

The data on height structure of *Taxus wallichiana* are drawn from Mawphlang and Moodymmai sites (Table 4.13). Additionally, the data from two other sites (Phudjaut-Rangthong and Nongmawlum-Pyrda), which were surveyed but were not selected for detailed study due to paucity of *T. wallichiana* individuals, are also shown in Table 4.14. Hence, from these four sites together, 310 individuals of *T. wallichiana* were recorded.

Table 4.14. Vertical height structure of *Taxus wallichiana* indiviuals in all the sites in Mawphlang.

Site	Height class (m)						
	0-4	4-8	8-12	12-16	16-20	>20	Total
Mawphlang	34	89	67	18	5	2	215
Moodymmai	31	6	7	3	2	2	51
Phudjaut Rangthong	4	9	3	0	0	0	16
Nongmawlum Pyrda	6	20	1	1	0	0	28
Total	75	124	78	22	7	4	310

The distribution of the pooled data of the four sites in six height classes showed a successive decline in the number of individuals from a lower to the next higher girth class from 4-8 m height class onwards (Table 4.14, Fig. 4.15). The number of individuals in <4 m height class was lesser (almost two-thrid) than the number of individuals in 4-8 m height class. The site Moodymmai showed a greater number of individuals in <4 m height class than in 4-8 m height class (Table 4.14). The individuals in <4 m girth class represent the seedling stage and indicate that the recruitment of seedlings is poor at most sites (Fig. 4.16). The sites, Phudjaut-Rangthong and Nongmawlum-Pyrda lacked individuals in medium to high height classes (Table 4.14) probably due to felling of *T. wallichiana* trees in the past at these sites (Fig. 4.16).

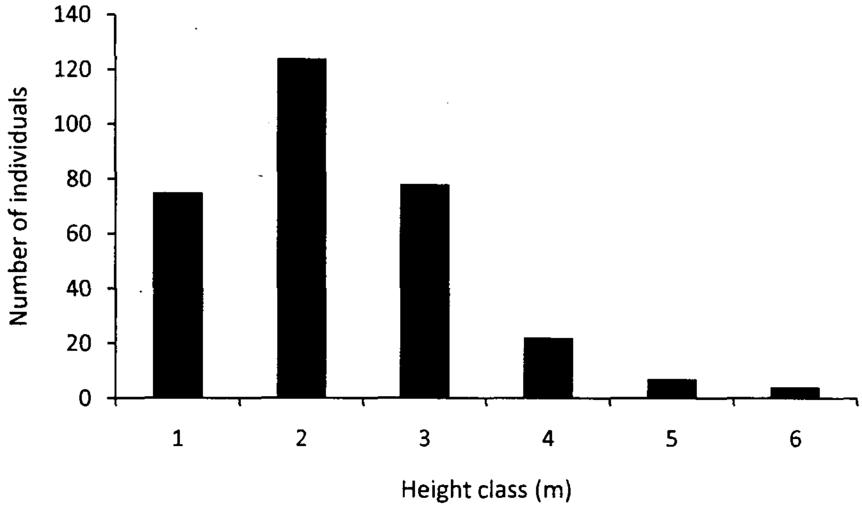


Fig. 4.15. A pooled height structure of *Taxus wallichiana* in six girth classes, *viz.*, 1 (<4 m), 2 (4-8 m), 3 (8-12 m), 4 (12-16 m), 5 (16-20 m), 6 (>20 m).

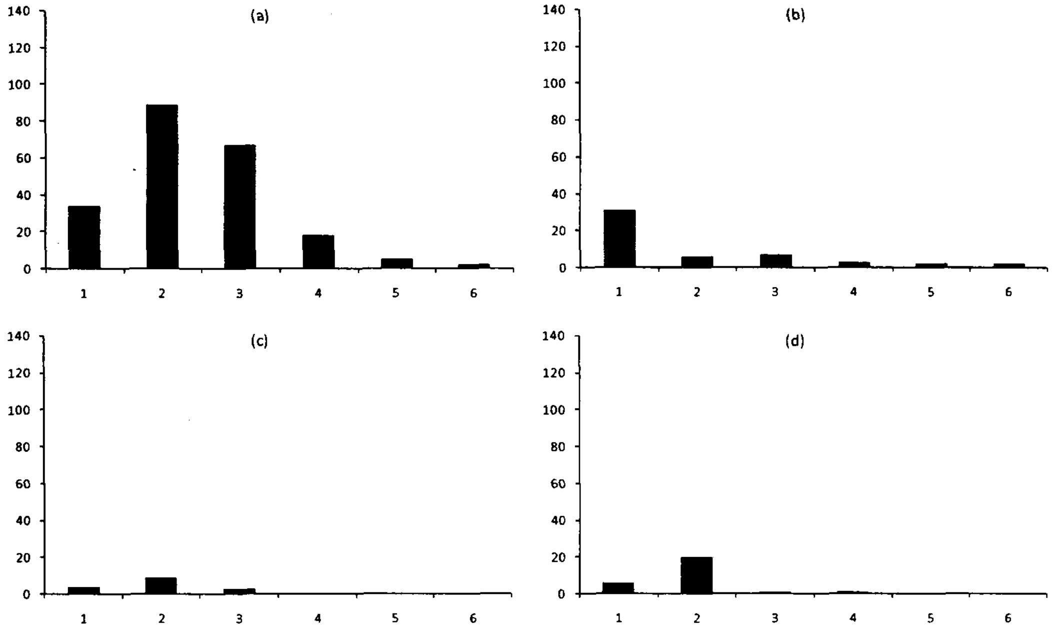


Fig. 4.16. Height structure of *Taxus wallichiana* in six girth classes, *viz.*, 1 (<4 m), 2 (4-8 m), 3 (8-12 m), 4 (12-16 m), 5 (16-20 m), 6 (>20 m) at four individual sites in Meghalaya (a, Mawphlang; b, Moodymmai; c, Phudjaut Rangthong and d, Nongmawlum Pyrda).

The variability from seedling to mature individual of *Taxus wallichiana* in measures of girth (cm) and height (m) is very high as evinced by the high values of CV at all four sites (Table 4.15). The variation in girth is more than in height. Among four sites, the maximum mean girth was observed at Mawphlang followed by Phudjaut Rangthong and maximum mean height was observed at Moodymmai followed by Phudjaut Rangthong.

Table 4.15. Variability in measures of girth or collar diameter (cm) and height (m) of *Taxus wallichiana* individuals at the four sites as depicted by minimum (Min), maximum (Max), mean and coefficient of variation (CV in %).

Site	Girth or collar diameter (cm)				Height (m)			
	Min	Max	Mean	CV	Min	Max	Mean	CV
Mawphlang	0.9	240.0	42.3		0.2	20.0	7.4	
Moodymmai	1.0	280.0	34.1		0.2	22.0	5.1	
Phudjaut Rangthong	18.5	118.0	39.6		1.0	9.0	5.4	
Nongmawlum Pyrda	7.0	36.4	20.1		2.0	13.0	5.0	
Total	0.9	280.0	34.0		0.2	22.0	5.7	

4.4. Discussion

The vegetation analysis of *T. wallichiana* habitats reveals a variation in composition, occurrences, and diversity of species between the two sites. Higher number of individuals is observed in Mawphlang (945), with a total of 61 species, compared to Moodymmai (435) with 49 species. However, numbers of family recorded is higher in Moodymmai with 32 as compared to Mawphlang with 26 (Table 4.5 and 4.10).

The dominating species in both the sites belongs to the family Fagaceae; Mawphlang was dominated by *Quercus dealbata* (IVI=47.7) and *Rhododendron arboreum* (IVI=30.6) was the second dominating species. This is in accordance with the findings of Rao *et al.* (1990). Ten species have IVI>10 out of which four belongs to family Fagaceae. Mawphlang recorded 9 rare species (IVI<1). In contrast, out of the 8 species in Moodymmai having IVI>10, only one belongs to family Fagaceae i.e. *Castanopsis tribuloides* (IVI=75.3) which was also recorded ~~the~~ as dominant, while *Pinus kesiya*, a secondary successional species, was next to it (Rao *et al.* 1990). *Taxus wallichiana* also exhibited IVI>10 and ranks fifth (IVI=12.5) and fourth (IVI=18.3) in Mawphlang and Moodymmai, respectively (Fig 4.10).

Maximum basal area and number of stems belongs to *Quercus dealbata* (107605 cm^2 ha^{-1} and 170) in Mawphlang and in *Castanopsis tribuloides* (7129885 cm^2 ha^{-1}and 107) in Moodymmai, respectively. Except *T. wallichiana* in Mawphlang and *A. stipulata* and *Cyathea* sp. in Moodymmai, all species with IVI>10 have more than 20 individuals. Species with IVI<10 exhibiting > 20 number of stems are *N. zeylanicum, C. indica* and *M. esculenta* of Mawphlang.

Diversity indices show a variation in between the two sites. Species richness, Shannon's diversity and Pielou's evenness index is observed to be higher in the undisturbed Mawphlang site and declines in the disturbed stands of Moodymmai, while it is *vice versa* for Simpson's dominance index (Table 4.12).

Mean girth of all the species is more in Moodymmai site (46.4 cm) compared to those in Mawphlang (41.7 cm). Sixteen families comprising of thirty nine species in Mawphlang and eighteen species in Moodymmai shows >30 cm mean girth. In both sites, >200 cm GBH is found to occur in species having IVI>10. Moodymmai has four species of >200 cm girth in which the maximum was in *Castanopsis tribuloides* (280.0 cm) while in Mawphlang it was recorded in two species, with the maximum in *Quercus lanceaefolia*

(201.1 cm). Maximum girth of Taxus was higher in Moodymmai with 219.0 cm compared to Mawphlang with 196.7 cm. Three species showed >210 cm girth in Moodymmai while none was observed in Mawphlang. Mean stem height of the species was higher in Moodymmai (8.8 m, CV-26.9 %), compared to Mawphlang (7.9 m, CV-19.0 %) and about twelve species in Mawphlang and ten in Moodymmai have mean stem height >10 m. Maximum height in Moodymmai belong to the dominant *Castranopsis tribuloides* (26.0 m) while in Mawphlang it occurred in a less frequent (IVI<10) *Schima* like species (26.5 m). *T. wallichiana* showed mean height of 9.9 m (CV-25.7 %) in Mawphlang and 7.1 m (CV- 24.8 %) in Moodymmai with the tallest recording 20.0 m each in both the sites. In Mawphlang fourteen species exhibited >20 m height out of which six have IVI<10. A less frequent (IVI<10) *Schima khasiana* has the maximum numbers with 5 individuals. Moodymmai has eight species with height >20 m and four have IVI<10.

Family-wise evaluation for both sites (Table 4.5 and 4.10) reveals that Fagaceae family is an important composition of Taxus habitat. The highest IVI is also exhibited by species of this family in both sites. Fagaceae exhibits maximum number of stems and basal area in both sites despite the fact that Rosaceae (Mawphlang) and Araliaceae (Moodymmai) has been recorded with more number of species. Out of ten species with IVI>10, Fagaceae has four species in the undisturbed forest of Mawphlang. In the disturbed site of Moodymmai, Fagaceae is monospecific and secondary succesional species, *Pinus kesiya* (Pinaceae) tends to become dominant, yet *Castanopsis tribuloides* showed the maximum IVI. Araliaceae is recorded with the highest mean girth (158.9 cm) and height (20.2 m) in Mawphlang. However, Fagaceae showed the maximum girth (201.1 cm) and Theaceae the maximum height (26.5 m). In Moodymmai Fabaceae has the highest mean girth (92.2

cm) and Eleagneaceae the highest mean height (20.0 m) with Fagaceae showing the maximum girth and height (280.0 cm and 26.0 m). The phytosociological study conducted is at par with the studies conducted by Rao *et al.* (1990, 1997), Barik *et al.* (1992, 1996), Upadhyay *et al.* (2003 and 2004). poor discussion ?

Population structure of the species (Fig 4.2 and 4.6) shows a peak in the lower girth class which explains that individuals regenerated well. Similarly, higher number of the species present (filled squares) in the smaller girth classes reveals a good regeneration of the species (4.3 and 4.7). Height structure reveals the lack of individuals in smaller height class which is also seen in the case of number of species present (filled squares) (Fig 4.4, 4.5, 4.8 & 4.9). ?

Evaluation of *Taxus* in all the sites (Mawphlang, Moodymmai and two random surveyed sites) showed a variation between them. Number of individuals ranged from 16 to 215 with the highest in Mawphlang. Pooled population structure showed scarcity of individuals in <10 cm girth. This is observed in three sites but it is *vice versa* in Moodymmai where <10 cm girth class recorded the maximum individuals showed a decreasing trend towards the other higher classes. This suggests that there occurred regeneration but individual growth of seedlings were being interfered by ~~many~~ other factors (Del Moral and Cates 1971, Thomas and Polwart 2003, Iszkulo and Boratynski 2004) and anthropogenic activities. Occurrence of individuals is extremely less in higher classes. Disturbance is less in Mawphlang. Hence, individuals are present in all girth classes. However, in other sites especially, Phudjaut-Rangthong and Nonhmawlum-Pyrda, in higher girth class none was observed. Height structure also showed lack of individuals in lower height class *i.e.* <4 m height. The seeds did show germination but seedlings did not survive long. ? This is in accordance with the findings of Iszkulo (2001) and Iszkulo and

Boratynski (2004). Less number of individuals in lower size classes explains the fact that seedlings are lacking in the sites. The individuals also show a decrease in number from lower to higher girth class indicating that they are decreasing with age. This may be due to various climatic factors and disturbance from grazing animals (Rikhari *et al.* 1998).

The phytosociology reveals that *T. wallichiana* is not a dominant species in either site and it showed a close association with broadleaf and conifer species. The regeneration is extremely low, and therefore the fate of the population depends on the availability of seedlings. Hence, *T. wallichiana* is facing a threat in Meghalaya.

CHAPTER V

NATURAL REGENERATION AND SEEDLING DYNAMICS OF TAXUS WALLICHIANA

CHAPTER V

NATURAL REGENERATION AND SEEDLING DYNAMICS OF *Taxus wallichiana*

5.1 Introduction

In nature, *T. wallichiana* reproduces through seeds (Anonymous 1976, Haridasan 1996, Purohit *et al.* 2001) but exhibits poor sucess (Beniwal and Haridarsan 1992, Chee 1994, Shukla *et al.* 1994, Rikhari *et al.* 1998, Rajewski *et al.* 2000, Purohit *et al.* 2001, Khali *et al.* 2003, 2004, Singh 2006, Pant and Samant 2008, Nimachow *et al.* 2010, Uniyal 2013). The poor regeneration is characterized by failure of germination of seeds affecting recruitment and survival of seedlings (Beniwal and Haridarsan 1992, Nimachow *et al.* 2010). Studies from different geographical locations have suggested that many seedlings do not survive for more than two years (Gieruszynski 1961, Ostrowski 1968, Pridnya 1984, 2002, Kopp 1991, Hulme 1996, Boratynski *et al.* 1997, Kopp and Chung 1997, Seidling 1999, Saniga 2000, Iszkulo 2001, Iszkulo and Boratynski 2004).

The natural regeneration of *T. wallichiana* may be influenced by multiple factors involving suitability of microhabitats (Hulme 1996) and disturbance. The dense undergrowth in the forest floor is known to impair the successful establishment of seedlings (Haridasan *et al.* 2001, Nimachow *et al.* 2010). Disturbance from grazing (Alverson *et al.* 1988, Perrin *et al.* 2006) and wildfire (Piovesan *et al.* 2009) impacts seedling survival. It has a strong negative effect on the recruitment, growth of seedlings and mature tree survival (Haeggstrom 1990, Gill *et al.* 1995, Kelley 1981, Sarmaja *et al.* 1991, Minore *et al.* 1996, Purohit *et al.* 2001). *Taxus* is susceptible to browsing and bark-stripping by wild animals, cattle, fowls, goats, deer, sheep, chilling injury, direct sunlight and fire, which are common in the Himalayan region. Hence low regeneration and recruitment of the seedlings is common (Minore *et al.* 1996, Purohit *et al.* 2001, Nimachow *et al.* 2010). The slow growth of yew seedlings (Gieruszynski 1961, Voliotis 1986, Garcia *et al.* 2000) and their poor performance in competition with seedlings of other tree species and with the herbs are other possible reasons for considerably small number of seedlings and saplings (Iszkulo and Boratynski 2004). Yew regeneration is directly related to the basal area of yew tree (Piovesan *et al.* 2009). Germination of the seeds occurs under the canopy of mother trees (Iszkulo and Boratynski 2004). Seeds drop down under the crowns of mother trees thus most of seedlings are found under the mother tree crowns, and only a small number of them outside. However, some are dispersed by birds or rodents (Sakakibara 1989, Minore *et al.* 1996) and consequently germinate outside the crowns of trees, where the light conditions are much better (Iszkulo and Boratynski 2004).

Mature yew trees have been reported to prevent successful yew regeneration (Hulme 1996, Iszkulo and Boratynski 2006, Watt 1926, Piovesan *et al.* 2009) by affecting seedling growth and survival (Del Moral and Cates 1971, Iszkulo and Boratynski 2004, Piovesan *et al.* 2009). Similarly, Thomas and Polwart (2003), Iszkulo and Boratynski, (2004) reported that *T. baccata* emits allelopathic substances which diminishes seed germination and eliminates seedlings in their early growth stages. The species is extremely slow growing in terms of girth increment (0.4-1.3 cm yr^{-1}; Anonymous 1976) and ring counts (average of 8-12 rings cm^{-1} of radius; Gamble 1922).

The natural regeneration is more pronounced under open or sparse canopy (Haridasan *et al.* 2001, Purohit *et al.* 2001, Nimachow *et al.* 2010). Generally, few seedlings and saplings are found sparsely scattered and isolated (Nimachow *et al.* 2010).

This Chapter presents the results of the study of seedling regeneration and dynamics of *T. wallichiana* in natural habitat. The specific objectives are: 1) to determine fruit and seed phenology of the trees of *T. wallichiana*, 2) to delineate spatial pattern of germination and seedling recruitment in natural conditions, and 3) to trace seedling survival and growth in subsequent years of germination.

5.2. Materials and Methods

The trees of *T. wallichiana* were surveyed for the presence of seedlings around them since only female trees show presence of seedlings and male trees lack seedlings around them. Seven female trees at Mawphlang, and three female trees at Moodymmai could be selected depending on the availability (Table 5.2). The remains of seeds and presence of seedlings at the base of the tree helped in determining the female trees (Iszkulo 2001). The selected trees were at a minimum distance of ten meters from each other. Observations on the seed bearing trees were also made during fruiting season to ensure whether they really wore fruits or not during the study period. The seed-bearing trees shall be referred to as 'mother trees'.

Observations were taken on how a fruit drops from the parent tree during fruiting season and simultaneously the pattern in which the seeds disperse around the mother tree. The germinated seeds (seedlings) around mother trees were estimated by quadrat sampling. The quadrats were laid under the tree crown in four directions, i.e. north, south, east and west to count and monitor the seedlings that occurred within them (Minore *et al.* 1996, Dalling *et al.* 1998, Germino *et al.* 2002). The quadrats of 1 x 1 m^2 were laid from the base of the tree towards the periphery covering a distance of 10 m.

Table 5.1. The characteristics of mother trees selected for natural regeneration study.

Tree number	Height (m)	Girth (cm)				
			South (m)	East (m)	North (m)	West(m)
Mawphlang						
1	15.2	85.1	5.8	5.5	5.9	6.3
2	14.0	112.0	5.0	4.2	6.0	5.8
3	6.5	33.4	3.8	4.5	4.0	3.5
4	6.8	34.1	4.5	6.0	5.0	4.5
5	7.0	33.0	3.5	2.6	3.3	2.5
6	9.0	41.1	2.0	2.0	1.0	2.3
7	8.2	55.8	5.5	5.5	6.2	6.0
Moodymmai						
1	12.5	219.0	6.0	4.0	7.5	5.8
2	12.5	133.0	4.5	4.8	5.0	3.0
3	20.0	118.0	5.0	5.0	5.8	4.5

The quadrats were placed at a distance of 1 m from the base of the tree followed by a gap of 1 m, and continued again alternately along the total 10 m length (Fig 5.1). Hence, a total of five quadrats were laid in each direction totaling to twenty quadrats for all the four directions. A gap of 1 m was maintained between the quadrats to maintain uniformity of the layout (Dovciak 2002).

All the germinated seedlings which occurred within the quadrats were tagged with aluminium foil, counted and monitored at monthly interval during the study period. In successive monthly censuses, the seedlings that survived and died were recorded. Simultaneously, the new recruits were recorded. From the data collected, the total number, mean and standard deviation of the occurrence of seedlings were calculated. The survival and mortality of seedlings was calculated by following Rao *et al.* (1990), Pandey and Shukla (1999) and Uma Shankar (2012).

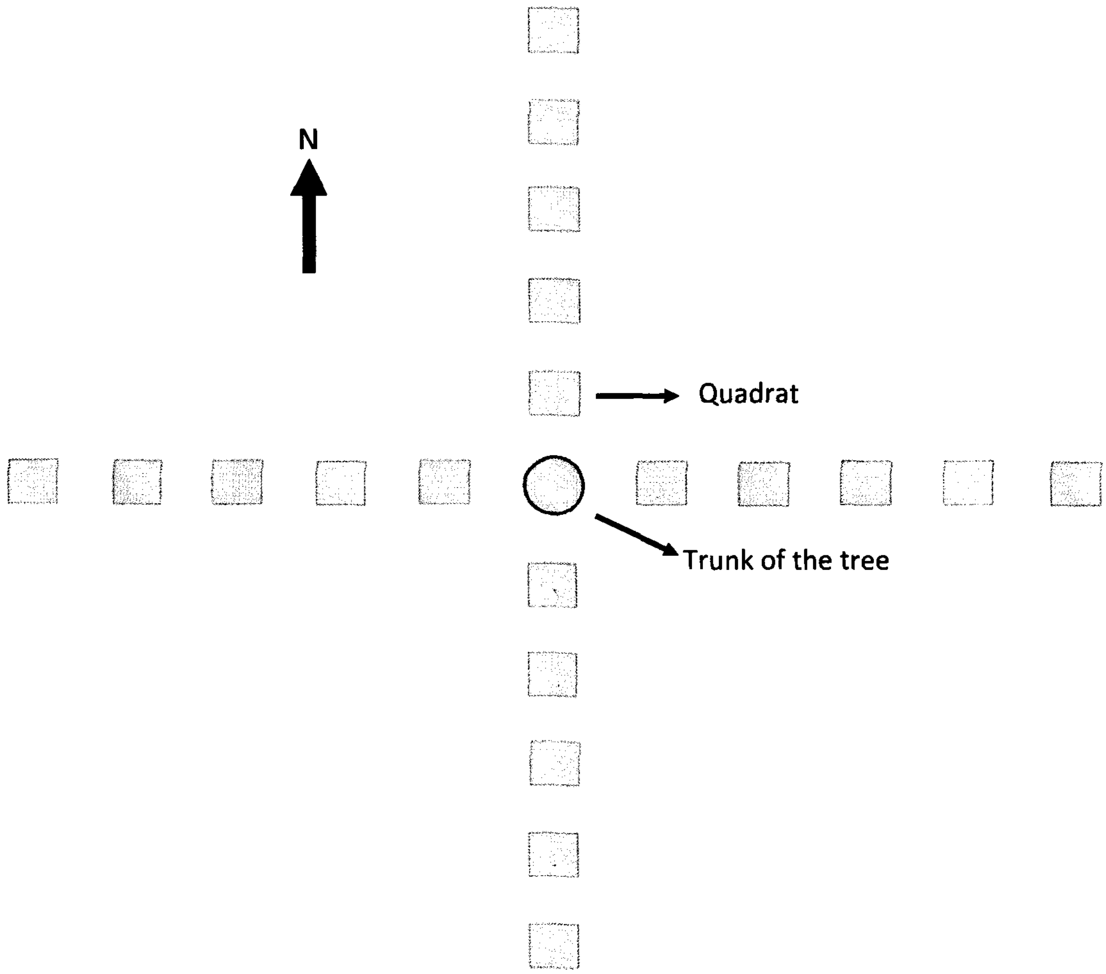


Fig. 5.1. The layout of sampling of seedlings around mother trees of *T. wallichiana*.

All the tagged seedlings were also monitored for their growth during the three year study period. The seedling height, collar diameter and leaf characteristics were recorded following Jayashankar *et al.* (1999), Khan *et al.* (1999) and Uma Shankar (2006, 2012). The height (cm) was recorded with the help of a measuring tape, collar thickness (cm) with a Vernier caliper and the number of leaves was counted manually. The calculations of basic statistical parameters such as sum, average, standard deviation, coefficient of variation and Analysis of Variance (ANOVA) were done in excel and Paleontological Statistics Software (PAST , version 1.94b).

5.3 Results

5.3.1 Seed dispersal

The seeds of *T. wallichiana* are borne on female trees with bright-red colored aril. The aril attracts dispersal agents such as birds who consume aril and effect dispersal. However, most seeds are dispersed passively due to gravitation and fall below or in vicinity of the tree.

5.3.2 Seed germination and seedling recruitment *in situ*

The germination of seeds of *T. wallichiana* occurs in natural conditions. The seeds falling in suitable microhabitats germinate profusely and those in unfavourable microhabitats fail to germinate. The suitability of a microhabitat for germination is determined by substratum, soil texture, moisture regime, load of litter/detritus and light interception.

The magnitude of seed germination was quantified by recording emergence of seedlings around individual fruiting trees. The seedling emergence was recorded in four directions (N, W, S, E) of a tree trunk up to a distance of 10 m by laying quadrats of 1 m^2 at an interval of 1 m distance. Hence a total of 20 quadrats were laid (5 quadrats in each of the four directions) around a tree. A total of 10 fruiting trees were selected for the study of seedling emergence. Of these 7 trees were located at Mawphlang and 3 trees at Moodymmai. The seedlings emerged in each quadrat were enumerated for all trees from 2006 through 2009.

The results of seedling emergence around 10 trees are presented in ~~T~~table 5.2 for 2006, ~~T~~table 5.3 for 2007, ~~T~~table 5.4 for 2008 and ~~T~~table 5.5 for 2009. Not all trees showed seedling emergence in all years: T5 and T6 showed seedling emergence in 2006 only and T10 in 2006 and 2009. The remaining trees showed seedling emergence in all years.

Table 5.2. The seedlings emerged (or seeds germinated) in twenty quadrats laid around each of the ten trees of *T. wallichiana* in 2006 in Meghalaya.

Tree #	Direction	Distance from trunk (m)					Total
		1-2	3-4	5-6	7-8	9-10	(1-10 m)
T1	South	8	3	0	2	3	16
	East	9	3	2	0	0	14
	North	9	5	0	6	0	20
	West	20	4	0	0	0	24
T2	South	7	2	2	0	0	11
	East	3	1	1	0	0	5
	North	0	1	2	2	2	7
	West	2	0	0	0	1	3
T3	South	4	4	0	0	0	8
	East	3	4	0	0	0	7
	North	1	1	0	0	0	2
	West	1	1	0	0	0	2
T4	South	4	2	1	0	0	7
	East	3	0	0	0	0	3
	North	3	1	2	0	0	6
	West	3	1	0	0	0	4
T5	South	0	0	0	0	0	0
	East	2	0	0	0	0	2
	North	2	1	0	0	0	3
	West	0	0	0	0	0	0
T6	South	3	0	0	0	0	3
	East	0	0	0	0	0	0
	North	1	0	0	1	0	2
	West	0	0	0	0	0	0
T7	South	3	1	5	0	1	10
	East	2	0	2	0	0	4
	North	3	1	0	0	0	4
	West	5	1	6	0	0	12
T8	South	2	0	0	0	0	2
	East	0	0	0	0	0	0
	North	3	0	0	0	0	3
	West	3	0	2	0	0	5
T9	South	2	1	2	0	0	5
	East	3	1	0	0	0	4
	North	3	0	0	0	0	3
	West	0	0	0	0	0	0
T10	South	0	0	0	0	0	0
	East	0	0	0	0	0	0
	North	0	0	0	0	0	0
	West	0	0	0	0	0	0

Table 5.3. The seedlings emerged (or seeds germinated) in twenty quadrats laid around each of the ten trees of *T. wallichiana* in 2007 in Meghalaya.

Tree #	Direction	Distance from trunk (m)					Total
		1-2	3-4	5-6	7-8	9-10	(1-10 m)
T1	South	19	6	3	2	0	30
	East	5	4	1	0	0	10
	North	8	7	0	0	0	15
	West	6	4	3	0	0	13
T2	South	11	9	2	2	0	24
	East	8	4	0	0	0	12
	North	7	5	1	2	0	15
	West	6	4	4	0	0	14
T3	South	5	2	0	0	0	7
	East	4	3	2	0	0	9
	North	3	0	0	0	0	3
	West	2	1	0	0	0	3
T4	South	3	2	0	0	0	5
	East	2	1	0	0	0	3
	North	4	0	0	0	0	4
	West	2	0	0	0	0	2
T5	South	0	0	0	0	0	0
	East	0	0	0	0	0	0
	North	0	0	0	0	0	0
	West	0	0	0	0	0	0
T6	South	0	0	0	0	0	0
	East	0	0	0	0	0	0
	North	0	0	0	0	0	0
	West	0	0	0	0	0	0
T7	South	3	1	0	0	0	4
	East	4	3	2	1	0	10
	North	5	5	2	0	0	12
	West	4	3	1	0	0	8
T8	South	3	4	0	0	0	7
	East	0	0	0	0	0	0
	North	6	3	0	0	0	9
	West	6	4	0	0	0	10
T9	South	4	0	0	0	0	4
	East	6	0	0	0	0	6
	North	4	1	0	0	0	5
	West	0	0	0	0	0	0
T10	South	0	0	0	0	0	0
	East	2	0	0	0	0	2
	North	5	0	0	0	0	5
	West	0	0	0	0	0	0

Table 5.4. The seedlings emerged (or seeds germinated) in twenty quadrats laid around each of the ten trees of *T. wallichiana* in 2008 in Meghalaya.

Tree #	Direction	Distance from trunk (m)					Total
		1-2	3-4	5-6	7-8	9-10	(1-10 m)
T1	South	12	9	1	0	0	22
	East	5	2	1	2	0	10
	North	16	8	2	1	0	27
	West	19	15	2	4	2	42
T2	South	8	5	2	1	2	18
	East	4	0	0	0	0	4
	North	8	9	3	1	2	23
	West	5	6	1	2	2	16
T3	South	3	2	0	0	0	5
	East	2	3	0	0	0	5
	North	4	1	0	0	0	5
	West	1	0	0	0	0	1
T4	South	2	2	1	0	0	5
	East	3	1	0	0	0	4
	North	2	2	0	0	0	4
	West	3	0	0	0	0	3
T5	South	0	0	0	0	0	0
	East	0	0	0	0	0	0
	North	0	0	0	0	0	0
	West	0	0	0	0	0	0
T6	South	0	0	0	0	0	0
	East	0	0	0	0	0	0
	North	0	0	0	0	0	0
	West	0	0	0	0	0	0
T7	South	2	0	1	0	0	3
	East	3	1	0	2	1	7
	North	8	3	3	0	0	14
	West	5	2	0	2	1	10
T8	South	5	2	0	0	0	7
	East	0	0	0	0	0	0
	North	6	2	0	0	0	8
	West	2	4	0	0	0	6
T9	South	3	0	0	0	0	3
	East	3	2	0	0	0	5
	North	4	2	0	0	0	6
	West	0	0	0	0	0	0
T10	South	0	0	0	0	0	0
	East	3	0	0	0	0	3
	North	2	0	0	0	0	2
	West	0	0	0	0	0	0

Table 5.5. The seedlings emerged (or seeds germinated) in twenty quadrats laid around each of the ten trees of *T. wallichiana* in 2009 in Meghalaya.

Tree #	Direction	Distance from trunk (m)					Total
		1-2	3-4	5-6	7-8	9-10	(1-10 m)
T1	South	11	7	2	2	3	25
	East	6	3	1	1	3	14
	North	6	6	1	2	0	15
	West	6	8	2	2	3	21
T2	South	6	4	0	0	2	12
	East	4	0	0	1	0	5
	North	4	2	0	0	2	8
	West	4	5	2	0	2	13
T3	South	2	1	0	0	0	3
	East	3	2	0	1	0	6
	North	4	0	0	0	0	4
	West	1	0	0	0	0	1
T4	South	2	2	0	0	0	4
	East	2	1	0	0	0	3
	North	3	0	0	0	0	3
	West	2	0	0	0	0	2
T5	South	0	0	0	0	0	0
	East	0	0	0	0	0	0
	North	0	0	0	0	0	0
	West	0	0	0	0	0	0
T6	South	0	0	0	0	0	0
	East	0	0	0	0	0	0
	North	0	0	0	0	0	0
	West	0	0	0	0	0	0
T7	South	4	2	1	1	0	8
	East	3	2	0	2	0	7
	North	6	4	3	0	0	13
	West	4	2	1	2	1	10
T8	South	4	0	0	0	0	4
	East	0	0	0	0	0	0
	North	7	4	0	0	0	11
	West	6	3	0	0	0	9
T9	South	4	0	0	0	0	4
	East	7	0	0	0	0	7
	North	5	1	0	0	0	6
	West	0	0	0	0	0	0
T10	South	0	0	0	0	0	0
	East	0	0	0	0	0	0
	North	0	0	0	0	0	0
	West	0	0	0	0	0	0

The occurrence of seedlings of *T. wallichiana* was maximum in the quadrats laid near the tree trunk and declined consistently with increasing distance from the trunk (Table 5.6). This trend occurred in all the years for the data of all ten trees pooled together. When data were segregated between the two sites, the trend for seven trees of Mawphlang was similar to the overall trend as mentioned above.

Table 5.6. Seedlings of *T. wallichiana* emerged (or seeds germinated) in 2006, 2007, 2008 and 2009 in Meghalaya. The data are presented for all ten trees together, for trees T1 through T7 from Mawphlang site and for T8 through T10 for Moodymmai site.

Year	Distance from trunk (m)					Total
	1-2	3-4	5-6	7-8	9-10	(1-10 m)
		Number of seedlings of	All ten trees			
2006	117	39	27	11	7	201
2007	147	76	21	7	0	251
2008	143	83	17	15	10	268
2009	116	59	13	14	16	217
Mean	130.8	64.3	19.5	11.8	8.3	234.5
SD	±16.5	±19.6	±6.0	±3.6	±6.7	±30.5
			Trees of Mawphlang (T1 through T7)			
2006	101	37	23	11	7	179
2007	111	64	21	7	0	203
2008	115	71	17	15	10	228
2009	83	51	12	14	16	176
Mean	102.5	55.8	18.3	11.8	8.3	196.5
SD	±14.3	±15.0	± 4.9	±3.6	± 6.7	± 24.2
			Trees of Moodymmai (T8 through T10)			
2006	16	2	4	0	0	22
2007	36	12	0	0	0	48
2008	28	12	0	0	0	40
2009	33	8	0	0	0	41
Mean	28.3	8.5	1.0	0.0	0.0	37.8
SD	± 8.8	±4.7	± 2.0	± 0.0	± 0.0	±11.1

However, at Moodymmai, most seedlings occurred in quadrats laid at 1-2 m and 3-4 m distance from the trunk and quadrats beyond this distance were almost devoid of seedlings. A two-factor ANOVA, performed on all ten trees, showed a significant effect of distance from the trunk ($F = 76.5$, $p<0.01$) and no effect of years ($F = 1.32$, $P=0.315$).

A graphic representation of the yearly mean values of seedlings emerged at different distances from the tree trunk shows an exponentially declining trend for all ten trees (Fig. 5.2a), for seven trees of Mawphlang site (Fig. 5.2b) and for three trees of Moodymmai site (Fig. 5.2c).

The ten trees showed wide variation in production of seedlings (germinants) of *T. wallichiana* (Table 5.7). T1 produced the maximum number of seedlings followed by T2, T7 and T8. The trees T5, T6 and T10 produced the least number of seedlings and in some years these trees failed to produce any seedlings. The variation between four years of observations in the number of seedlings produced by a tree was not pronounced; for example, T1 consistently produced higher number of seedlings in all years and T10 consistently produced fewer seedlings in all years (Table 5.7). A two-factor ANOVA, showed a significant effect of trees ($F = 37.1$, $p<0.01$) and no effect of years ($F = 1.43$, $P=0.255$).

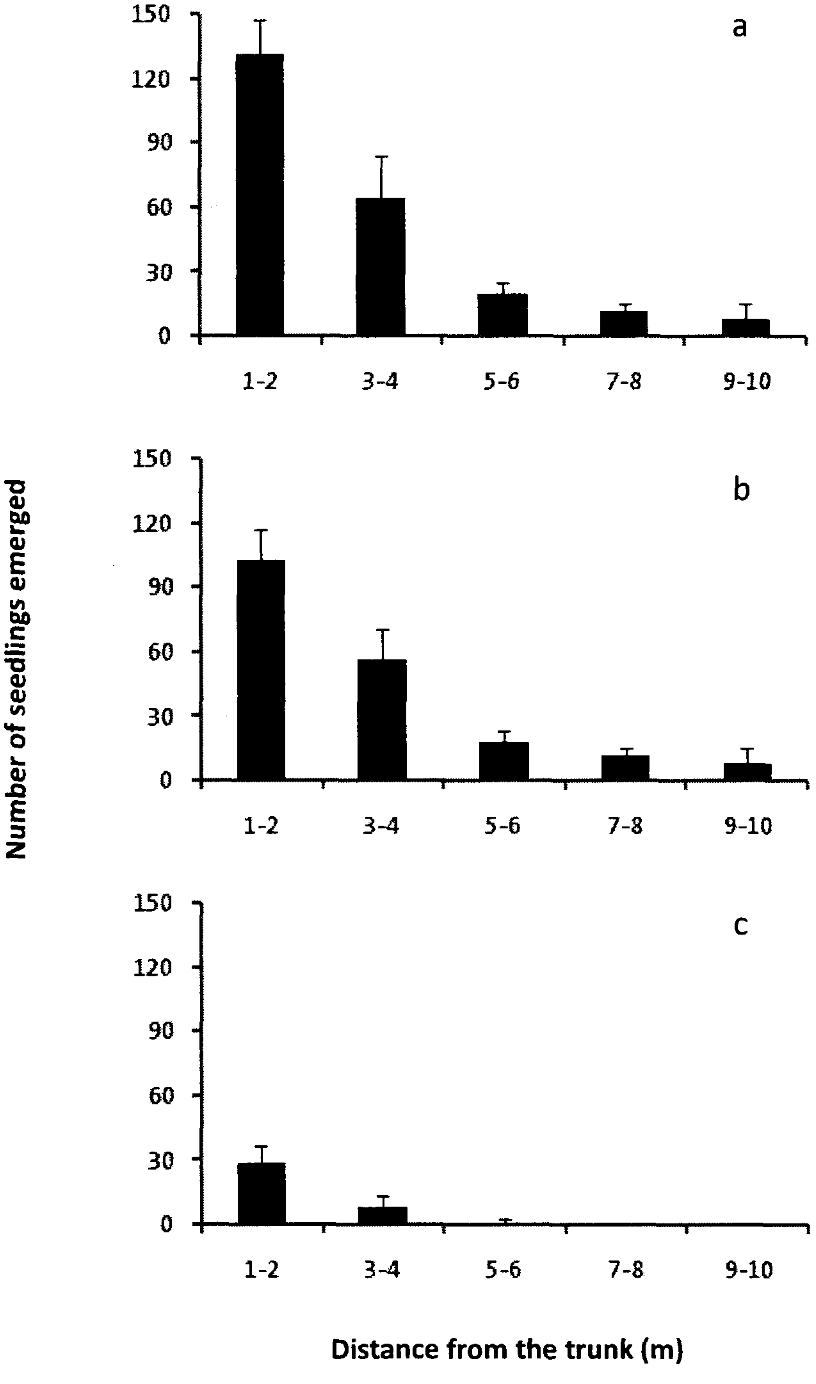


Fig. 5.2. Pattern of occurrence of seedlings of *T. wallichiana* emerged (or seeds germinated) in quadrats located at increasing distance from the tree trunk for the data averaged for the years 2006, 2007, 2008 and 2009 for all ten trees (Fig. 5.2a), for trees T1 through T7 from Mawphlang site (Fig. 5.2b) and for T8 through T10 for Moodymmai site (Fig. 5.2c). The error bars are based on standard deviation values and indicate the variability among years.

Table 5.7. Variability in number of seedlings of *T. wallichiana* emerged (or seeds germinated) in different years (2006, 2007, 2008 and 2009) and from different trees (T1 through T10) in Meghalaya. The trees T1 through T7 are from Mawphlang site and T8 through T10 from Moodymmai site.

Tree number	Year				Mean ± SD
	2006	2007	2008	2009	
T1	74	68	101	75	79.5 ± 14.7
T2	26	65	61	38	47.5 ± 18.6
T3	19	22	16	14	17.8 ± 3.5
T4	20	14	16	12	15.5 ± 3.4
T5	5	0	0	0	1.3 ± 2.5
T6	5	0	0	0	1.3 ± 2.5
T7	30	34	34	38	34.0 ± 3.3
T8	10	26	21	24	20.3 ± 7.1
T9	12	15	14	17	14.5 ± 2.1
T10	0	7	5	0	3.0 ± 3.6
Mean ± SD	20.1 ± 21.3	25.1 ± 24.3	26.8 ± 31.7	21.8 ± 23.5	

A graphic representation of the mean number of seedlings in years 2006, 2007, 2008 and 2009 shows only little variability (which is statistically insignificant) for all ten trees (Fig. 5.3a), for seven trees of Mawphlang site (Fig. 5.3b) and for three trees of Moodymmai site (Fig. 5.3c).

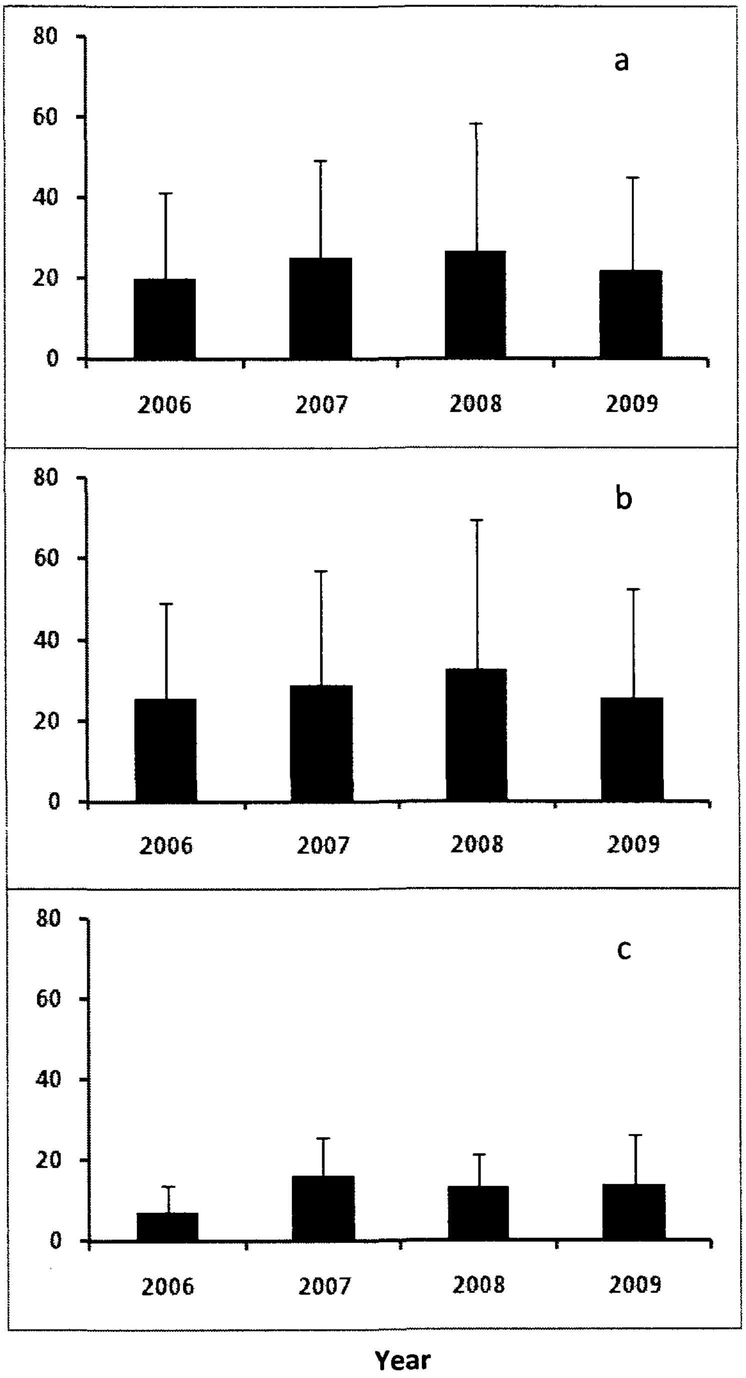


Fig. 5.3. The mean number of seedlings of *T. wallichiana* produced per tree in the years 2006, 2007, 2008 and 2009. The averages are for all ten trees (Fig. 5.3a), for trees T1 through T7 from Mawphlang site (Fig. 5.3b) and for T8 through T10 for Moodymmai site (Fig. 5.3c). The error bars are based on standard deviation values and indicate the variability among trees.

5.3.3 Seedling dynamics

The seedlings emerged under each tree in the years 2006, 2007, 2008 and 2009 were tagged individually and tracked to study their survival in the field conditions. The survival of seedlings emerged in 2006 was followed for three years, of seedlings emerged in 2007 was followed for two years and of seedlings emerged in 2008 was followed for one year (Table 5.8). The values of the seedlings surviving in the subsequent years were also worked out as percentage of the seedlings recruited and these values are presented in Table 5.9. The values for the seedlings recruited under each tree were pooled for all ten trees (T1 through T10), for trees T1 through T7 from Mawphlang site and for T8 through T10 for Moodymmai site and are presented both in absolute numbers and in percentage values (Table 5.10).

The survival of seedlings emerged in 2006, after one year of recruitment varied widely for individual trees: maximum 70% for T7 and minimum zero for T6 at Mawphlang site, and maximum 10% for T8 and zero for T10 at Moodymmai site (Table 5.9). Hence, survival of seedlings ranged from zero to 70% for all ten trees with an overall average of only one-third seedling surviving in the first year of recruitment (Table 5.10). At the end of second year, only one-fourth of the seedlings survived and at the end of third year only one-sixth of seedlings survived (Table 5.19).

The survival of seedlings emerged in 2007, after one year of recruitment, was even lower, i.e., only 6% which declined further to only 1% at the end of second year. The survival of seedlings emerged in 2008 was nearly 10% after one year of recruitment (Table 5.10).

Hence, the individual trees varied in terms of survival of seedlings. The trees T3, T4 and T7 showed better survival than others. Also, survival of seedlings emerged in different years (cohorts) also varied: those emerged in 2006 survived the most (Table 5.9).

Table 5.8. Survival of seedlings of *T. wallichiana* emerged in different years (2006, 2007, 2008 and 2009) from different trees (T1 through T10) in Meghalaya. The trees T1 through T7 are from Mawphlang site and T8 through T10 from Moodymmai site. The values in bold face indicate the cohort of seedlings emerged in respective years and arrow indicates the remaining seedlings of that cohort in the next year.

Tree number	2006		2007		2008		2009
T1	**74**	→	16	→	11	→	4
			68	→	3	→	1
					101	→	7
							75
T2	**26**	→	5	→	4	→	2
			65	→	2	→	0
					61	→	3
							38
T3	**19**	→	9	→	8	→	6
			22	→	6	→	1
					16	→	4
							14
T4	**20**	→	11	→	11	→	11
			14	→	3	→	1
					16	→	3
							12
T5	**5**	→	2	→	0	→	0
			0	→	0	→	0
					0	→	0
							0
T6	**5**	→	0	→	0	→	0
			0	→	0	→	0
					0	→	0
							0
T7	**30**	→	21	→	14	→	8
			34	→	2	→	0
					34	→	7
							38
T8	**10**	→	1	→	1	→	1
			26	→	0	→	0
					21	→	1
							24
T9	**12**	→	1	→	0	→	0
			15	→	0	→	0
					14	→	0
							17
T10	**0**	→	0	→	0	→	0
			7	→	0	→	0
					5	→	0
							0

Table 5.9. Percentage survival of seedlings of *T. wallichiana* emerged in different years (2006, 2007, 2008 and 2009) from different trees (T1 through T10) in Meghalaya. The trees T1 through T7 are from Mawphlang site and T8 through T10 from Moodymmai site. The values in bold face indicate the cohort of seedlings emerged in respective years and arrow indicates the remaining seedlings of that cohort in the next year.

Tree number	2006		2007		2008		2009
T1	**100**	→	21.6	→	14.9	→	5.4
			100	→	4.4	→	1.5
					100	→	6.9
							100
T2	**100**	→	19.2	→	15.4	→	7.7
			100	→	3.1	→	0.0
					100	→	4.9
							100
T3	**100**	→	47.4	→	42.1	→	31.6
			100	→	27.3	→	4.6
					100	→	25.0
							100
T4	**100**	→	55.0	→	55.0	→	55.0
			100	→	21.4	→	7.1
					100	→	18.8
							100
T5	**100**	→	40.0	→	0.0	→	0.0
			0.0	→	0.0	→	0.0
					0.0	→	0.0
							0.0
T6	**100**	→	0.0	→	0.0	→	0.0
			0.0	→	0.0	→	0.0
					0.0	→	0.0
							0.0
T7	**100**	→	70.0	→	46.7	→	26.7
			100	→	5.9	→	0.0
					100	→	20.6
							100
T8	**100**	→	10.0	→	10.0	→	10.0
			100	→	0.0	→	0.0
					100	→	4.8
							100
T9	**100**	→	8.3	→	0.0	→	0.0
			100	→	0.0	→	0.0
					100	→	0.0
							100
T10	**0.0**	→	0.0	→	0.0	→	0.0
			100	→	0.0	→	0.0
					100	→	0.0
							0.0

The survival of seedlings emerged from the trees from two sites, viz., Mawphlang and Moodymmai, showed a significant variation (Table 5.10) and site Mawphlang fared better than site Moodymmai.

Table 5.10. Survival of seedlings of *T. wallichiana* recruited (ib bold face) and survived (in normal face) in different years (2006, 2007, 2008 and 2009) for all ten trees (T1 through T10), for trees T1 through T7 from Mawphlang site and for T8 through T10 for Moodymmai site.

Tree number	2006		2007		2008		2009
Number of seedlings recruited							
All ten trees							
T1 through T10	**201**	→	66	→	49	→	32
			251	→	16	→	3
					268	→	25
							218
Trees of Mawphlang (T1 through T7)							
T1 through T7	**179**	→	64	→	48	→	31
			203	→	16	→	3
					228	→	24
							177
Trees of Moodymmai (T8 through T10)							
T8 through T10	**22**	→	2	→	1	→	1
			48	→	0	→	0
					40	→	1
							41
Values as percentage of seedlings recruited							
All ten trees							
T1 through T10	**100**	→	32.8	→	24.4	→	15.9
			100	→	8.0	→	1.5
					100	→	12.4
							100
Trees of Mawphlang (T1 through T7)							
T1 through T7	**100**	→	35.8	→	26.8	→	17.3
			100	→	8.9	→	1.7
					100	→	13.4
							100
Trees of Moodymmai (T8 through T10)							
T8 through T10	**100**	→	9.1	→	4.5	→	4.5
			100	→	0	→	0
					100	→	4.5
							100

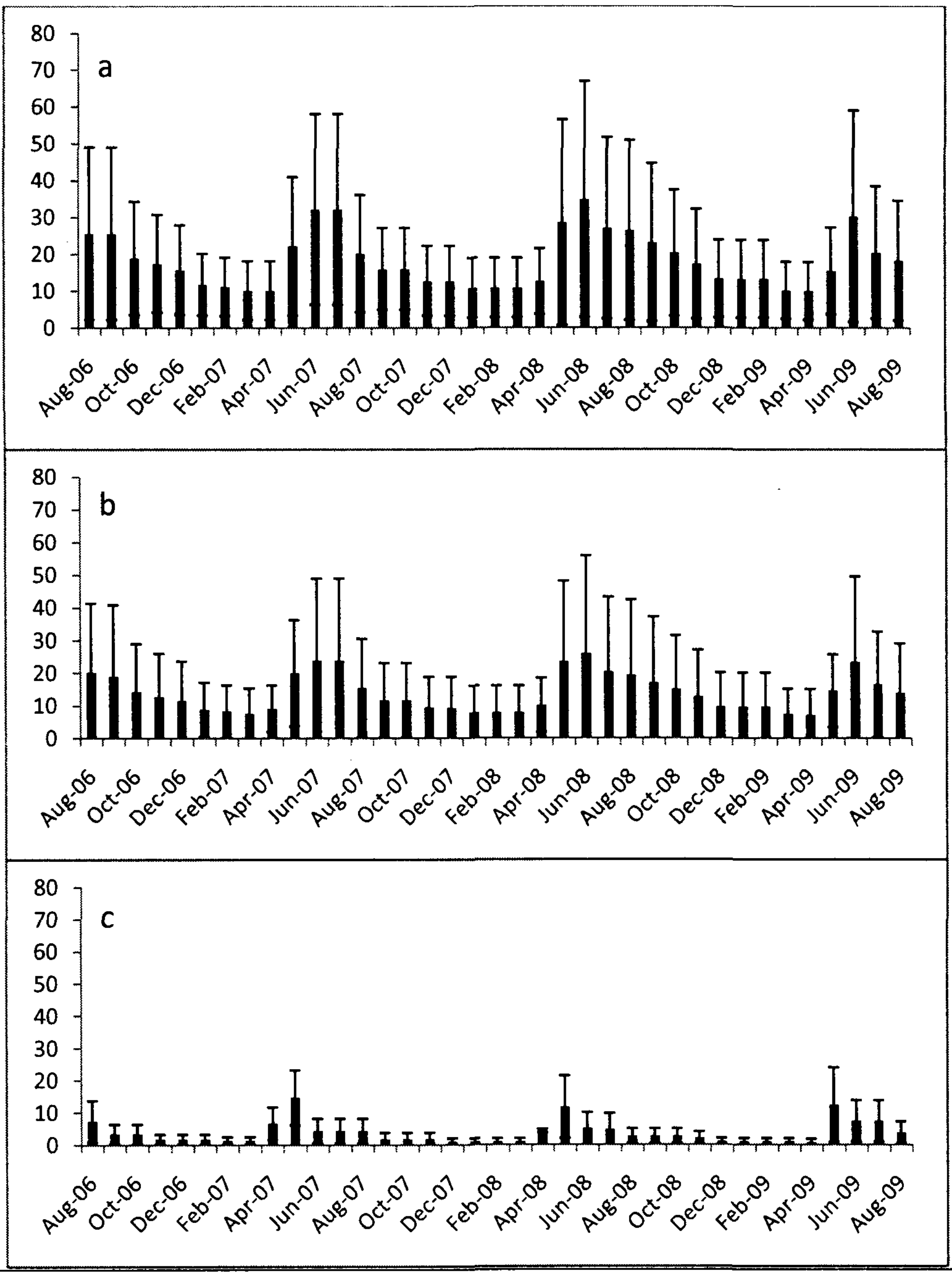


Fig. 5.4. Monthly seedling dynamics of *T. wallichiana* between August, 2006 and August, 2009 for all ten trees (Fig. 5.4a), for trees T1 through T7 from Mawphlang site (Fig. 5.4b) and for T8 through T10 for Moodymmai site (Fig. 5.4c). The error bars are based on standard deviation values and indicate the variability among trees.

5.3.4. Seedling growth

Growth of *T. wallichiana* seedlings, in terms of height (cm) as well as collar thickness (cm) was found to be extremely slow. The average height increment of the seedlings varies from 1.0 – 2.0 cm per year and collar thickness varies from 0.2 – 0.25 cm per year during the study period (Fig 5.5a and 5.5b).

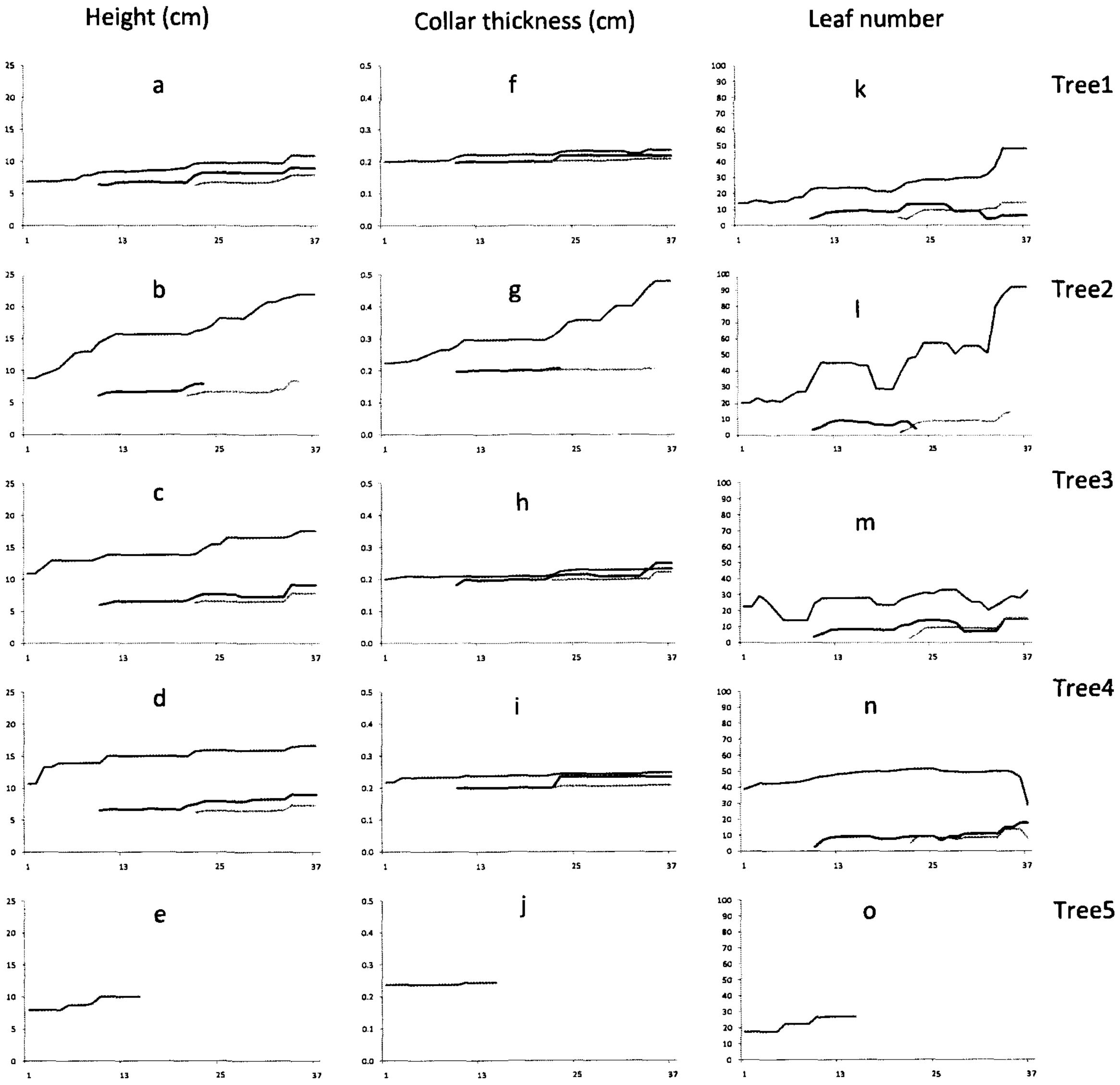


Fig. 5.5a. Temporal pattern of growth of seedlings of *T. wallichiana* between August, 2006 and August, 2009. X axis represents time (in months) for three years, and Y axis representsseedling height (for figures a, b, c, d and e), collar thickness (for f, g, h, i and j) or leaf number (for k, l, m, n and o) of Trees 1, 2, 3, 4 and 5.

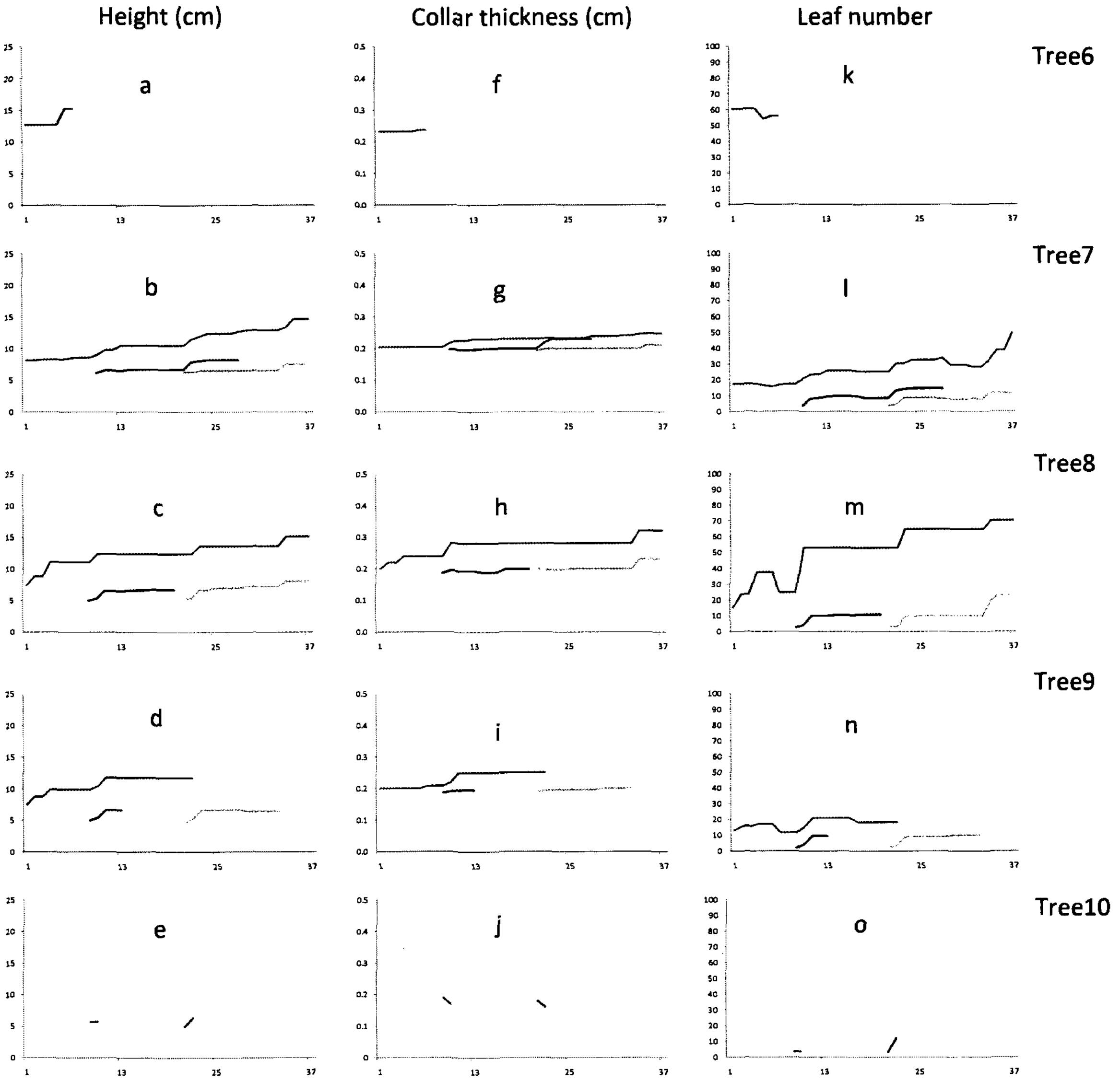


Fig. 5.5b. Temporal pattern of growth of seedlings of *T. wallichiana* between August, 2006 and August, 2009. X axis represents time (in months) for three years, and Y axis representsseedling height (for figures a, b, c, d and e), collar thickness (for f, g, h, i and j) or leaf number (for k, l, m, n and o) of Trees 6, 7, 8, 9 and 10.

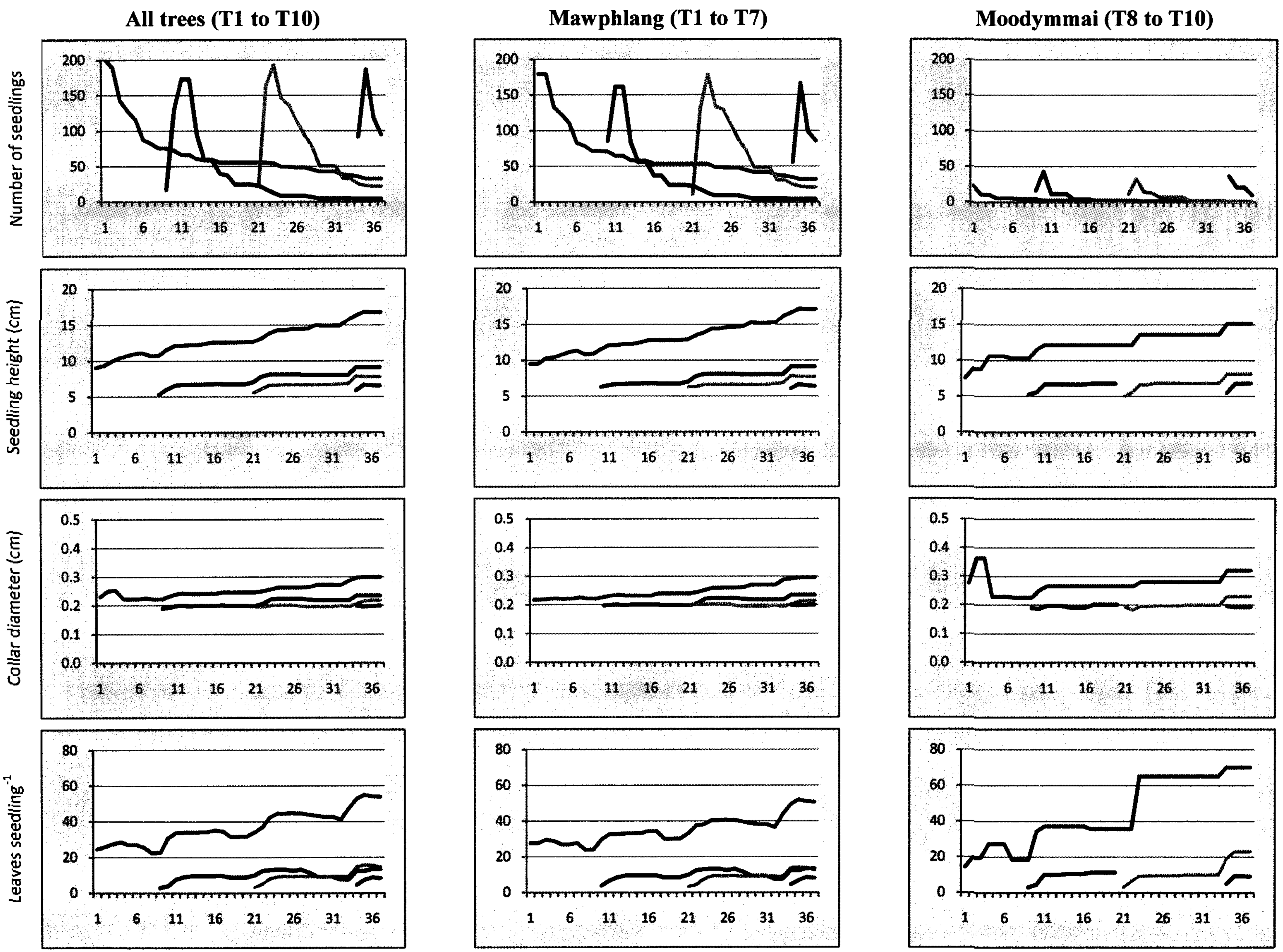


Fig. 5.6. Seedling dynamics (number of seedlings) and seedling growth in terms of height (cm), collar diameter (cm) and number of leaves seedling^{-1} for seedlings recruited in 2006 (blue), 2007 (red), 2008 (green) and 2009 (purple) over 36 months (August, 2006 to August, 2009).

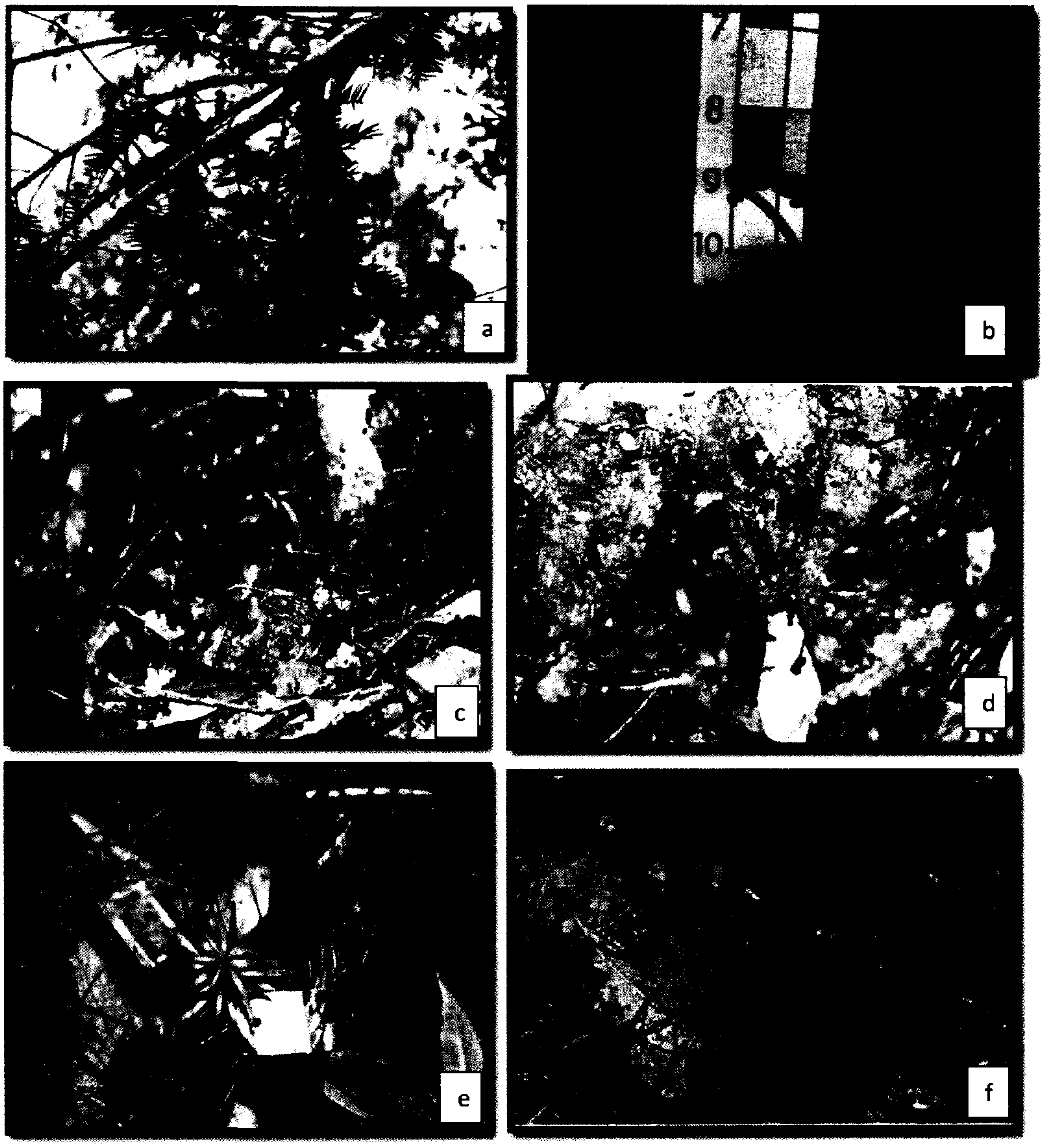


Fig 5.7. (a) Fruiting, (b) epigeal germination, (c, d) seeds and seedling emergence, and (e, f) juvenile seedlings of *T. wallichiana* on the forest floor.

5.4. Discussion

T. wallichiana fruits fall on the ground near the tree trunk establishing a seed bank. These seeds germinate profusely during favorable climate. Presence of seedlings in all directions in all the ten trees (Tables 5.2, 5.3, 5.4 and 5.5) during the entire study period shows that they are distributed all around the mother tree. The regeneration of *T. wallichiana* seedlings occurs under the crown of the mother trees depending on the manner in which the seeds would fall. This finding is in accordance with the findings of Minore *et al.* (1996) and Iszkulo and Boratynski (2004). The crown length does not extend beyond 7 m in all the ten trees (Table 2.5), yet seedlings, though less, are found at such distance. This clearly indicates that the seeds, being light (250 mg) fall and then drop-and-roll a little distance. Minore *et al.* (1996) also reported that most yew seeds not consumed by birds or mammals tend to drop from the crown and remain nearby with little local dispersal.

There were more number of seedlings near the bole of the parent tree which explains that seeds are concentrated near the tree bole and decreases as we move away from the tree. At Mawphlang, seedlings were found till a distance of 10 m, but at Moodymmai no seedlings occurred beyond 4 m. The mean number of seedlings for all ten trees was 130.8 at a distance of 1-2 m which decreased to 64.3 at a distance of 3-4 m indicating that the seeds occurring at a distance of 2 m are nearly double that of 4 m from the tree bole. After a distance of 4 m from the tree bole there is a drastic reduction in the mean number of seedlings which is only 1/4th the mean of 1-2 m distance. The extreme less seedlings after a distance of 4 m and above explains the fact that seeds at such distances are less dispersed, as they may be picked up by birds from the exterior of the canopy. Overall, the seedlings are present in all directions and in all the years showing a significant effect of distance from the trunk (F = 76.5, $p<0.01$).

There was a wide variation in the number of seedlings produced by individual ten trees (F = 37.1, $p<0.01$). During the study period we observed that all the ten trees did not show fruiting; some variation was observed in the number of fruiting years among them which may be because of some biological or ecological factors. Di-Fazio *et al.* (1997) and Pilz (1996a) stated that flowering and seed production for Pacific yew in western Oregon was found to be related to overstory openness and tree vigor. However, seeds were present in the soil around the trees which did not show fruiting during the study period. This may be because they had fruited in the earlier years and the seeds have remained viable even after many years.

It is reported that yew seeds have been found to survive in a soil seed bank for several years (Minore *et al.* 1996). Yew seeds can be stored at 18 to 20°C without losing viability, provided that they have reached sufficient maturity, and that they probably will remain viable for decades under these conditions (Walters-Vertucci *et al.* 1996). Minore (1994) and Minore *et al.* (1996) also reported that viable seeds of Pacific yew have been found in soil seed banks for several years. This character of the seeds may be responsible for the successive regeneration every year, in Tree 3, 4, 9 and 10 even if they did not fruit during the study period (Table 5.7). Tree 1 and 7 fruited every year, Tree 2 fruited only in 2007, Tree 8 did fruit, but towards the end of the study period, i.e. in 2009 while the rest did not show fruiting. Hence, Tree 1, 2, 7 and 8 has higher mean number of seedlings (79.5, 47.5, 34.0 and 20.3 per year) compared to the other trees (Table 5.7). However, Tree 5 and 6 did not show regeneration every year which may be because of disturbances like grazing. Tree 1 and 7 fruited every year but there is a variation in the mean number of seedlings between them. Tree 1 shows the maximum mean number of seedlings (79.5 per year) which is twice that of Tree 7 (34.0 per year). This may be because Tree 1 has longer crown length (11.7 m north to south and 11.8 m east to west) compared to that of Tree 7 (6.8 m north to south and 5.1 m east to west) (Table 5.1). Tree 2 showed fruiting only once, i.e., in 2007 but it has higher mean number of seedlings than tree 7 and Tree 8. This might be due to the differences in seed germination and seedling mortality associated with aspect, shading and solar radiation (Minore *et al.* 1996).

During the study, we observed that most of the seedlings died just after 1-2 months after regeneration. Tables 5.8 and 5.9 show a sudden decrease in the seedling number in the same year it regenerated. The survival percentage decreased to less than three-fourth of the total in most of the trees, while some are left with no seedlings at all, in the first year itself. However, seedlings recorded in 2006 showed a higher survival percentage than the 2007 and 2008 recruits because some of them are already established when the study was conducted. The value as percentage of seedlings recruited is given in ~~T~~table 5.10. It is observed that out of the 100 percent of seedlings emerged in 2006; only 66 survived in 2007, out of which only 49 in 2008 and 32 in 2009 remained.

Regeneration occurs during the month of May-June; hence more is the density of seedlings during these months. This is followed by a sudden drop for the first few months after which the density decreases slowly till the pre-monsoon season. With the onset of the next monsoon season, the density increases again and the same trend repeats again year after year. This continuous trend of rise and fall in the seedling density in a cyclic manner, structure (Fig 5.5). There is massive death of the seedlings mainly during the monsoon season which can be assumed that they cannot withstand the excessive moisture of the season. Besides survival it has also been observed that the seedlings show very

Incomplete sentence

limited growth, both, in height as well as collar thickness (Fig 5.5a, b) which is in accordance with the findings of Minore *et al.* (1996) and Thomas and Polwart (2003).

From the above findings, it can be assumed that yew seeds germinate abundantly in natural forests but do not survive for long after gemination. The seed does germinate but the seedling survival and growth is limited. It may be because of some intrinsic factors which may be genetic, allelopathic, or extrinsic factors such as grazing, fire or human disturbance. During the study, it was observed that Moodymmai forest, being a community forest, is highly disturbed due the presence of paddy fields and human settlement in the adjacent areas. Moreover it is a pine-dominant forest thus regeneration of seedlings is hampered. However, Mawphlang forest, being a sacred-grove and a pure forest, has not been infested by pines, yet survival of most of the seedlings did not last long. The reason may be due to the presence of excessive *T. wallichiana* seeds and leaf litter buried in the soil layers years after years around the mother trees which may have had a negative effect on their growth and survival.

Our findings are in concurrence with the findings of Del Moral and Cates (1971), Iszkulo and Boratynski (2004), Piovesan *et al.* (2009) who reported that mature yew trees inhibit self-regeneration, seedlings growth and survival. While Thomas and Polwart (2003) reported that *T. baccata* emits allelopathic substances which diminished the seed germination and eliminated the seedlings in their first growth stages. According to Singh *et al.* (1999), it was reported that many of the gymnospermous trees exhibit ~~A~~allelopathy and majority of them are, however, conifers. Of the seven taxonomic families of conifers, six families, *viz.*, Araucariaceae, Cupressaceae, Pinaceae, Podocarpaceae, Taxaceae, and Taxodiaceae are reported to show this phenomenon. The allelochemicals released from the tree bark, needles, litter and root/mycorrhizal exudates remain in the soil and interfere with the germination of seeds or growth and development of young seedlings thus preventing their natural regeneration. Autoinhibition due to the allelopathy has been reported in *Abies balsamea* (Thibault *et al.* 1982), *Araucaria cunninghamia* (Bevege 1968), *Cunninghamia lanceolata* (Zhang 1993*), Picea abies* (Gallet 1994, Pellissier 1994)*, Picea mariana* (Thomas 1974*),* and *Pinus radiata* (Chu-Chou 1978). In some cases phenolic compounds particularly p-hydroxy acetophenone have been implicated (Gallet 1994). Studies on allelopathy of some species of gymnosperms have been done but no information is available on *T. wallichiana* till date.

CHAPTER VI

SEED GERMINATION AND SEEDLING SURVIVAL OF TAXUS WALLICHIANA

CHAPTER VI

SEED GERMINATION AND SEEDLING SURVIVAL OF *Taxus wallichiana*

6.1 Introduction

The seeds of most *Taxus* species are difficult to germinate as compared to other coniferous species (Pilz 1996a,b). *T. wallichiana* also shows poor regeneration in natural conditions (Rikhari *et al.* 1998, Chapter V in this study). *T. wallichiana* has a long seed dormancy period, 2-3 years (Chee 1994). Little information is available on the frequency of good seed crops among the yews, but most species produce some seeds almost every year (Chadwick and Keen 1976, Harlow and Harrar 1958). Flowering and seed production in Pacific yew in western Oregon was related to overstory openness and tree vigor (DiFazio *et al.* 1997, Pilz 1996a). However, predation of fruit on trees in the open was higher, limiting seed production (DiFazio *et al.* 1998). In dioecious species, good seed crops are produced where there is a good intermixture of male and female trees. Pollen may limit seed production in some populations of Canada yew where deer browse has created widely spaced plants that produce little pollen (Allison 1990).

Yew seeds are orthodox in storage characteristics and if stored at low temperature, may retain viability for several years. The viability of yew seeds can be maintained for 5 or 6 years if they are dried just after extraction at room temperature for 1 or 2 weeks and then stored in sealed containers at 1° to 2° C (Heit 1967).

Yew seeds are slow to germinate; natural germination usually does not take place until the second spring after seed fall (Suszka 1978). Viable yew seeds of Pacific yew have been found in soil seed banks for several years (Minore 1994). Although a variety of birds and small mammals eat, digest, and disperse yew seeds (Bartkowiak 1978), germination does not appear to be hastened by their passing through the alimentary canal of birds. Yew seeds have a strong but variable dormancy that can be broken by warm-plus-cold stratification (Suszka 1978). One recommendation is to hold the seeds for 150 to 210 days at 16 to 18 °C, then for 60 to 120 days at 2 to 5 °C (Heit 1967, 1969).

Germination of yew seeds is epigeal. Because of the deep dormancy of the seeds, germination will be sporadic over the course of several years. Germination percentages after the first year do not indicate the potential of the seeds to germinate, (Heit 1969, Pilz 1996b). Official testing rules recommend tetrazolium staining as the first choice in testing viability, followed by germination in sand at 30° C for 28 days after 270 days of stratification (ISTA 1993).

The literature reveals that several methods have been adopted to improve seed germination of *Taxus*. However, the fact remains that *Taxus* seeds germinate after a minimum of one year and no literature is available which shows an improvement or enhancement in its germination time. Treating the seeds in alternate warm and cold environment has been recommended but its success varies.

The objectives of this study were: 1) to study morphometric characteristics of fruits (fruit weight and fruit dimensions) and seeds (seed weight and seed dimensions), 2) to determine the effect of morphometric characteristics on germination percentages and seedling survival (seedling dynamics), and 3) to quantify early seedling growth pattern.

6.2 Materials and Methods

6.2.1 Fruit and seed extraction and measurement of morphometric traits

Fruits of *T. wallichiana* were collected when ripened in December from Mawbeh, Mawphlang, Moodymmai, PHE, and BSI-Umiam. The details of fruit collection and tree characteristics from the respective sites are given in Table 6.1. The fruits were weighed immediately after collection to avoid moisture loss. Simultaneously, fruit dimensions (length and width) were measured before shrinkage.

Table 6.1. The characteristics of the trees which were the source of fruits in different years (2006 to 2009).

Tree #	Girth (cm)	Height (m)	Location	Year of collection			
				2006	2007	2008	2009
T1	90.2	11.0	Mawphlang	√			
T2	240.1	18.5	Mawphlang	√	√	√	√
T3	28.0	5.5	Mawbeh	√		√	
T4	95.5	6.0	PHE			√	√
T5	72.4	8.5	BSI1-Umiam			√	√
T6	40.1	8.0	BSI2-Umiam			√	
T7	38.3	6.4	BSI3-Umiam			√	
T8	130.2	7.0	BSI4-Umiam			√	
T9	119.0	12.0	Moodymmai				√

Each fruit contains only one seed. The seeds were extracted by removing pulp (aril). The seeds were weighed fresh and their dimensions (length, width and thickness) were measured using a caliper. The collected seeds were stored at room temperature (5-15°C) for 90 days and then transferred to a refrigerator for 60 days (0-5°C) in order to attain a warm-and-cold stratification (Suszka 1978).

The biometric data of eight quantitative traits (fruit weight, fruit length, fruit diameter, fruit thickness, seed weight, seed length, seed diameter and seed thickness) were subjected to statistical analyses. Microsoft Excel and STATISTICA version 6 were used to calculate numerical characteristics such as sample size (n), range (minimum and maximum), arithmetic mean value, standard deviation (SD) and coefficient of variation (CV) of a trait. The numerical characteristics were determined at the level of individual tree (seven trees), and for entire gamut of fruits and seeds (all trees) together. Analysis of variance (ANOVA) was carried out to test the null hypothesis that there are no significant differences between group means. R. A. Fisher's least significant difference (LSD) test was used to determine the differences or similarities between pairs of means. Simple linear regression models were fitted to the scatters of two traits. Pearson's correlation coefficient was used to depict the relationship between the two traits.

6.2.2 Seed viability evaluation

For testing viability, an incision is carefully made up to one-half of its thickness with a sharp blade to expose the internal tissue which consists of the embryo and endosperm. If an embryo is opaque and developed, with visible cotyledon buds, and gametophyte tissue is white and fills the seed cavity, the seed can be considered mature. The seed is then soaked in 0.1% TTC (Tetrazolium Chloride solution) for 24-48 hours and then examined for staining. If both the embryo and gametophyte are stained, the seed is considered viable (Edward 1987).

6.2.3 Seed sowing and seedling growth in nethouse

Sowing was done during the spring season (May), of 2009 for 2010 for seeds collected respectively in 2008 and 2009. The seeds were sown in individual polybags filled with a mixture of garden soil and sand in 1:1 ratio. The polybags were housed in a nethouse and watered regularly to maintain soil moisture. The polybags were observed at a regular interval of 3 days to notice germination. When first occurrence of germination was noted, the polybags were surveyed daily and newly germinated seeds were recorded. The observation for germination in polybags continued for two years. Hence, the seeds sown in 2009 were observed until 2011 and the seeds sown in 2010 were observed until 2012.

6.2.4 Seed sowing and germination by pit-burial method

The seeds collected in 2007 were sown immediately after collection in December, 2007. A 'pit-burial' method was devised for sowing of seeds. In this method, a pit of 120 cm length and 30 cm width with a depth of 40 cm was dug in the Botanical garden of the North-Eastern Hill University, Shillong. A 10 cm thick layer of sand was laid at the bottom of the pit. The seeds were placed over the sand such that the seeds were spread apart by at least one inch (2.5 cm) from each other. About 2 cm thick layer of sand was laid over the seeds. The rest of the pit was filled with decomposing litter up to the ground level. The pit was watered periodically to maintain moisture.

How many seeds were [illegible]

The seeds in the pit were observed at weekly interval until first trace of cracking of seed coat was found. Another freshly collected seedlots was also sown in December 2007, in pits, but with home-garden soil mixed with decomposed as well as fresh leaf litter. In one half of the pit, seeds were sown along with the arils intact, while the other half were sown with seeds with the arils removed. Another fresh seedlots of 2007 were similarly sown in December 2007 in *Taxus* growing areas of Moodymmai and Mawphlang (outside Sacred grove). This was done keeping in mind the fallen seeds buried in the soil of Mawphlang site which germinated profusely.

6.3 Results

6.3.1 Seed viability

The seeds of *T. wallichiana* showed good viability for all the sites (Table 6.2). After storage for six months in the laboratory, viability declined significantly from 85.2% to 58.7% (Table 6.2). The viable seeds were identifiable through TTC test (Fig. 6.1).

Table 6.2. Viability test of *T. wallichiana* seeds collected from five different sites in Meghalaya.

Site	Fresh seed		Seeds stored for six months	
	Seeds tested (number)	Viable seeds (%)	Seeds tested (number)	Viable seeds (%)
BSI-Umiam	100	80.3	30	66.7
Mawbeh	100	93.1	30	36.7
Mawphlang	100	91.0	30	70.0
Moodymmai	100	79.4	30	63.3
PHE	100	97.2	30	56.7
All sites	500	85.2	150	58.7

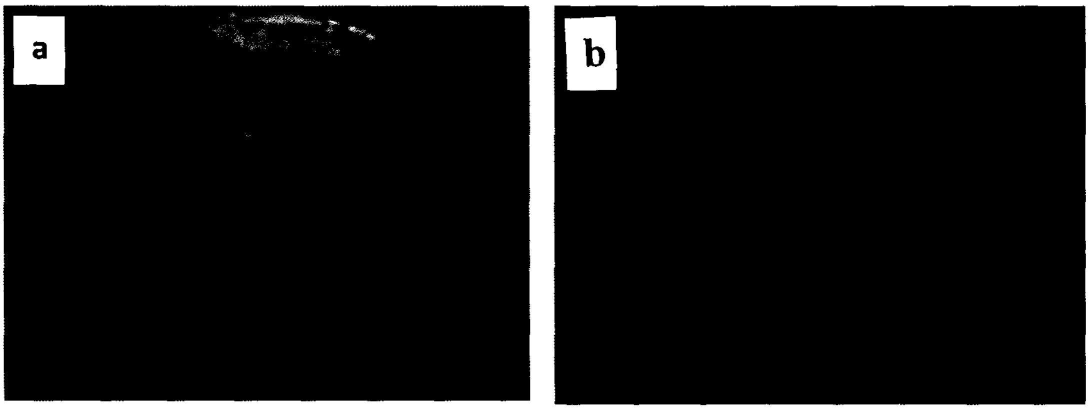


Fig. 6.1. Determination of the viability of a seed by TTC test. A deep pink stained cotyledon-embryo mass indicates viability (a) and a poorly stained or not stained mass indicates non-viability of the seeds (b).

6.3.2 Fruit characteristics

The fruit weight showed significant variation among trees in all the years, i.e., 2006, 2008 and 2009 (Table 6.3). Hence, mean fruit weight varied could vary from tree-to-tree. The maximum fruit weight in all the three years was exhibited by T2 (270 mg in 2006, 274 mg in 2008 and 258 mg in 2009). An individual fruit's weight ranged up to four-fold, from 101.1 to 398.5 mg in 2006, from 123.5 to 399.2 mg in 2008 and from 111.2 to 387.1 mg in 2009 (Table 6.3). The mean fruit weight was 257.8 mg in 2006, 252.6 mg in 2008 and 227.4mg in 2009 (Fig. 6.3). The yearly variation in mean fruit weight was significant following one-way ANOVA results. The variation between 2006 and 2008 was insignificant, but the variation between 2006 and 2009, and between 2008 and 2009 was significant. Thus ~~Hence, m~~ M mean fruit weight also varied ~~could vary~~ from year-to-year. A mean across the years for all fruits (n=2487) showed 246.7 mg fruit weight. The coefficient of variation ranged from 11.6% to 29.6% among trees and it was 22% for all fruits of all years.

The fruit length showed significant variation among trees in both the years, i.e., 2008 and 2009 (Table 6.4). The data for the year 2006 were not available for fruit length. Why? Strange? The maximum fruit length was exhibited by T8 in 2008 (8.7 mm) and T2 in 2009 (9.12 mm). Hence, mean fruit length varied ~~could vary~~ from tree-to-tree. An individual fruit's length ranged up to less than two-fold, from 5.02 to 9.80 mm in 2008 and from 8.04 to 9.98 mm in 2009 (Table 6.4). The mean fruit length was 8.70 mm in 2008 and 9.10 mm in 2009 (Fig. 6.3). The yearly variation in mean fruit length was significant following one-way ANOVA results. The variation between 2008 and 2009 was significant. Thus ~~Hence~~, mean fruit length also varied ~~could vary~~ from year-to-year. A mean across the years for all fruits (n=2487) showed 8.09 mm fruit length. The coefficient of variation ranged from 4.31% to 10.02% among trees and it was 12.37% for all fruits of all years.

Table 6.3. Tree-to-tree variation in 2006, 2008 and 2009 and year-to-year variation in **fruit weight (mg)** of *T. wallichiana*.

Tree and site	N	Minimum	Maximum	Mean ± SD	CV (%)
Tree-to-tree variation in 2006					
T1, Mawphlang	227	101.1	344.0	231.3 ± 48.6	21.0
T2, Mawphlang	493	145.5	398.5	270.0 ± 47.2	17.5
T3, Mawbeh					
One-way Anova				F=102.6, p<0.01	
Tree-to-tree variation in 2008					
T2, Mawphlang	186	134.1	398.1	274.4 ± 59.2	21.6
T3, Mawbeh	157	123.5	310.0	193.9 ± 57.3	29.6
T4, PHE	250	132.2	399.2	255.3 ± 60.3	23.6
T5, BSI-Umiam	138	153.2	398.6	256.7 ± 44.1	17.2
T6, BSI-Umiam	110	151.1	307.7	241.6 ± 31.5	13.1
T7, BSI-Umiam	69	189.5	399.1	288.7 ± 45.5	15.8
T8, BSI-Umiam	126	152.4	398.6	273.1 ± 46.1	16.9
One-way Anova				F=47.6, p<0.01	
Tree-to-tree variation in 2009					
T2, Mawphlang	200	141.8	387.1	258.2 ± 51.9	20.1
T4, PHE	220	111.2	322.1	208.2 ± 40.8	19.6
T5, BSI-Umiam	180	137.8	334.7	214.0 ± 29.7	13.9
T9, Moodymmai	131	183.9	317.1	230.8 ± 26.7	11.6
One-way Anova				F=64.2, p<0.01	
Year-to-year variation					
All-2006	720	101.1	398.5	257.8 ± 50.9	19.7
All-2008	1036	123.5	399.2	252.6 ± 59.3	23.5
All-2009	731	111.2	387.1	227.4 ± 44.7	19.6
One-way Anova				F=71.0, p<0.01	
All years (2006+2008+2009)					
All seeds	2487	101.1	399.2	246.7 ± 54.4	22.0

Table 6.4. Tree-to-tree variation in 2006, 2008 and 2009 and year-to-year variation in **fruit length (mm)** of *T. wallichiana*.

Tree and site	N	Minimum	Maximum	Mean ± SD	CV (%)
Tree-to-tree variation in 2006					
T1, Mawphlang	227				
T2, Mawphlang	493				
T3, Mawbeh	190				
One-way Anova					
Tree-to-tree variation in 2008					
T2, Mawphlang	186	6.40	10.39	8.34 ± 0.73	8.79
T3, Mawbeh	157	5.28	6.91	6.17 ± 0.27	4.31
T4, PHE	250	6.31	10.32	8.07 ± 0.72	8.92
T5, BSI-Umiam	138	5.54	9.90	7.60 ± 0.76	10.02
T6, BSI-Umiam	110	5.52	8.76	7.00 ± 0.55	7.86
T7, BSI-Umiam	69	6.78	10.41	8.12 ± 0.72	8.89
T8, BSI-Umiam	126	5.02	9.80	8.70 ± 0.62	7.16
One-way Anova				F=263.4, p<0.01	
Tree-to-tree variation in 2009					
T2, Mawphlang	200	8.04	10.70	9.12 ± 0.50	5.45
T4, PHE	220	6.19	9.66	8.22 ± 0.48	5.89
T5, BSI-Umiam	180	6.91	9.60	8.08 ± 0.47	5.77
T9, Moodymmai	131	8.04	9.98	9.19 ± 0.40	4.34
One-way Anova				F=271.6, p<0.01	
Year-to-year variation					
All-2006	910				
All-2008	1036	5.02	10.41	7.73 ± 1.03	13.36
All-2009	731	6.19	10.70	8.60 ± 0.68	7.92
One-way Anova				F=397.4, p<0.01	
All years (2006+2008+2009)					
All seeds	2487	5.02	10.70	8.09 ± 1.00	12.37

The fruit width showed significant variation among trees in both the years, i.e., 2008 and 2009 (Table 6.5). The data for the year 2006 were not available for fruit width. The maximum fruit width was exhibited by T2 in 2008 (8.35 mm) and by T2 in 2009 (8.70 mm). Hence, mean fruit width ~~could vary~~ varied from tree-to-tree. An individual fruit's width ranged up to less than two-fold, from 5.00 to 9.80 mm in 2008 and from 7.35 to 9.46 mm in 2009 (Table 6.5). The mean fruit width was 7.60 mm in 2008 and 8.49 mm in 2009 (Fig. 6.2). The yearly variation in mean fruit width was significant following one-way ANOVA results. The variation between 2008 and 2009 was significant. ~~Hence~~ Thus, mean fruit width ~~could vary~~ varied from year-to-year. A mean across the years for all fruits (n=2487) showed 7.63 mm fruit width. The coefficient of variation ranged from 3.79% to 13.77% among trees and it was 13.92% for all fruits of all years.

The fruit thickness showed significant variation among trees in both the years, i.e., 2008 and 2009 (Table 6.6). The data for the year 2006 were not available for fruit thickness. The maximum fruit thickness was exhibited by T4 in 2008 (8.60 mm) and T2 in 2009 (9.32 mm). The mean fruit thickness varied from tree-to-tree. An individual fruit's thickness ranged up to less than two-fold, from 4.72 to 7.79 mm in 2008 and from 6.29 to 8.81 mm in 2009 (Table 6.6). The mean fruit thickness was 6.38 mm in 2008 and 8.09 mm in 2009 (Fig. 6.2). The yearly variation in mean fruit thickness was significant following one-way ANOVA results. The variation between 2008 and 2009 was significant. Hence, mean fruit thickness ~~could vary~~ varied from year-to-year. A mean across the years for all fruits (n=2487) showed 6.39 mm fruit thickness. The coefficient of variation ranged from 5.13% to 16.16% among trees and it was 17.29% for all fruits of all years.

Table 6.5. Tree-to-tree variation in 2006, 2008 and 2009 and year-to-year variation in **fruit width (mm)** of *T. wallichiana*.

Tree and site	N	Minimum	Maximum	Mean ± SD	CV (%)
Tree-to-tree variation in 2006					
T1, Mawphlang	227				
T2, Mawphlang	493				
T3, Mawbeh	190				
One-way Anova					
Tree-to-tree variation in 2008					
T2, Mawphlang	186	6.31	10.00	8.35 ± 0.74	8.91
T3, Mawbeh	157	4.98	6.75	5.63 ± 0.38	6.66
T4, PHE	250	5.99	10.00	8.02 ± 0.87	10.82
T5, BSI-Umiam	138	5.67	9.47	7.49 ± 0.77	10.24
T6, BSI-Umiam	110	5.30	8.84	7.15 ± 0.64	8.98
T7, BSI-Umiam	69	5.17	9.92	7.68 ± 1.06	13.77
T8, BSI-Umiam	126	5.00	9.80	7.60 ± 0.89	11.70
One-way Anova				F=215.4, p<0.01	
Tree-to-tree variation in 2009					
T2, Mawphlang	200	7.65	9.81	8.70 ± 0.43	4.96
T4, PHE	220	5.12	8.05	6.90 ± 0.45	6.58
T5, BSI-Umiam	180	6.31	9.10	7.55 ± 0.50	6.67
T9, Moodymmai	131	7.35	9.46	8.49 ± 0.32	3.79
One-way Anova				F=713.6, p<0.01	
Year-to-year variation					
All-2006	910				
All-2008	1036	4.98	10.00	7.48 ± 1.15	15.44
All-2009	731	5.12	9.81	7.84 ± 0.87	11.14
One-way Anova				F=49.6, p<0.01	
All years (2006+2008+2009)					
All seeds	2487	4.98	10.00	7.63 ± 1.06	13.92

Table 6.6. Tree-to-tree variation in 2006, 2008 and 2009 and year-to-year variation in **fruit thickness (mm)** of *T. wallichiana*.

Tree and site	N	Minimum	Maximum	Mean ± SD	CV (%)
Tree-to-tree variation in 2006					
T1, Mawphlang	227				
T2, Mawphlang	493				
T3, Mawbeh	190				
One-way Anova					
Tree-to-tree variation in 2008					
T2, Mawphlang	186	4.67	8.22	6.10 ± 0.58	9.55
T3, Mawbeh	157	4.08	5.67	4.86 ± 0.31	6.47
T4, PHE	250	4.25	8.60	6.03 ± 0.74	12.30
T5, BSI-Umiam	138	4.59	7.95	6.01 ± 0.73	12.13
T6, BSI-Umiam	110	4.37	6.90	5.76 ± 0.55	9.55
T7, BSI-Umiam	69	4.12	8.46	6.20 ± 1.00	16.16
T8, BSI-Umiam	126	4.72	7.79	6.38 ± 0.61	9.63
One-way Anova				F=86.5, p<0.01	
Tree-to-tree variation in 2009					
T2, Mawphlang	200	6.29	9.32	8.18 ± 0.50	6.17
T4, PHE	220	4.22	7.08	5.95 ± 0.45	7.51
T5, BSI-Umiam	180	4.01	8.20	6.57 ± 0.52	7.89
T9, Moodymmai	131	6.29	8.81	8.09 ± 0.42	5.13
One-way Anova				F=1035.9, p<0.01	
Year-to-year variation					
All-2006	910				
All-2008	1036	4.08	8.60	5.89 ± 0.80	13.52
All-2009	731	4.01	9.32	7.10 ± 1.09	15.38
One-way Anova				F=725.8, p<0.01	
All years (2006+2008+2009)					
All seeds	2487	4.01	9.32	6.39 ± 1.10	17.29

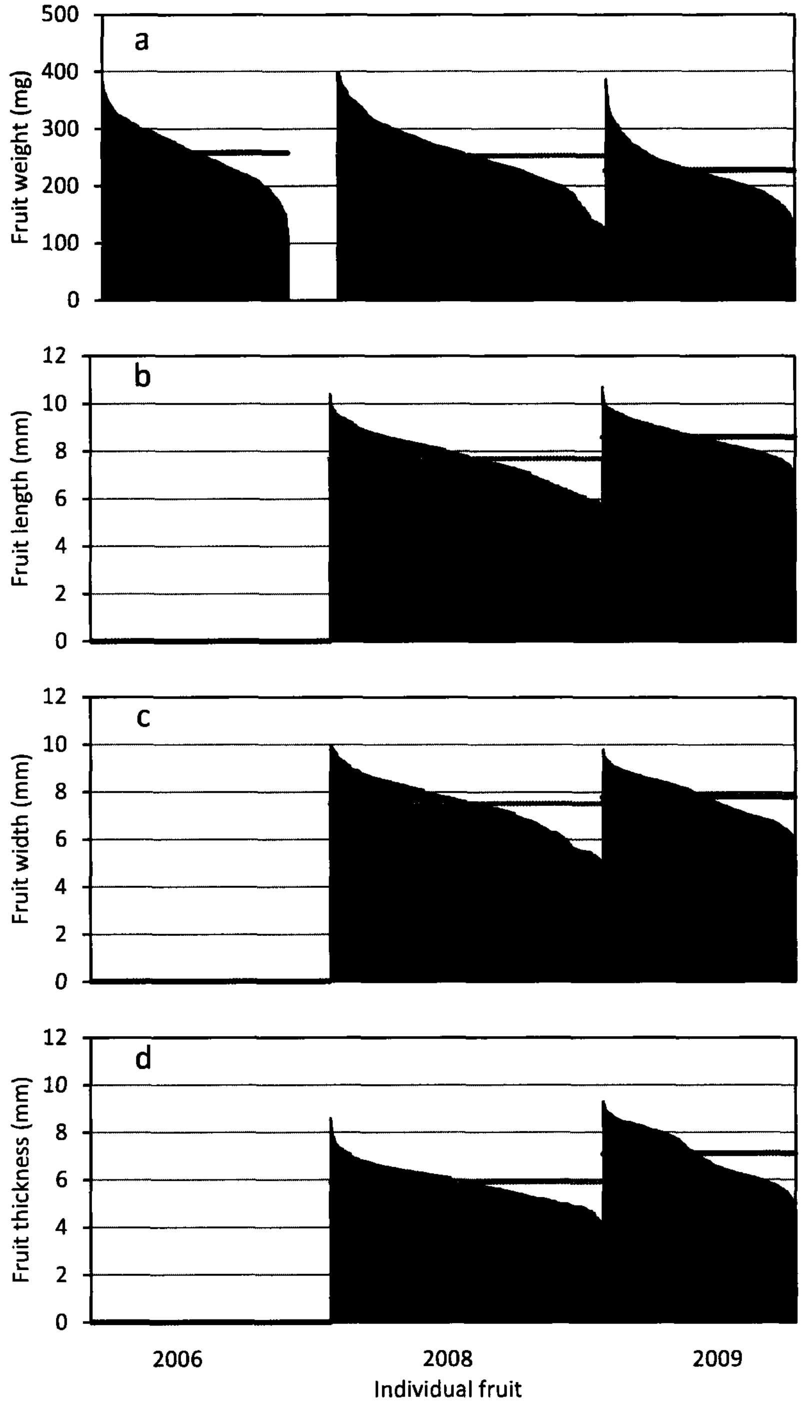


Fig. 6.2. The range of individual fruit measurements (from maximum to minimum in black) and mean (in coloured horizontal lines) of fruit weight, fruit length, fruit width and fruit thickness in the years 2006, 2008 and 2009. The data for fruit length, fruit width and fruit thickness were not available for the year 2006.

6.3.3 Seed characteristics

The seed weight showed significant variation among trees in all the years, i.e., 2006, 2008 and 2009 (Table 6.7). Hence, mean seed weight ~~could vary~~ varied from tree-to-tree. The maximum seed weight was exhibited by T1 in 2006 (80.3 mg), T8 in 2008 (91.4 mg) and T4 in 2009 (85.0 mg). An individual seed's weight ranged up to about two-fold, from 40.1 to 99.4 mg in 2006, from 40.2 to 99.7 mg in 2008 and from 48.9 to 99.7 mg in 2009 (Table 6.7). The mean seed weight was 78.5 mg in 2006, 74.4 mg in 2008 and 80.6 mg in 2009 (Fig. 6.3). The yearly variation in mean seed weight was significant following one-way ANOVA results. The variation between 2006 and 2009 was insignificant, but the variation between 2006 and 2008, and between 2008 and 2009 was significant. ~~Hence~~ thus, mean seed weight ~~could vary~~ also varied from year-to-year. A mean across the years for all seeds (n=2677) showed 77.5 mg seed weight. The coefficient of variation ranged from 5.6% to 22.6% among trees and it was 14.9% for all seeds of all years.

The seed length showed significant variation among trees in all the years, i.e., 2006, 2008 and 2009 (Table 6.8). Hence, mean seed length ~~could vary~~ varied from tree-to-tree. The maximum seed length was exhibited by T2 in 2006 (7.91 mm), T8 in 2008 (8.13 mm) and T2 in 2009 (8.08 mm). An individual seed's length ranged up to about two-fold, from 5.02 to 7.91 mm in 2006, from 4.20 to 8.13 mm in 2008 and from 4.74 to 8.08 mm in 2009 (Table 6.8). The mean seed length was 6.70 mm in 2006, 6.24 mm in 2008 and 7.08 mm in 2009 (Fig. 6.3). The yearly variation in mean seed length was significant following one-way ANOVA results. The variation between any pair of two years was significant. ~~Hence~~ thus, mean seed length ~~could vary~~ also varied from year-to-year. A mean across the years for all seeds (n=2677) showed 6.63 mm seed length. The coefficient of variation ranged from 3.93% to 8.73% among trees and it was 9.62% for all seeds of all years.

Table 6.7. Tree-to-tree variation in 2006, 2008 and 2009 and year-to-year variation in **seed weight (mg)** of *T. wallichiana*.

Tree and site	N	Minimum	Maximum	Mean ± SD	CV (%)
Tree-to-tree variation in 2006					
T1, Mawphlang	227	58.5	97.4	80.3 ± 8.3	10.4
T2, Mawphlang	493	45.1	89.8	79.8 ± 7.1	8.9
T3, Mawbeh	190	40.1	99.4	72.8 ± 14.2	19.6
One-way Anova				F=44.5, p<0.01	
Tree-to-tree variation in 2008					
T2, Mawphlang	186	51.4	96.5	74.4 ± 9.4	12.7
T3, Mawbeh	157	40.2	99.5	61.2 ± 13.8	22.6
T4, PHE	250	51.4	99.7	72.4 ± 9.9	13.7
T5, BSI-Umiam	138	62.6	99.3	82.3 ± 8.1	9.8
T6, BSI-Umiam	110	42.3	97.6	66.3 ± 7.8	11.7
T7, BSI-Umiam	69	50.6	98.3	78.2 ± 8.8	11.3
T8, BSI-Umiam	126	71.3	99.1	91.4 ± 5.1	5.6
One-way Anova				F=147.5, p<0.01	
Tree-to-tree variation in 2009					
T2, Mawphlang	200	63.2	99.6	84.1 ± 7.6	9.0
T4, PHE	220	56.8	99.7	85.0 ± 9.5	11.1
T5, BSI-Umiam	180	48.9	97.1	75.4 ± 9.9	13.1
T9, Moodymmai	131	54.4	98.2	75.2 ± 10.2	13.6
One-way Anova				F=60.2, p<0.01	
Year-to-year variation					
All-2006	910	40.1	99.4	78.5 ± 9.8	12.5
All-2008	1036	40.2	99.7	74.4 ± 13.1	17.6
All-2009	731	48.9	99.7	80.6 ± 10.3	12.8
One-way Anova				F=69.9, p<0.01	
All years (2006+2008+2009)					
All seeds	2677	40.1	99.7	77.5 ± 11.6	14.9

Table 6.8. Tree-to-tree variation in 2006, 2008 and 2009 and year-to-year variation in **seed length (mm)** of *T. wallichiana*.

Tree and site	N	Minimum	Maximum	Mean ± SD	CV (%)
Tree-to-tree variation in 2006					
T1, Mawphlang	227	5.54	7.02	6.31 ± 0.27	4.22
T2, Mawphlang	493	6.11	7.91	6.89 ± 0.30	4.41
T3, Mawbeh	190	5.02	7.14	6.67 ± 0.33	4.99
One-way Anova				F=286.4, p<0.01	
Tree-to-tree variation in 2008					
T2, Mawphlang	186	4.80	7.90	6.24 ± 0.38	6.10
T3, Mawbeh	157	4.20	6.37	5.41 ± 0.47	8.73
T4, PHE	250	4.80	8.00	6.24 ± 0.47	7.60
T5, BSI-Umiam	138	5.28	6.90	6.17 ± 0.33	5.34
T6, BSI-Umiam	110	5.12	7.72	5.87 ± 0.44	7.41
T7, BSI-Umiam	69	5.33	7.85	6.66 ± 0.39	5.93
T8, BSI-Umiam	126	5.75	8.13	7.48 ± 0.31	4.11
One-way Anova				F=321.0, p<0.01	
Tree-to-tree variation in 2009					
T2, Mawphlang	200	5.39	8.08	7.34 ± 0.36	4.89
T4, PHE	220	6.00	7.94	7.14 ± 0.34	4.70
T5, BSI-Umiam	180	4.74	7.44	6.62 ± 0.36	5.50
T9, Moodymmai	131	6.55	8.07	7.23 ± 0.28	3.93
One-way Anova				F=158.2, p<0.01	
Year-to-year variation					
All-2006	910	5.02	7.91	6.70 ± 0.38	5.74
All-2008	1036	4.20	8.13	6.24 ± 0.70	11.18
All-2009	731	4.74	8.08	7.08 ± 0.44	6.18
One-way Anova				F=286.4, p<0.01	
All years (2006+2008+2009)					
All seeds	2677	4.20	8.13	6.63 ± 0.64	9.62

The seed width showed significant variation among trees in all the years, i.e., 2006, 2008 and 2009 (Table 6.9). Hence, mean seed width ~~could~~ ~~vary~~ varied from tree-to-tree. The maximum seed width was exhibited by T3 in 2006 (6.70 mm), T2 in 2008 (6.80 mm) and T4 in 2009 (6.81 mm). An individual seed's width ranged up to about one-and-a half-fold, from 4.75 to 6.70 mm in 2006, from 4.10 to 6.80 mm in 2008 and from 4.00 to 6.81 mm in 2009 (Table 6.9). The mean seed width was 5.63 mm in 2006, 5.09 mm in 2008 and 5.18 mm in 2009 (Fig. 6.3). The yearly variation in mean seed width was significant following one-way ANOVA results. The variation between any pair of two years was significant. Hence, mean seed width could vary from year-to-year. A mean across the years for all seeds (n=2677) showed 5.30 mm seed width. The coefficient of variation ranged from 3.96% to 11.36% among trees and it was 8.28% for all seeds of all years.

The seed thickness showed significant variation among trees in all the years, i.e., 2006, 2008 and 2009 (Table 6.10). Hence, mean seed thickness could vary from tree-to-tree. The maximum seed thickness was exhibited by T2 in 2006 (5.98 mm), T8 in 2008 (5.42 mm) and T9 in 2009 (5.76 mm). An individual seed's thickness ranged up to about two-fold, from 3.93 to 5.98 mm in 2006, from 3.05 to 5.42 mm in 2008 and from 3.34 to 5.76 mm in 2009 (Table 6.10). The mean seed thickness was 5.11 mm in 2006, 4.31 mm in 2008 and 4.51 mm in 2009 (Fig. 6.3). The yearly variation in mean seed thickness was significant following one-way ANOVA results. The variation between any pair of two years was significant. Hence, mean seed thickness could vary from year-to-year. A mean across the years for all seeds (n=2677) showed 4.64 mm seed thickness. The coefficient of variation ranged from 2.47% to 16.58% among trees and it was 10.48% for all seeds of all years.

Table 6.9. Tree-to-tree variation in 2006, 2008 and 2009 and year-to-year variation in **seed width (mm)** of *T. wallichiana*.

Tree and site	N	Minimum	Maximum	Mean ± SD	CV (%)
Tree-to-tree variation in 2006					
T1, Mawphlang	227	5.02	5.98	5.45 ± 0.22	3.96
T2, Mawphlang	493	5.01	6.30	5.55 ± 0.29	5.23
T3, Mawbeh	190	4.75	6.70	6.04 ± 0.34	5.66
One-way Anova				F=264.6, p<0.01	
Tree-to-tree variation in 2008					
T2, Mawphlang	186	4.25	6.80	5.18 ± 0.32	6.15
T3, Mawbeh	157	4.10	5.70	4.76 ± 0.54	11.36
T4, PHE	250	4.33	6.48	5.18 ± 0.34	6.59
T5, BSI-Umiam	138	4.16	6.28	5.20 ± 0.31	6.05
T6, BSI-Umiam	110	4.48	5.70	5.06 ± 0.27	5.28
T7, BSI-Umiam	69	4.30	5.66	5.00 ± 0.27	5.46
T8, BSI-Umiam	126	4.39	5.97	5.14 ± 0.34	6.58
One-way Anova				F=29.3, p<0.01	
Tree-to-tree variation in 2009					
T2, Mawphlang	200	4.93	6.80	5.46 ± 0.24	4.44
T4, PHE	220	4.00	6.81	4.97 ± 0.27	5.50
T5, BSI-Umiam	180	4.06	6.50	5.15 ± 0.38	7.33
T9, Moodymmai	131	4.56	5.84	5.16 ± 0.25	4.75
One-way Anova				F=101.8, p<0.01	
Year-to-year variation					
All-2006	910	4.75	6.70	5.63 ± 0.36	6.38
All-2008	1036	4.10	6.80	5.09 ± 0.35	7.65
All-2009	731	4.00	6.81	5.18 ± 0.35	6.67
One-way Anova				F=566.8, p<0.01	
All years (2006+2008+2009)					
All seeds	2677	4.00	6.81	5.30 ± 0.44	8.28

Table 6.10. Tree-to-tree variation in 2006, 2008 and 2009 and year-to-year variation in **seed thickness (mm)** of *T. wallichiana*.

Tree and site	N	Minimum	Maximum	Mean ± SD	CV (%)
Tree-to-tree variation in 2006					
T1, Mawphlang	227	4.49	5.48	4.97 ± 0.12	2.47
T2, Mawphlang	493	4.32	5.98	5.19 ± 0.30	5.78
T3, Mawbeh	190	3.93	5.54	5.09 ± 0.33	6.44
One-way Anova				F=52.2, p<0.01	
Tree-to-tree variation in 2008					
T2, Mawphlang	186	3.79	5.10	4.37 ± 0.21	4.89
T3, Mawbeh	157	3.05	5.41	4.14 ± 0.69	16.58
T4, PHE	250	3.76	4.99	4.33 ± 0.23	5.29
T5, BSI-Umiam	138	3.91	5.26	4.40 ± 0.24	5.44
T6, BSI-Umiam	110	3.78	4.90	4.30 ± 0.23	5.38
T7, BSI-Umiam	69	3.50	4.79	4.14 ± 0.25	6.04
T8, BSI-Umiam	126	3.78	5.42	4.41 ± 0.22	5.08
One-way Anova				F=13.9, p<0.01	
Tree-to-tree variation in 2009					
T2, Mawphlang	200	4.04	5.41	4.83 ± 0.21	4.41
T4, PHE	220	3.34	4.91	4.17 ± 0.20	4.70
T5, BSI-Umiam	180	3.45	5.48	4.41 ± 0.33	7.57
T9, Moodymmai	131	4.09	5.76	4.72 ± 0.26	5.56
One-way Anova				F=277.3, p<0.01	
Year-to-year variation					
All-2006	910	3.93	5.98	5.11 ± 0.29	5.65
All-2008	1036	3.05	5.42	4.31 ± 0.35	8.18
All-2009	731	3.34	5.76	4.51 ± 0.37	8.19
One-way Anova				F=1444.2, p<0.01	
All years (2006+2008+2009)					
All seeds	2677	3.05	5.98	4.64 ± 0.49	10.48

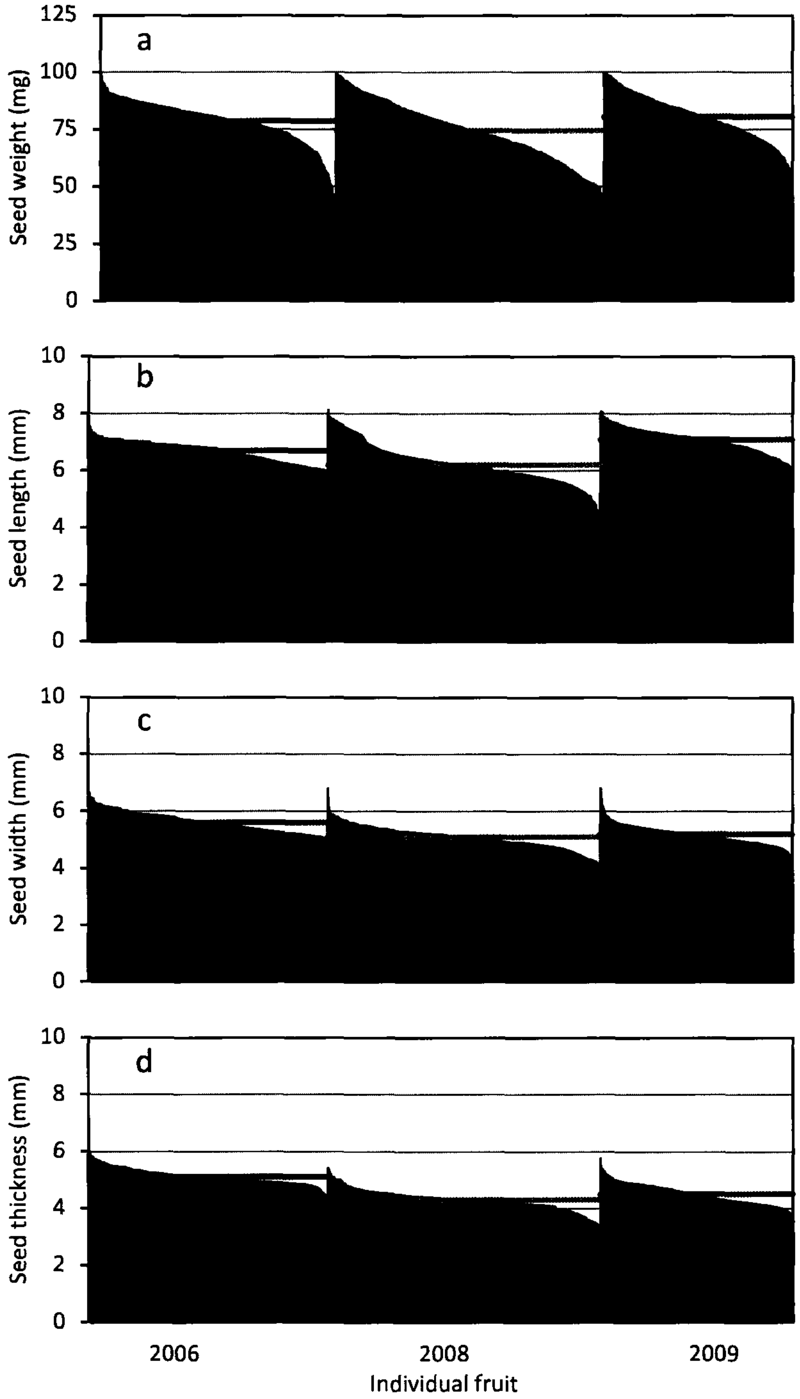


Fig. 6.3. The range of individual seed measurements (from maximum to minimum in black) and mean (in coloured horizontal lines) of seed weight, seed length, seed width and seed thickness in the years 2006, 2008 and 2009.

6.3.4 Relationships among fruit and seed characteristics

The characteristics of fruits showed a significant relationship with the respective characteristics of seeds. Fruit weight was significantly correlated with seed weight (Fig. 6.4a). This relationship was positive and yielded a low value of correlation coefficient (r = 0.392), presumably due to high variability (large CV value) in fruit weight as well as seed weight.

Fruit length was significantly correlated with seed length (Fig. 6.4b). This relationship was positive and yielded a larger value of correlation coefficient (r = 0.675), presumably due to low variability (large CV value) in fruit length as well as seed length.

Fruit width was significantly correlated with seed width (Fig. 6.4c). This relationship was positive and yielded a fairly large value of correlation coefficient (r = 0.417), presumably due to low variability (large CV value) in fruit width as well as seed width.

Fruit thickness was significantly correlated with seed thickness (Fig. 6.4d). This relationship was positive and yielded a larger value of correlation coefficient (r = 0.502), presumably due to low variability (large CV value) in fruit thickness as well as seed thickness.

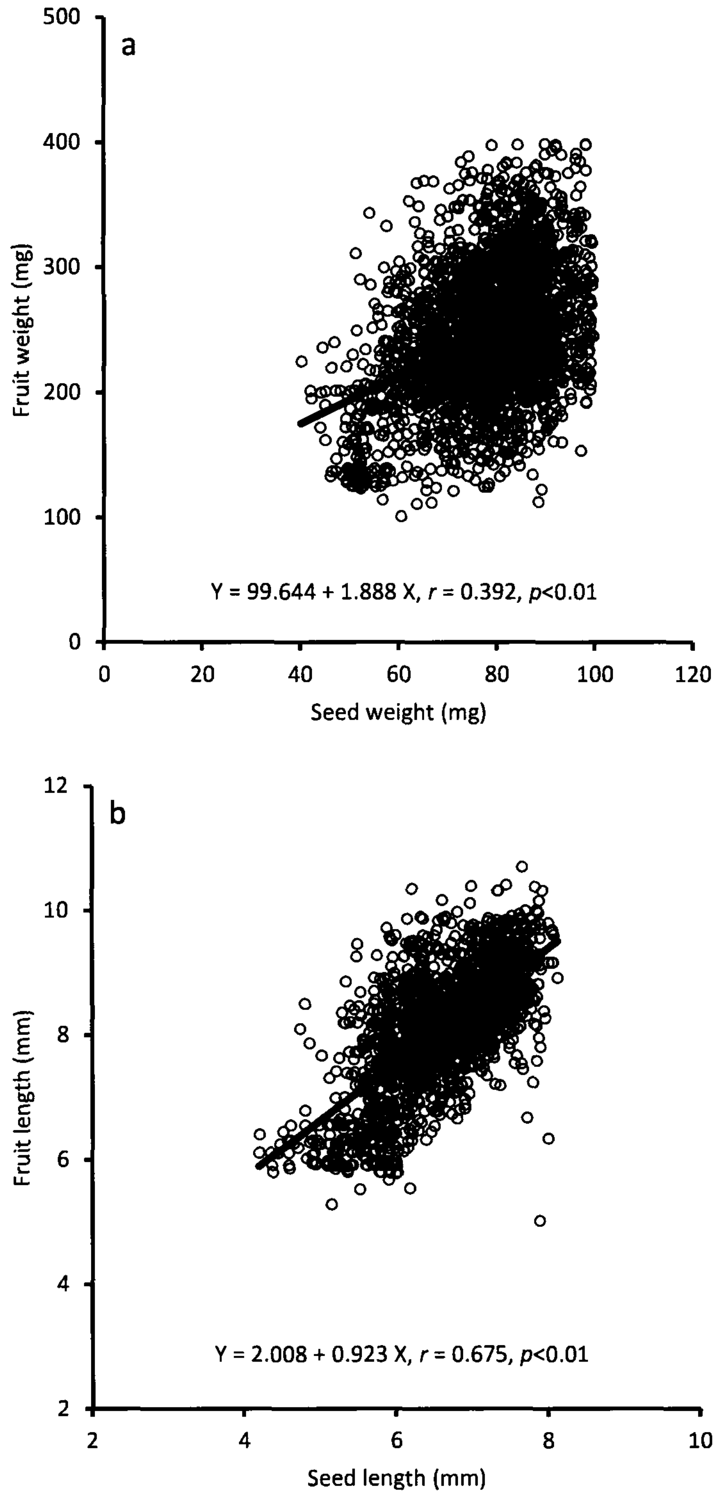


Fig. 6.4. A simple linear regression between weight (a) and length (b) of fruits and seeds of *T. wallichiana*. Regression equation, Pearson's correlation coefficient (r) and significance level (p) are shown.

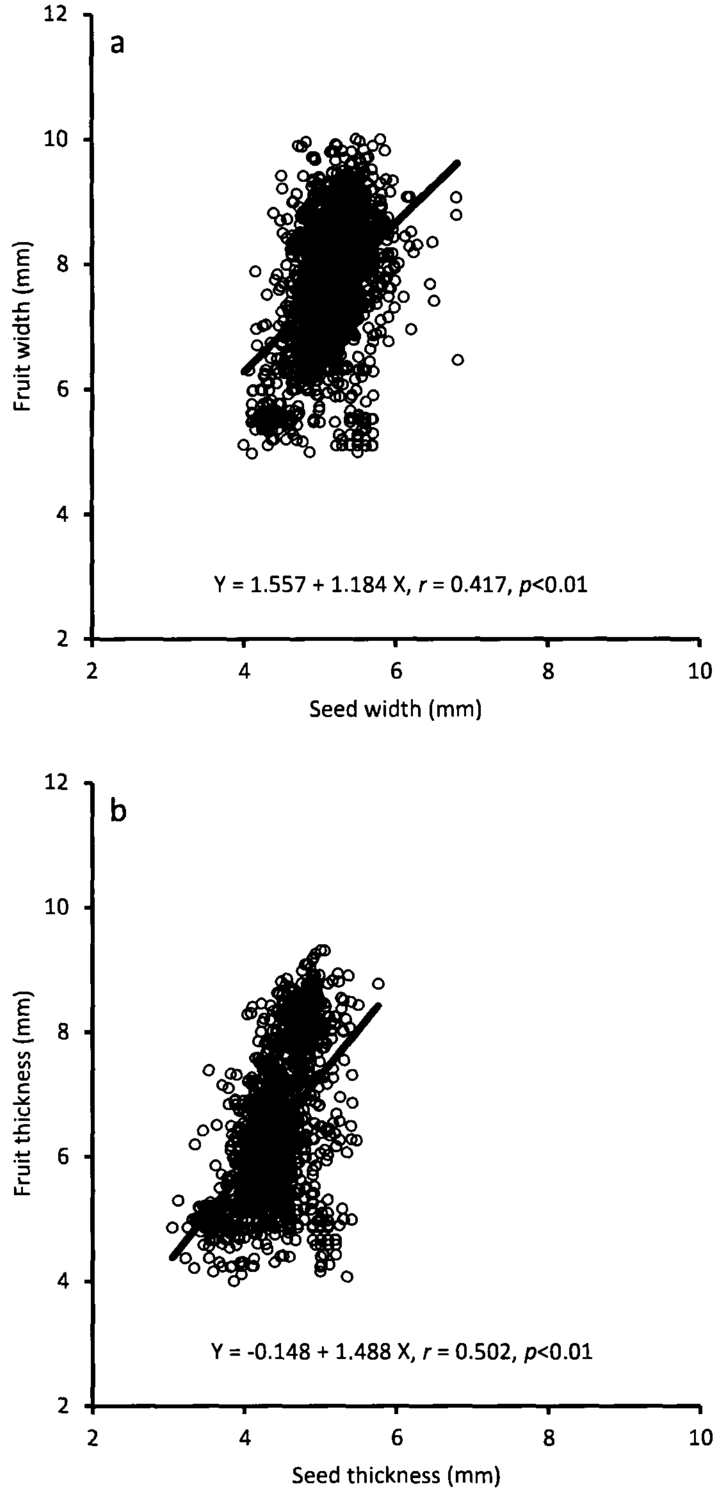


Fig. 6.5. A simple linear regression between width (a) and thickness (b) of fruits and seeds of *T. wallichiana*. Regression equation, Pearson's correlation coefficient (*r*) and significance level (*p*) are shown.

6.3.5 Seed germination by pit-burial method

A total of 200 labeled seeds were sown in each of the two pits in December, 2007 in rows 5 cm apart. The germination was 19% after one year, but seedlings all died (Fig. 6.7).

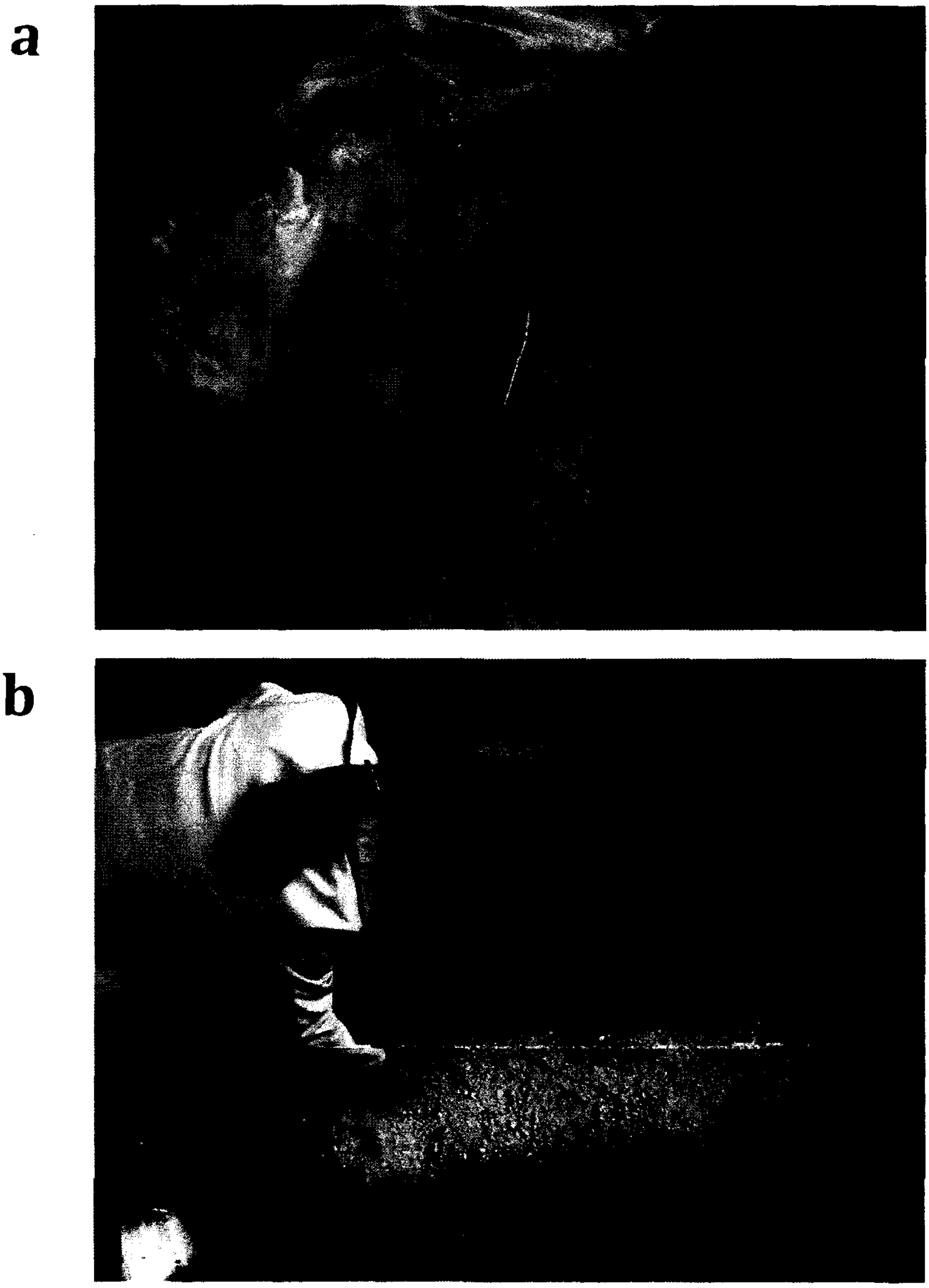


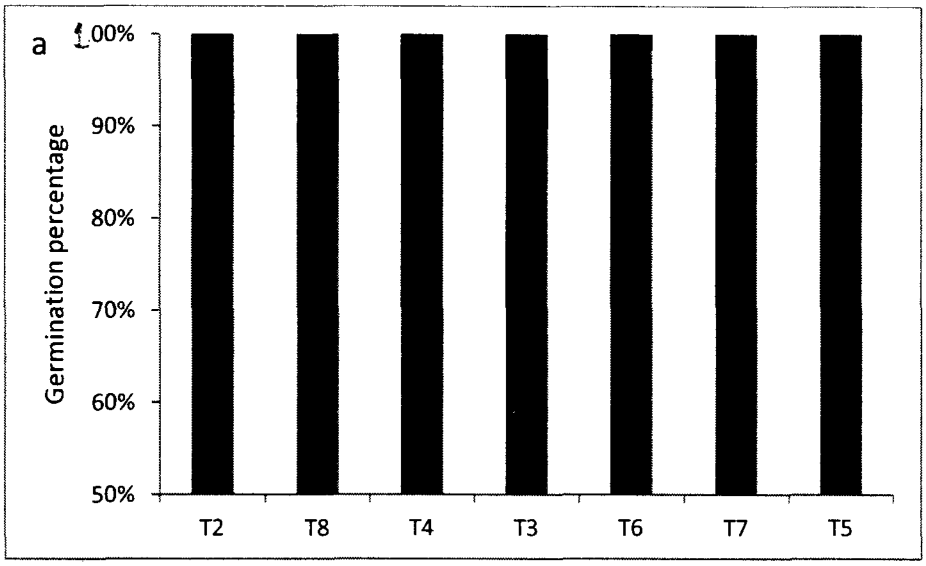
Fig. 6.6. Seed germination by pit-burial method: a) labeled seeds ready for sowing, and b) sowing of labeled seeds at 5 cm distance from each other in the pits.

6.3.6 Seed germination in nethouse

The germination of seeds of *T. wallichiana* was carried out in a nethouse. A total of 1036 seeds from seven trees were sown in May, 2009 (Table 6.11). Of these, 77 seeds germinated after 10 months (in March, 2010) and 17 seeds germinated after 22 months (in March, 2011). Hence, only 9.1% seeds germinated. The percentage of germination varied greatly among trees, i.e., from 0.7% to 14% (Fig. 6.7a). Four trees showed >10% germination and three trees <2% germination. A total of 1001 seeds from seven trees were sown in May, 2010 (Table 6.10). Of these, 77 seeds germinated after 10 months (in March, 2011) and 19 seeds germinated after 22 months (in March, 2012). Variation among trees was similar to the preceding trend (Fig. 6.7b).

Table 6.11. Germination of seeds of *T. walichiana* sown in 2009 and in 2010 in polythene bags in nethouse.

Source tree of seeds	Number of seeds sown	Seeds germinated in next year	Seeds germinated after two years	Total number of seeds germinated	Seed germination (%)
Seeds sown in 2009					
T2, Mawphlang	186	21	5	26	14.0
T4, PHE	250	22	7	29	11.6
T5, BSI	138	0	1	1	0.7
T6, BSI	110	0	2	2	1.8
T7, BSI	69	0	1	1	1.4
T8, BSI	126	16	1	17	13.5
T9, Moodymmai	157	18	0	18	11.5
Total	1036	77	17	94	9.1
Seeds sown in 2010					
T2, Mawphlang	200	31	6	37	18.5
T4, PHE	220	28	8	36	16.4
T5, BSI	80	0	1	1	1.3
T6, BSI	100	1	1	2	2.0
T7, BSI	90	0	1	1	1.1
T8, BSI	180	28	5	33	18.3
T9, Moodymmai	131	15	2	17	13
Total	1001	103	24	127	12.7



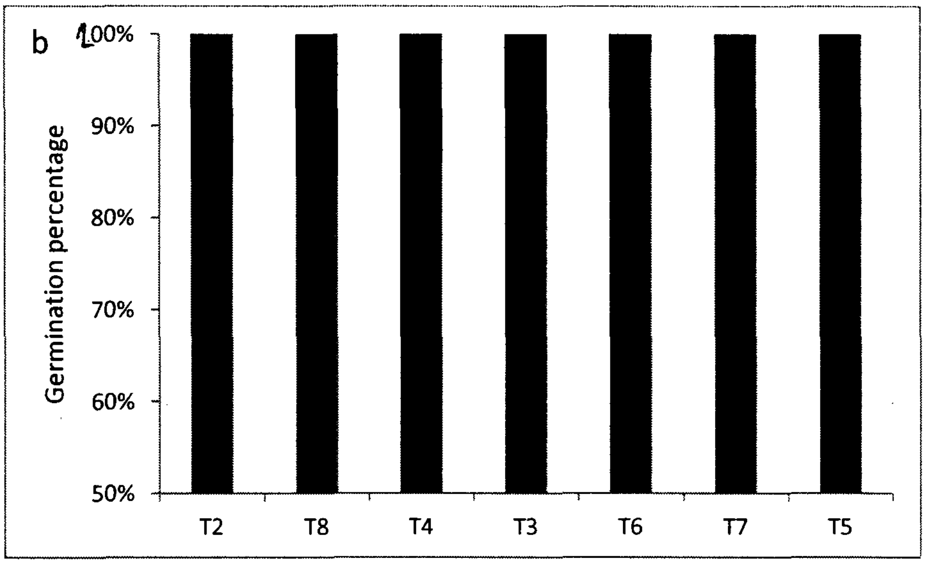


Fig. 6.7. Seed germination of *T. wallichiana* for seeds sown in 2009 (a) and for seeds sown in 2010 (b) in nethouse. The black portion of the stacked bar on the top indicates the percentage of seeds germinated and the grey portion of the stacked bar on the bottom indicates the percentage of seeds failed to germinate. The lables of the seven trees are shown on x-axis.

The germination of seeds is epigeal, with radicle protruding from the seed first (Fig. 6.8). The radicle penetrates the soil and gets rooted. Subsequently, the seed coat ruptures and cotyldedons free themselves of the seed coat forming an inverted-v shape. The radicle penetrates the soil quickly and plumule length increases faster than the radicle. The cotyledonary leaves begin to straighten and distinguish themselves.

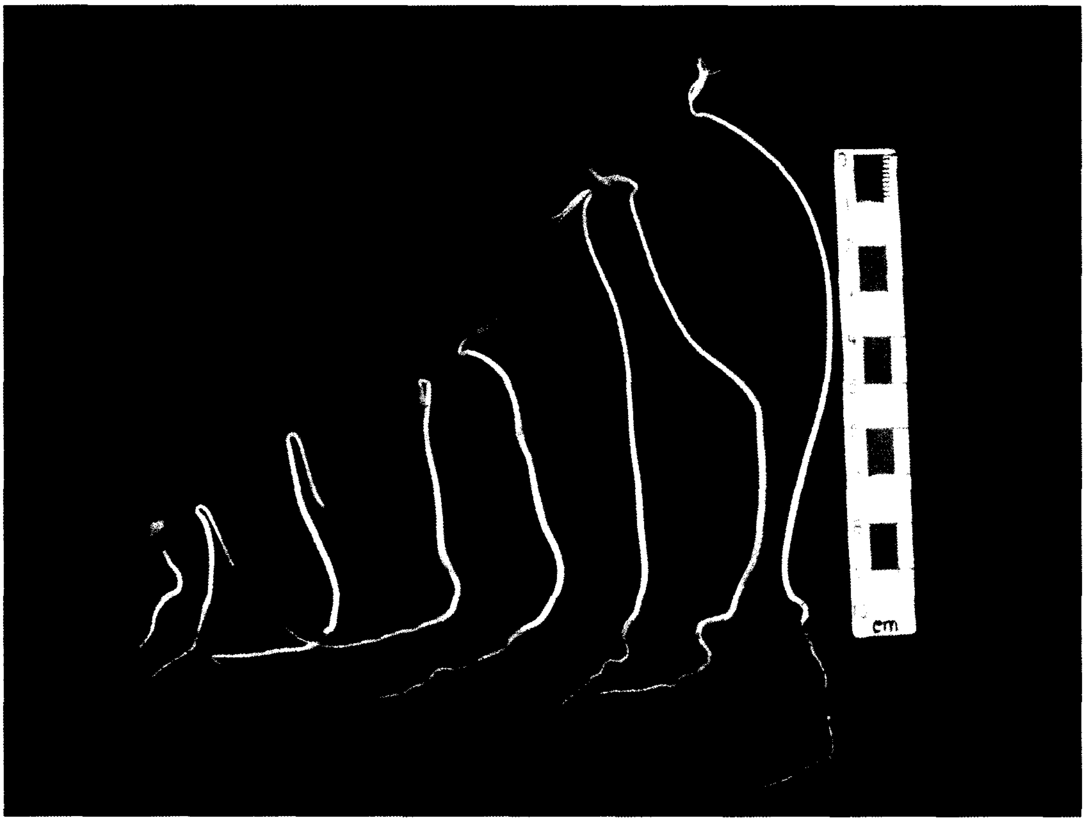


Fig. 6.8. Stages of seed germination and early growth of seedlings of *T. wallichiana* as recorded in 2010.

The survival of seedlings was poor and almost all seedlings died within a year of germination. The major causes of the death of the seedlings included root damage and lack of development of leaves.

6.4 Discussion

Seed viability of *T. wallichiana* was higher in the beginning (on fresh seeds) and declined on storage, from 85.2% to 58.7% (Table 6.1). In *T. baccata*, seed viability can be high, approaching 100% (USDA 1948). The viability of *T. baccata* seeds can be maintained artificially for up to 4 years by storing in damp sand or peat at 'low temperatures' (USDA 1974). The seeds can also be stored for 5-6 years by drying at room temperature to about 10% moisture content and then storing at 1-2 °C (Heit 1968, 1969) or even lower at -3 °C (Suszka 1985).

The variation in morphometric traits of fruits and seeds of *T. wallichiana* have not been studied as the literature survey does not reveal any results of such a study, although morphometric traits play an important role in seed germination and seedling growth (Uma Shankar 2006, 2012, Uma Shankar and Synrem 2012). An idea of the available variation in fruit and seed characteristics and germination behavior of a species is helpful in selecting the best available geographic source of seeds (Kertadikara and Prat 1995, Wright 1976). The vigorous growth of the seedlings and subsequent survival in the field depends mainly on the quality of seeds (Abideen *et al.* 1993, Khan *et al.* 1999, Uma Shankar 2006, 2012).

Variation in weight and dimensions of fruits and seeds may result from the diversity in edapho-climatic conditions of the habitats combined with genetic variability (Friis 1992, Willan 1985). While several species exhibit little variability (stenospermous), others reveal large variability (euryspermous). Although studies on germination and seedling growth have been carried out in many species, those on variation in fruit and seed characteristics and their implication on germination and seedling growth are few

(Barzdajn 2002, Bednorz 2007, Jayasankar *et al.* 1999, Loha *et al.* 2006, Major 2002, Uma Shankar 2006, 2012, Uma Shankar and Synrem 2012, Wulff 1986).

A considerable variation in morphometric traits of fruits of *T. wallichiana* was observed among trees and among years. In 2006, T2 scored better than T1 in terms of fruit weight. In 2008, T7 (=T2=T8) scored better than T3, T4, T5 and T6 In 2009, T2 scored the best among all trees. Hence, T2 scored the best of fruit weight in all years. Variation among trees in terms of fruit length was also pronounced. In 2008, T8 scored the best in terms of fruit length. Although T2 showed a lower value than T8, the difference between these two trees was insignificant. In 2009, T9 (=T2) scored the best in terms of fruit length. Although T2 showed a marginally lower value than T9, the difference between these two trees was insignificant. Variation among trees in terms of fruit width was also pronounced. In 2008, T2 scored the best in terms of fruit width. In 2009 also, T2 scored the best in terms of fruit width. Variation among trees in terms of fruit thickness was also pronounced. In 2008, T8 (=T7=T2) scored better than T3, T4, T5 and T6 in terms of fruit thickness. Although T2 showed a marginally lower value than T8, the difference between these two trees was insignificant. In 2009, T2 scored the best in terms of fruit thickness. An overall assessment of the weight and dimensions of fruits, T2 emerged as the superior tree among all followed by T8 and T9. The tree T2 is characterized by the maximum age, girth and height among all trees (Table 6.1).

Among years, 2006 scored the best in terms of fruit weight. But, in terms of dimensions of fruits (length, width and thickness), the year 2009 fared better than 2008 (data for 2006) were not available. Notwithstanding, it is clear that mean characteristics of fruis vary interyearly presumably due to yearly fluctuations in the climatic conditions such as rainfall, temperature and humidity.

The coefficient of variation was more for weight than for dimensions. An overall CV was 22% for fruit weight, 12.4% for fruit length, 13.9% for fruit width, and 17.3% for fruit thickness. The trend that the coefficient of variation is more for weight than for dimensions was in conformity with the findings in *P. nepaulensis* (Uma Shankar and Synrem 2012) wherein the CV for fruit weight was 21.6%; however, the CV for fruit length (7.15%) and for fruit diameter (8.41%) were smaller than the respective values for *T. wallichiana*. The coefficient of variation for all fruit traits varied from tree-to-tree. For the superior tree T2, the values were in the middle of the range of CV for individual trees. In *P. nepaulensis* (Uma Shankar and Synrem 2012), the superior tree exhibited lowest values of CV. Among years, the coefficient of variation was higher in 2008 and lower in 2009 for fruit traits, signifying that the interyearly variations in environmental conditions may be causing the range of variation in fruit traits.

A considerable variation in morphometric traits of seeds of *T. wallichiana* was observed among trees and among years. In 2006, T1 and T2 scored better than T3 in terms of seed weight. In 2008, T8 scored better than T2, T3, T4, T5, T6 and T7 in terms of seed weight. In 2009, T2 and T4 scored better than T5 and T9. Hence, T2 scored the best of seed weight in two of the three years (in 2008, T8 scored the best). Variation among trees in terms of seed length was also pronounced. In 2006, T2 scored better than other trees. In 2008, T8 scored the best in terms of seed length. In 2009, T2 scored the best in terms of seed length. Variation among trees in terms of seed width was also pronounced. In 2006, T3 scored better than other trees. In 2008, T2 (=T4=T5=T8) scored better than T3, T6 and T7 in terms of seed width. In 2009 also, T2 scored the best in terms of seed width. Variation among trees in terms of seed thickness was also pronounced. In 2006, T2 scored the best in terms of seed thickness. In 2008, T2 (=T4=T5=T8) scored better than

T3, T6 and T7 in terms of seed thickness. In 2009, T2 scored the best in terms of seed thickness. An overall assessment of the weight and dimensions of seeds, T2 emerged as the superior tree among all followed by T8. The tree T2 is characterized by the maximum age, girth and height among all trees (Table 6.1).

Among years, 2006 and 2009 scored significantly better than 2008 in terms of seed weight. This trend was also consistent with respect to the measures of other dimensions of seeds (length, width and thickness). Notwithstanding, it is clear that mean characteristics of seed vary interyearly presumably due to yearly fluctuations in the climatic conditions such as rainfall, temperature and humidity.

The coefficient of variation was more for weight than for other dimensions. An overall CV was 14.9% for seed weight, 9.6% for seed length, 8.3% for seed width, and 10.5% for seed thickness. The trend that the coefficient of variation is more for weight than for other dimensions was in conformity with the findings in *P. nepaulensis* (Uma Shankar and Synrem 2012) wherein the CV for seed weight was 20.8%; however, the CV for seed length (7.86%) and for seed diameter (7.98%) were smaller than the respective values for *T. wallichiana*. The coefficient of variation for all seed traits varied from tree-to-tree. For the superior tree T2, the values were on the lower side or in the middle of the range of CV for individual trees. In *P. nepaulensis* (Uma Shankar and Synrem 2012), the superior tree exhibited lowest values of CV. Among years, the coefficient of variation was higher in 2008 and lower in 2006 and 2009 for seed traits, signifying that the interyearly variations in environmental conditions may be causing the range of variation in seed traits.

The environmental factors seem to play a role in determining fruit and seed morphology of *T. wallichiana* as the trees producing the absolute maximum and absolute minimum values of fruit and seed traits (tree # 4) occurred in different locations.

It is widely believed that the tree-to-tree variation in fruit and seed traits is common and may be determined both by genetic and environmental factors (Michaels *et al.* 1988; Obeso 1993, Roach and Wulff 1987, Vaughton and Ramsey 1998). However, it is also argued that the most within-species variation occurs within a plant rather than among plants or populations (Michaels *et al.* 1988, Obeso 1993, Vaughton and Ramsey 1998), indicating a greater role of environment during development rather than genetic differences between mothers.

CHAPTER VII

GENERAL DISCUSSION

CHAPTER VII

GENERAL DISCUSSION

Taxus wallichiana ~~is~~ occurs in natural habitats of Meghalaya. In the present sudy, the natural habitats *viz.,* Mawphlang, Moodymmai, Nongmawlum-Pyrda and Phudjaut-Rangthong, ~~Mawphlang~~ revealed presence of *T. wallichiana* with appreciable number of individuals. The site Mawphlang is a sacred grove and exposed to little human interferences rendering protection to the species.

Taxus wallichiana formed an important component of the subcanopy of the forests as suggested by its IVI that ranked fifth (IVI-12.5) in Mawphlang and fourth (IVI-18.3) in Moodymmai. However, the vegetation was dominated by *Quercus dealbata* (IVI-47.7) in Mawphlang and *Castanopsis tribuloides* (IVI-75.3) in Moodymmai, and co-dominated by *Rhododendron arboreum* and *Pinus kesiya*, respectively. Similar finding was reported by Rao *et al.* (1990). Fagaceae dominated the community structure, especially in Mawphlang, in which four out of ten species with IVI >10 belong to this family. From both the study sites comprising a total area of one hectare, 1380 tree individuals were recorded out of which 68.5% represented Mawphlang with 61 species and 31.5% with 49 species represented Moodymmai. All species with IVI>10 had more than 20 individuals except for *T. wallichiana* in Mawphlang and *A. stipulata* along with *Cyathea* sp. in Moodymmai. With Simpson's dominance index as an exception, all indices were higher in Mawphlang as compared to Moodymmai suggesting a more diverse structure of vegetation.

Mean girth of species of both the sites depicts a more or less same age composition of plants. Sixteen families comprising of thirty nine species in Mawphlang and eighteen species in Moodymmai show~~s~~ >30 cm mean girth. Comparatively, larger trees (GBH>200 cm) occured in species having IVI>10 with four species in Moodymmai dominated by *Castanopsis tribuloides* (280.0 cm), while two species dominated in Mawphlang, with the maximum in *Quercus lanceaefolia* (201.1 cm). However, we recorded three species of >210 cm girth in Moodymmai. Largest Taxus trees with 219.0 cm GBH was seen in Moodymmai and with 196.7 cm in Mawphlang. Moodymmai (8.8 m) had higher mean height of the species compared to Mawphlang (7.9 m). Twelve species in Mawphlang and ten in Moodymmai had mean height of >10 m. *Taxus wallichiana* had taller individuals in Mawphlang but with the tallest recording at 20.0 m each in both the sites. ~~In Mawphlang exhibited~~. *Schima khasiana* among fourteen species six of which had IVI<10, recorded 5 individuals of >20 m height in Mawphlang, and in Moodymmai eight species out of which four had similar records. Species from Fagaceae family were the dominant associate in terms of IVI within Taxus habitat, despite Rosaceae (Mawphlang) and Araliaceae (Moodymmai) recording higher number of species. The present study revealed similar results with findings from Rao et al. (1990, 1997), Barik et al. (1992, 1996) and Upadhyay et al. (2003 and 2004).

Population structure of all species showed a peak in the lower girth class which explains that individuals regenerated well (4.2 and 4.6). Taxus in a pooled population structure showed scarcity of individuals in <10 cm girth. This study is in agreement with results suggested by Del Moral and Cates (1971), Thomas and Polwart (2003), Iszkulo and Boratynski (2004) that there occurred regeneration but individual growth of seedlings were being interfered by many factors including anthropogenic activities. However, in Mawphlang individuals of all girth classes are present suggesting lesser disturbances. The seeds of Taxus did show germination but with low survival as suggested by the height structure that showed lack of individuals in lower height class *i.e.* <4 m height as also reported by Iszkulo (2001) and Iszkulo and Boratynski (2004). The individuals also decreased in number from lower to higher girth class indicating that they are decreasing with age whereby Rikhari et al. (1998) suggested ~~justified~~ that the cause may be due to various climatic factors and disturbance from grazing animals. The study reveals that Taxus is not available in plenty and is facing a threat in Meghalaya if not attended to immediately.

Red colour *Taxus* fruits are mostly consumed by birds, and those that are left out fall~~s~~ on the ground, remain buried in the soil for about 1.5 to 2 years, and germinate profusely on obtaining suitable favorable condition. Minore et al. (1996) also reported that most yew seeds not consumed by birds or mammals tend to drop from the crown and remain nearby with little local dispersal. Presence of seedlings in all directions around the mother trees during the study period shows that they are distributed randomly beneath the canopy with no specific direction. Literature is scarce to support this finding but is in tune with those of Minore et al. (1996) and Iszkulo and Boratynski (2004). The crown length usually extends upto 7 m, yet seedlings, though decreasing with distance from the trunk are found around such distance. There was more number of seedlings near the bole of the parent tree which explains that number of seeds decreases as we move away from the tree. This clearly indicates that the seeds, being light (250 mg), fall~~s~~ and then drop-and-rolls a little distance. The study observed that the seeds occurring at a distance of 2 m are nearly double that of 4 m from the tree bole and further reduced with distance.

During the study period we observed that studied trees did not fruit regularly which may be attributed to biological or ecological factors similar to reports from Di-Fazio et al. (1997) and Pilz (1996a) for Pacific yew in western Oregon. However, seeds present in the soil around the trees that did not fruit during the study period must have been from the previous years and seedlings germinated thereon were due to high viability as suggested by Minore et al. (1996). Walters-Vertucci *et al.* (1996) and Minore et al. (1996) reported that yew remains viable for several years provided that they have reached sufficient maturity. This character of the seeds may be responsible for the successive regeneration every year, in all studied trees during the study period. This might be due to the differences in seed germination and seedling mortality associated with aspect, shading and solar radiation (Minore et al. 1996).

The survival % decreased to less than three-fourth of the total survival %, in most of the trees, with rapid mortality just after 1-2 months of regeneration; while some are left with no seedlings at all. However, higher survival percentage in 2006 may be due to already established seedlings when the study started. More density of seedlings during May-June suggests a favourable weather condition for the regeneration of seeds, which drops suddenly probably due to the excessive moisture followed by dry and cold winter till the pre-monsoon season, thereby repeating the cycle. This continuous trend of rise and fall in the seedling density in a cyclic manner, gives a typical U-shaped curve structure. Limited growth of seedling was also observed in accordance with the findings of Thomas and Powart (2003).

Taxus seed germinates abundantly in Mawphlang which is a prestine and undisturbed natural forest but does not survive for long due to some intrinsic factors which may be genetical or due to allelopathic impact. Allelopathic effect on the seedlings from various point of views have been mentioned in studies conducted by Del Moral and Cates (1971), Iszkulo and Boratynski (2004), Piovesan et al. (2009) and Thomas and Polwart (2003) in other yew species but information on *Taxus wallichiana* is scarce or not available till date.

There is a variation in fruits and seeds characters of *Taxus wallichiana* and the variation is more prominent in fruits than seeds. The group mean of the seeds weight and length showed a slight change when compared to collection years. The weight of fruit and seed showed more variability than the length, width and thickness of both fruits and seeds (Fig 6.1 - 6.6). This finding is in accordance with the finding of Uma Shankar and Synrem (2012). The analysis of variance shows that the fruit weight, length, width and thickness were positively related with seed weight, length, width and thickness (Fig. 6.7).

The germination of seeds was tried in various treatments and success was observed only in seeds sown in Polythene. Overall, the germination of seeds from different trees of different habitats was very poor. The maximum germination was about 14% from the tree from Mawphlang. Seeds collected from from BSI and PHE did not germinate at all (only 1-2 seeds). Analysis of variance conducted between years variation in germination of seeds did not show any significant effect.

CHAPTER VIII

SUMMARY

CHAPTER VIII

SUMMARY

1. In India, Taxaceae is represented by two genera, namely *Taxus* and *Amentotaxus* (Sahni 1990). The genus Taxus has only one species, *Taxus wallichiana* Zucc. var. *wallichiana* or simply *Taxus wallichiana* Zucc. Locally, the species is known as 'Himalayan Yew'. The species of the yew family are known as the source of "taxol", an anti-cancer drug. Over-exploitation of yew has raised concerns for its conservation as the species is considered 'threatened'.
2. Himalayan yew is distributed throughout Hindu-Kush Himalaya, from Pakistan in the west to Myanmar in the east. Generally, it occurs between an altitude range of 1500-3600 m. In the sub-Himalayan tracts, Himalayan yew is found in Khasi and Jaintia Hills of Meghalaya.
3. The Himalayan yew is found associated with broadleaved as well as conifer tree species. It forms associations with different species at different stages of succession. In the Indian Himalayan Region (IHR), it is generally found as an understorey species in most forest communities. Abundance of yew is low as compared to its associated species (Dhar *et al.* 1997, Rikhari *et al.* 2000, Samant *et al.* 2002, Joshi 2002, Pant and Samant 2005, 2008).
4. The information on the populations and regeneration of *Taxus wallichiana* is not available from northeastern region of India to complement those from central Himalayan region and other parts of the world. Further, studies on seed traits, germination and early growth of seedlings in natural habitats have not been

undertaken to understand its seed ecology. Hence this study was undertaken with the following objectives:

- To assess the population structure of *Taxus wallichiana* in subtropical forests containing *Taxus* as an important element, and
- To study natural regeneration and seedling dynamics of *Taxus wallichiana*.

5. Himalayan yew is a slow growing, long-lived, medium-sized, shade-loving, evergreen tree usually attaining a height up to 20 m (Sahni 1990, Shukla *et al.* 1994) and a gbh (girth at breast height) up to 1.5 m (Sahni 1990) or up to 1.8 m (Hynniewta and Singh 1996).
6. *T. wallichiana* is dioecious, i.e., bearing male and female cones on separate trees. The young male and female trees are morphologically alike and cannot be distinguished until they bear reproductive structures, i.e., male and female strobili. Male cones are green, turning yellow in leaf axils. The female cones are solitary in axils (Shukla *et al.* 1994). The fruit is marked by a single seed encapsulated within a succulent, bring-red arillate cup (Haridasan, 1996, Iszkulo 2001, Uma Shankar 2005). The aril (pulp) is edible by birds.
7. In the present study, two sites, viz., Mawphlang and Moodymmai were selected for detailed study. Mawphlang is about 30 km from the state capital, Shillong. The forest stand at Mawphlang is relatively undisturbed, dense and evergreen with broad-leaved trees not exceeding 20 m in height. It represents a relic of the climax vegetation which has been left undisturbed due to religious beliefs of the local tribals. Moodymmai is situated in Jaintia Hills district, about 65 km from Shillong. The forest stand at Moodymmai is experiences anthropogenic

disturbance in form of firewood collection, grazing and collection of NTFPs (Fig. 3.2). The dominant species here include *Pinus kesiya* and *Castanopsis* sp.

8. The community structure of the two forests, Mawphlang and Moodymmai harbouring Himalayan yew was studied and the objectives were to: a) ascertain floristic composition of different habitats of *T. wallichiana*, b) determine the associates of *T. wallichiana*, and c) assess the regeneration status of *T. wallichiana*.
9. At Mawphlang, a total of 945 individuals ≥10 cm gbh belonged to 61 species. *Quercus dealbata* and *Rhododendron arboretum* were the two most dominant species. A total of ten species exhibited an IVI >10 and together these species accounted for an IVI of 172 which is nearly two-third of the total IVI. *Taxus wallichiana* ranked 5th with an IVI of 12.5 only.
10. The girth of all individuals at Mawphlang ranged from 10.1 to 201.1 cm with a mean value of 41.7 cm and CV of 1093.2%. A total of ten species recorded girth between 10 and 30 cm and only nineteen species had maximum girth >100 cm, and among them only two species >200 cm. The remaining 32 species exhibited girth between 10 and 100 cm. The girth of *Taxus wallichiana* ranged from 11.2 to 196.7 with a mean of 68.6 cm and CV of 3293.4%. The height of all individuals at Mawphlang ranged from 1.5 to 26.5 m with a mean value of 7.9 m and CV of 19%. The height of *Taxus wallichiana* ranged from 3 to 20 m with a mean of 9.9 m and CV of 25.7%.
11. The population structure of individuals at Mawphlang showed a successive decline in number of individuals from a lower to the next higher class. Hence, the regeneration at the stand level was good. The vertical height structure of

individuals at Mawphlang showed a successive decline in number of individuals from a lower to the next higher class from 4-8 m class onwards. The number of individuals in 0-4 m class was lesser than that in 4-8 m class.

12. At Mawphlang, Rosaceae with 8 species was on top followed by Fagaceae with 7 species, Lauraceae, Symplocaceae and Theaceae with 4 species each, Magnoliaceae with 3 species, Hamamelidaceae, Myricaceae, Rubiaceae and Rutaceae with 2 each each, and the rest with only one species each. Fagaceae was the most dominant family in terms of the number of stems and the basal area. Ericaceae exhibited the second highest accumulation of basal area. Symplocaceae exhibited the second highest accumulation of the number of stems. Ericaceae exhibited the third highest accumulation of the number of stems. The family Taxaceae, represented with only *T. Wallichiana*, had 18 individuals, 11,459 mm^2 basal area, 68.6 cm mean girth and 9.9 m mean height of individuals.
13. At Moodymmai, a total of 435 individuals $\geq$10 cm gbh belonged to 49 species. *Castanopsis tribuloides*, *Pinus kesiya* and *Schima wallichii* were the three most dominant species. A total of eight species exhibited IVI >10 and together these species accounted for an IVI of 187.4 which is nearly two-third of the total IVI. *Taxus wallichiana* ranked 4th with an IVI of 18.3 only.
14. The girth of all individuals at Moodymmai ranged from 10 to 280 cm with a mean value of 46.4 cm and CV of 2028%. A total of twenty species recorded girth between 10 and 30 cm and only ten species had maximum girth >100 cm, and among them only four species >200 cm. The remaining 19 species exhibited girth between 10 and 100 cm. The girth of *Taxus wallichiana* ranged from 10 to 219 with a mean of 52.6 cm and CV of 2612%. The height of all individuals at

Moodymmai ranged from 1.5 to 26.0 m with a mean value of 8.8 m and CV of 26.9%. The height of *Taxus wallichiana* ranged from 1.5 to 20 m with a mean of 7.1 m and CV of 24.8%.

15. The population structure of individuals at Moodymmai showed a successive decline in number of individuals from a lower to the next higher class. Hence, the regeneration at the stand level was good. The vertical height structure of individuals at Moodymmai showed a successive decline in number of individuals from a lower to the next higher class from 4-8 m class onwards. The number of individuals in 0-4 m class was lesser than that in 4-8 m class.
16. At Moodymmai, Araliaceae with 4 species was on top followed by Caprifoliaceae, Fabaceae and Lauraceae with 3 species each, Moraceae, Oleaceae, Rosaceae, Rutaceae and Theaceae with 2 species, and the rest with only one species each. Fagaceae was the most dominant family in terms of the number of stems and the basal area (Table 4.9). Pinaceae exhibited the second highest accumulation of basal area. Theaceae exhibited the second highest accumulation of the number of stems. Araliaceae exhibited the third highest and Pinaceae the fourth highest accumulation of the number of stems. The family Taxaceae, represented with only *T. wallichiana*, had 25 individuals, 10694 mm^2 basal area, 52.6 cm mean girth and 7.1 m mean height of individuals.
17. The two sites varied with respect to various phytosociological parameters. The most pronounced variation between the two sites was due to the mean number of stems per quadrat ($p<0.001$) followed by the mean basal area per quadrat ($p<0.03$). The mean number of species per quadrat did not vary significantly between the two sites ($p<0.91$). Similarly, the mean girth of individuals per

quadrat did not vary between the two sites (p<0.60). Further, the mean height of individuals per quadrat also did not vary between the two sites (p<0.53).

18. In nature, *T. wallichiana* reproduces through seeds but exhibits poor sucess. The poor regeneration is characterized by failure of germination of seeds affecting recruitment and survival of seedlings. Studies from different geographical locations have suggested that many seedlings do not survive for more than two years. Hence, a study of seedling regeneration and dynamics of *T. wallichiana* in natural habitat was undertaken and the specific objectives were: 1) to determine fruit and seed phenology of the trees of *T. wallichiana*, 2) to delineate spatial pattern of germination and seedling recruitment in natural conditions, and 3) to trace seedling survival and growth in subsequent years of germination.
19. Not all trees showed seedling emergence in all years: T5 and T6 showed seedling emergence in 2006 only and T10 in 2006 and 2009. The remaining trees showed seedling emergence in all years.
20. The occurrence of seedlings of *T. wallichiana* was maximum in the quadrats laid near the tree trunk and declined consistently with increasing distance from the trunk. This trend occurred in all the years for the data of all ten trees pooled together. When data were segregated between the two sites, the trend for seven trees of Mawphlang was similar to the overall trend as mentioned above.
21. The ten trees showed wide variation in production of seedlings (germinants) of *T. wallichiana*. T1 produced the maximum number of seedlings followed by T2, T7 and T8. The trees T5, T6 and T10 produced the least number of seedlings and in some years these trees failed to produce any seedlings.

22. The survival of seedlings emerged in 2006 ranged from zero to 70% for all ten trees with an overall average of only one-third seedling surviving in the first year of recruitment. At the end of second year, only one-fourth of the seedlings survived and at the end of third year only one-sixth of seedlings survived.
23. The survival of seedlings emerged in 2007, after one year of recruitment, was even lower, i.e., only 6% which declined further to only 1% at the end of second year. The survival of seedlings emerged in 2008 was nearly 10% after one year of recruitment. Hence, the individual trees varied in terms of survival of seedlings.
24. The survival of seedlings emerged from the trees from two sites, viz., Mawphlang and Moodymmai, showed a significant variation (Table 5.10) and site Mawphlang fared better than site Moodymmai.
25. Growth of *T. wallichiana* seedlings, in terms of height (cm) as well as collar thickness (cm) was found to be extremely slow. The average height increment of the seedlings varies from 1.0 – 2.0 cm per year and collar thickness varies from 0.2 – 0.25 cm per year during the study period.
26. The success of the germination depends on seed vigour. Hence, morphometric traits of seeds were studied. The objectives of this study were: 1) to study morphometric characteristics of fruits (fruit weight and fruit dimensions) and seeds (seed weight and seed dimensions), 2) to determine the effect of morphometric characteristics on germination percentages and seedling survival (seedling dynamics), and 3) to quantify early seedling growth pattern.
27. The seeds of *T. wallichiana* showed good viability for all the sites. After storage for six months in the laboratory, viability declined significantly from 85.2% to 58.7%.

28. The fruit weight showed significant variation among trees in all the years, i.e., 2006, 2008 and 2009. Hence, mean fruit weight could vary from tree-to-tree. The maximum fruit weight in all the three years was exhibited by T2 (270 mg in 2006, 274 mg in 2008 and 258 mg in 2009). The mean fruit weight was 257.8 mg in 2006, 252.6 mg in 2008 and 227.4 mg in 2009.
29. The fruit length showed significant variation among trees in both the years, i.e., 2008 and 2009. The maximum fruit length was exhibited by T8 in 2008 (8.7 mm) and T2 in 2009 (9.12 mm). Hence, mean fruit length could vary from tree-to-tree. The mean fruit length was 8.70 mm in 2008 and 9.10 mm in 2009.
30. The fruit width showed significant variation among trees in both the years, i.e., 2008 and 2009. The maximum fruit width was exhibited by T2 in 2008 (8.35 mm) and by T2 in 2009 (8.70 mm). Hence, mean fruit width could vary from tree-to-tree. The mean fruit width was 7.60 mm in 2008 and 8.49 mm in 2009.
31. The fruit thickness showed significant variation among trees in both the years, i.e., 2008 and 2009. The maximum fruit thickness was exhibited by T4 in 2008 (8.60 mm) and T2 in 2009 (9.32 mm). The mean fruit thickness varied from tree-to-tree. The mean fruit thickness was 6.38 mm in 2008 and 8.09 mm in 2009.
32. The seed weight showed significant variation among trees in all the years, i.e., 2006, 2008 and 2009. Hence, mean seed weight could vary from tree-to-tree. The maximum seed weight was exhibited by T1 in 2006 (80.3 mg), T8 in 2008 (91.4 mg) and T4 in 2009 (85.0 mg). The mean seed weight was 78.5 mg in 2006, 74.4 mg in 2008 and 80.6 mg in 2009.
33. The seed length showed significant variation among trees in all the years, i.e., 2006. 2008 and 2009. Hence, mean seed length could vary from tree-to-tree. The

maximum seed length was exhibited by T2 in 2006 (7.91 mm), T8 in 2008 (8.13 mm) and T2 in 2009 (8.08 mm). The mean seed length was 6.70 mm in 2006, 6.24 mm in 2008 and 7.08 mm in 2009.

34. The seed width showed significant variation among trees in all the years, i.e., 2006, 2008 and 2009. Hence, mean seed width could vary from tree-to-tree. The maximum seed width was exhibited by T3 in 2006 (6.70 mm), T2 in 2008 (6.80 mm) and T4 in 2009 (6.81 mm). The mean seed width was 5.63 mm in 2006, 5.09 mm in 2008 and 5.18 mm in 2009.
35. The seed thickness showed significant variation among trees in all the years, i.e., 2006, 2008 and 2009. Hence, mean seed thickness could vary from tree-to-tree. The maximum seed thickness was exhibited by T2 in 2006 (5.98 mm), T8 in 2008 (5.42 mm) and T9 in 2009 (5.76 mm). The mean seed thickness was 5.11 mm in 2006, 4.31 mm in 2008 and 4.51 mm in 2009.
36. The characteristics of fruits showed a significant relationship with the respective characteristics of seeds. Fruit weight was significantly correlated with seed weight ($r = 0.392$). Fruit length was significantly correlated with seed length ($r = 0.675$). Fruit width was significantly correlated with seed width ($r = 0.417$). Fruit thickness was significantly correlated with seed thickness ($r = 0.502$).
37. The germination of seeds of *T. wallichiana* was carried out in a nethouse. A total of 1036 seeds from seven trees were sown in May, 2009. Of these, 77 seeds germinated after 10 months (in March, 2010) and 17 seeds germinated after 22 months (in March, 2011). Hence, only 9.1% seeds germinated. The percentage of germination varied greatly among trees, i.e., from 0.7% to 14%. Four trees showed >10% germination and three trees <2% germination.

38. A total of 1001 seeds from seven trees were sown in May, 2010. Of these, 77 seeds germinated after 10 months (in March, 2011) and 19 seeds germinated after 22 months (in March, 2012). Variation among trees was similar to the preceding trend.
39. The germination of seeds is epigeal, with radicle protruding from the seed first. The survival of seedlings was poor and almost all seedlings died within a year of germination.
40. The present study on *Taxus wallichiana* in the State of Meghalaya highlights that the species occurs in limited density and in limited geography. The poor regeneration coupled with the extraction of various parts of the tree (leaf, bark, wood) by the people are principal threats for the survival of the species. Developing nursery protocols for propagation of the species both through seeds and vegetative means and undertaking plantations or augmenting natural populations shall help saving the species from local extinction.

CHAPTER VIII

REFERENCES

REFERENCES

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