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DECLARATION

I hereby, declare that this is an original work and I have not committed, to my knowledge, any academic dishonesty or resorted to plagiarism in writing the dissertation titled **"Ecological and Adaptation of Tertiary Relic Plant of *Tetracentron sinense* with Climate change in Bhutan Himalaya"** All the sources of information and assistance received during entire course of the study are duly acknowledged.

Karma Tshering
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ABSTRACT

The term “endemic” for the current study referred to native and restricted range of habitat in local climatic condition. “Tertiary” is period of first cenozoic era of 69 million year ago of geologic time scale and “relic” for species surviving from earlier time. Habitat ecology, regeneration structure and radial growth performance of tertiary relic plant, *Tetracentron sinense* Oliv, monotypic genus in family Tetracentraceae was investigated in Lamperi and Nobding. *T. sinense* is primitive and vesselless angiosperm and has trachied like gymnosperm for water transporting tissue. The principle of “ecological amplitude” in Dendrochronology applies to endemic, *T. sinense* distribution in Bhutan, highly vulnerable and in high risk of extinction. 25 trees from 15 plots (Nobding) and 19 trees from 8 plots (Lamperi) were cored and enumerated for vegetation assessment in quadrate of 20 m x 20 m with *T. sinense* in centre. DBH and height were recorded for tree diversity (Height $\geq$ 1.3 m) and regeneration (Height < 1.3 m) from a sub plot of 2 m x 2 m was enumerated. *T. sinense* thrives in humid broad leaved of evergreen and deciduous forest up to transitional zone of mixed conifer in steep slopes, rocky cliffs, stream margin, and roadsides. *Quercus oxyodon* Miq, *Acer campbellii* Hok. *et al, Acer sikkimense* Miq are dominated tree species in *T. sinense* community. The cored samples were measured in the J2X software program and checked by COFECHA programme. Pair sample *t* test revealed, there is significant difference in radial growth performance in two sites and are non responsive to climatic factors due to low sensitivity. Simple linear regression showed that ring width has relatively more association with minimum temperature which revealed that species will not adapt with increasing temperature in climate change scenario. The protection of *T. sinense* and their companion species through natural process and artificial measure are crucial to preserve the ancient diversity of declining species in the biodiversity hotspot country through formulating critical conservation policy due to its remnant botanical feature.

Key words: Complacent, Ecological amplitude, Monotypic genus, Sensitive, Ring chronology

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ACRONYMS

APG	Angiosperm phylogeny Group
COP	Conference of Party
UNEP	United Nations Environment Programme
DoFPS	Department of Forest and Park Services
WMD	Watershed Management Division
MoAF	Ministry of Agriculture and Forest
RNRRDC	Renewable Natural Resources Development Center
CNR	College of Natural Resources
IUCN	International Union for Conservation of Nature
CITES	Convention on International Trade in Endangered Species for flora and fauna
NDRC	Non Disruptive Road Crossing
BSc	Bachelor of Science
RSG	Rufford Small Grant
UWICE	Ugyen Wangchuk Institute of Conservation and Environment
GPS	Global Positioning System
SPSS	Statistical Package for Social Science
Masl	Meter above sea level
DB	Diameter at breast height
Db	Diameter at base
Ha	Hectare
Ht	Height
m	Meter
m^2	Meter square
Nob	Nobding
Lam	Lamperi
Temp	Temperature
g	gram

CHAPTER ONE

Introduction

1.1. Background

Bhutan is centrally placed in the distribution of the rich Eurasian flora and is home to primitive angiosperms like *Decaisnea insignis* Walter and vesselless primitive angiosperm *Tetracentron sinense* (Oshawa, 2012). The study on habitat ecology, regeneration structure and radial growth performances of tertiary relic plant of *T. sinense* is felt significantly urgent owing to endemic and concerns of future extinction in biodiversity hotspot country. Species are major pillar of Earth's life support that is biologically rich and greatly threatened by numerous factors. Earth's climate has been persistently changing due to enhanced anthropogenic activity and added to the impact of natural forcing regimes on climate tremendously. (Jansen *et al.*, 2007). Threats to biodiversity from climate factors could be acute in the Eastern Himalaya, which is rich in endemic species that have narrow and restricted ranges of distribution (Root *et al*., 2003).

T. sinense is a tertiary relic plant, primitive, endemic, monotypic species, vessel less angiosperm with peculiar remnant botanical features. According to the paper written by (Fu, 1992) cited in (Xiaohong *et al*., 2013) is stated as 'rare' in International Union for the Conservation of Nature (IUCN). *T. sinense* is listed in Appendix III in CITES (Convention on International Trade in Endangered Species) and only occurs in a few restricted areas in East Asia (Doweld 1998; Fu and Bartholomew 2001; Qin 2004). The rapid destruction and fragmentation of natural habitats are the principal causes of species extinction throughout the world (Crooks & Sanjayan, 2006). *T. sinense* conservation is of great concern for China and for the world, because of their rarity and their phylogenetic traits.

The environmental factors like soil, slope, aspect, temperature, rainfall play decisive role in plant persistence for biological diversity to thrive in particular site. The composition, structure and vegetative functions of surrounding species are also most critical ecological attributes which indicates huge variations in response to environmental as well as anthropogenic variables. The associated species play a vital role in growth of particular species through ecological interaction of neutralism, amensalism, commensalism, parasitism, mutualism and allelopathy resulting different forest composition and structure. The size distribution are useful indicator of forest structure and dynamic of species population assessing through inverse J shape, uni-modal and sporadic distribution.

The formations of narrow and wide rings in tree make up a specific pattern as a response to environmental factors such as light, temperature, drought, soil properties, wind direction, and anthropogenic causes. Radial growth performance with climatic factors will determine the adaptability of relic species as climatic factors is the decisive role for plant growth, but all species will not record the signal for climate reconstruction due to low sensitivity. As climatic change discussions are on focus everywhere, it is imperative to understand the ecological habitat and growth performances of endemic plant with climatic factors to formulate conservation policy to avoid further extinction from this landscape

1.2. Problem statement

T. sinense populations in the wild are reduced by forest destruction and over exploitation, its distribution is scattered, and it is listed as a rare and threatened species in China (chen *et al.*, 2007). Tertiary relict species is not widely distributed and found in restricted geographical area. The information on growth respond and habitat ecology of this species is not available and highlighted in any studies. The lack of basic ecological information including the importance of relict and endemic plant species may lead to the loss of biodiversity principally primitive and relict plants (Wangda *et al.*, 2013). As the species remained least concerned, documentation with its habitat ecology, regeneration structure and radial growth performance is fundamental for conservation and management action for endemic plant.

1.3. Research Objectives

1. Clarify the habitat, environmental attributes and associated floristic composition of *T. sinense.*
2. Find out the regeneration mechanism of *T. sinense* and
3. Investigate the radial growth performances of *T. sinense* in relation to climate change

1.4. Research question

1. What are the environment characteristics and species associated for growth of *T. sinense?*
2. How is the regeneration of *T. sinense* thriving in western Bhutan?
3. How *T. sinense* respond to climatic factors?

1.5. Conceptual framework model of the study

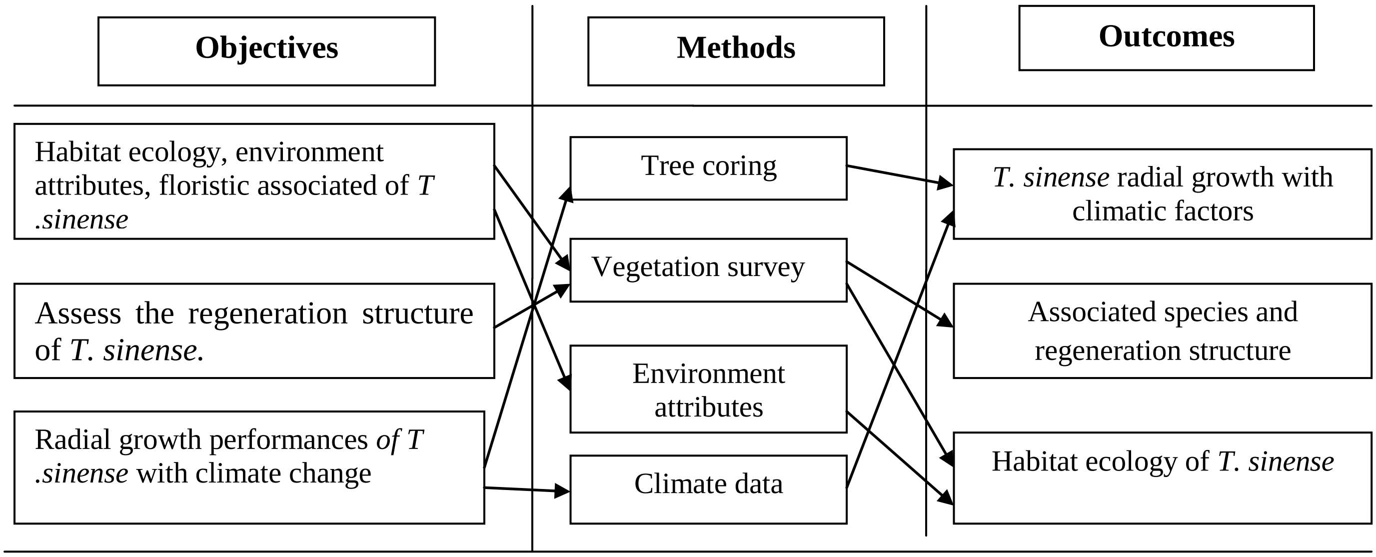

Figure 1.1. Conceptual framework for the study

1.6. Evolution of *T sinense* in taxonomy

T. sinense is under Tetracentracea family and order Trochodendrales with subclass hamamelidae and in class magnoliopsida. Tetracentron is one of the earliest branching eudicots (APG, 2009). The homoxylic genera Tetracentron and Trochodendron included in monotypic families of Tetracentraceae and Trochodendraceae respectively (Doweld, 1998). They occupy relatively stable and unquestioned position among primitive, in ` lower ' Hamamelididae. Prantl (1888) was the first to publish a family name for Trochodendraceae in line with the rules of botanical nomenclature and provisionally stated that Tetracentron merits familial rank, although he continued to treat the genus as belonging to a sub family of Magnoliaceae. Nevertheless, Hallier (1912) removed both genera from Magnoliaceae and placed them into a distinct tribe of Hamamelidaceae.

The inclusion of Trochodendron and Tetracentron in Hamamelididae is supported by modern studies of oral morphology and anatomy (Endress, 1986). Crane *et al*. (1989) demonstrated a highly isolated, basal position of Trochodendron and Tetracentron within their subclass, but continued to treat them as natural hamamelids. Tetracentron share the common feature with Trochodendron of lacking vessel element in wood, unusual in angiosperm and considering very primitive resulting classification into two genera in basal position in the angiosperms. However, research on molecular phylogenetic by Angiosperm phylogeny Group and many other shown that these two genera are not basal angiosperm, but basal eudicots. The occurrence of this primitive species in the Bhutanese cool temperate forests indicates their strong connection to both East Nepal and South West China. It may penetrate into East Himalaya from South West China through "Himalayan corridor", and reach to the Iswa valley, one of the tributaries of the Arun River, East Nepal (Ohsawa *et al*., 1983).

1.7. Morphological characteristics

T. sinense is a bisexual deciduous broad leaved canopy tree up to 40 m or tall with arching branches. This tree is typically medium sized deciduous tree with a broad rounded crown that features gracefully arching branches clad with alternate, acuminate (pointed), heart-shaped (rarely truncate rounded) and leaves up to 3 - 5" long with rugose surfaces and 5-7 palmate veins. Twigs are grayish brown with leaves alternate on the current shoot. Inflorescences are short pedunculate with 80 – 125 sessile flowers. Flowers are yellowish green and hermaphrodite. There are 4 sepals and are ovate orbicular but petals are absent. There are four stamens and are exerted at anthesis, and then the filaments are subterete or slightly flattened. Anthers are dehiscent by a lateral slit. There are four styles and are erect at first, and then become recurved and subulate at anthesis. Stigmas are along the ventral surface of the style. The inflorescence is spiked. Flower buds appeared at the end of April in this population.

Flowering started by the beginning of June, and reached its maximum by the beginning of July, and finished at the beginning of August. Fruiting started four weeks after the commencement of blooming. Fruits became mature by the beginning of October. Thus, the flowering period of the population lasted for about two months, and fruiting period for about 3 months. The weight per 1,000 seeds is 0.87– 0.9 g. Seeds are minute and wind dispersed with serrated margins.

CHAPTER TWO

Literature review

2.1. Tree rings and climatic factors

Tree rings are formed in perennial dicotyledons (deciduous and coniferous trees) that grow in regions with a pronounced seasonality (Raven *et al*., 1999). Tree growth is natural process of recording the event of occurrences in the environment about the local climatic condition during its survival by density of wood within each tree ring. Trees respond and exhibit to their surrounding environment and are subject to climatic parameters such as fluctuation in temperature, wind direction, precipitation, drought, cloudy day, soil moisture. (Fritts, 1976). Any environmental change has an impact on tree growth; the impact may be immediate or lagged by one or more years. The natural ranges of climate system can be reconstructed from the examination of past through tree ring analysis (Morgan *et al*., 1994).

Climatic factor influence the growth of tree ring width across all spatial and temporal scales recording the trends of past climatic phenomena. The vegetation change and ecological respond with climate variation in particular area can be demonstrated in tree ring. (Friedrich *et al*., 2004). The annual growth of a tree is the result of many complex and interconnected biochemical processes and physiological factors as tree directly interact with the local environment by leaves and the roots. The information from dendroclimatology provide significant information of past climate change and further enhance to understand the climate variability that should hold true in future. (Vaganov *et al.,* 1999). Variation in wood density, isotopic composition and ring width have all proven to be potential sources of palaeo climatic information (Hughes *et al.,* 1982). Tree rings generally grow wider during warm periods and narrower during cold periods, so the rate of tree growth provides a picture of Earth's temperature over the past centuries.

2.2. Primitive and rare species in Bhutan Himalaya

T. sinense is vessel less angiosperm and has tracheid like gymnosperm for water transporting tissue. Eastern Himalaya is one of the world's famous hotspot and rich repositories of biodiversity. The region is also a meeting ground for the Indo-Malayan, Palaearctic, and Sino-Japanese biogeographical realms with diverse ecological, altitudinal gradients and an associated diversity of flora and fauna (CEPF, 2007). The most fragile ecosystems are easily affected by the slight change of the environmental restriction. These changes of climatic condition will subsequently affect the biodiversity of the region as a whole (Brooks *et al*., 2006).

It is now rare in its native habitat, because of a poor ability to regenerate. It is currently listed on Appendix III of Convention of International Trade of Endangered Species (CITES). Many Tertiary relict tree species are now represented by only a few living specimens in China and *T. sinense* conservation is of great concern in the world, because of their rarity and their phylogenetic traits (Tang, 2013).

2.3. Habitat distribution pattern

T. sinense is native to southern China and the eastern Himalaya, where it grows at altitudes of 1100 – 3500 m.a.s.l in a temperate zone. It is native to streams margins, forest margins, moist slopes and bottomlands in central to southwestern China, northern Vietnam, northern Myanmar (Burma), eastern Nepal and northeastern India. No information is traced out from Bhutan Himalaya. *T. sinense* occurred in unstable habitats by stream banks, on steep slopes, on scree slopes, or on roadsides near streams in narrow valleys, all places subject to frequent natural disturbances, whereas none were found on stable gentle slopes free of major disturbances at similar altitudes.

Its altitudinal distribution range was found to be 500 – 2900 m in ravines or valley bottoms of the Himalaya region (Ohsawa, 1987). During flowering and pollination in natural population, the decrease of population density and harsh environmental condition might be one of crucial reasons resulting in endanger for this species (Gan *et al.*, 2013). The global climate change is also producing severe impacts on plant diversity, which have already been recognized by Chinese authorities (NDRC, 2007). The incidence of natural disasters such as floods, forest fires, landslides, storms or droughts which have direct effects on biodiversity. The habitat is not confined as fragmentation of ecosystems is evident as the region faces pressure from migration, economic development, and population growth as well as from climate change for endemic plants. (Beniston, 2003).

2.4. Influence of climatic factors on species extinction

Temperature is an important factor affecting forest growth and survival attributed with water availability, which results from rainfall, snowfall in mountains and the soil‘s capacity to store water are considered as the most relevant parameters especially during critical phases such as spring and early autumn (ELRAD, 2009). Climate has major influence on the rate of photosynthesis and respiration and on other forest processes acting through temperature, moisture and radiation regimes over medium and long time periods (UNEP, 2009). The Eastern Himalaya is known for diverse habitats and eco regions that are subject to a high level of human induced threats (Myers *et al.*, 2000). The climate change is already forcing change of biodiversity and ecosystem to adopt shifting in habitat, changing life cycle and the development of new physical characters.

Threats to biodiversity from change in climatic factors could be severe in the Eastern Himalaya, which is rich in endemic species that have narrow and restricted ranges of distribution (Root *et al.*, 2003). The endemic plant species are considered more vulnerable to change in climatic factors and may face high risk of extinction due to their confined geographic distribution. Human induced activities and climate change threatens biodiversity and heightens the impacts of climate change on population and ecosystems (Gitay *et al.*, 2002).

2.5. Environment characteristics

The surrounding floristic diversity plays a crucial role in growth of particular species. Some species rely on each other (co-existence) and some are parasite which entirely depends on other for survival. Environment factors are important for plant species to thrive in that particular site. The distribution of plant habitat is closely related to topography and landform (Fakhireh *et al.*, 2012). The establishment, growth, regeneration and distribution of the plant communities are controlled by many factors, such as geographical position, physiographic features, climatic factors, and human impacts. (Ozcelik *et al.*, 2013). Changes of aspect have different effects on forest growth owing to its influence on solar radiation, air temperature and wind speed. Different plant species will respond differently to climate change and environment factors so as to endemic species. Some species will stay in place but adapt to new climatic conditions through natural selection system. Other species will move to higher latitudes or altitudes and some species may become extinct with competition and selection (Keutgen *et al.*, 1997).

2.6. Floristic composition, structure and regeneration pattern

Floristic composition and structure of a forest also revealed a difference in species richness, density and basal area due to factors like topography, soil conditions and canopy opening (Coelho *et al*., 2012). Forest structure is the way in which the attributes of trees are distributed including essential features like structural type, size, shape and spatial distribution of vertical and horizontal (Gadow *et al.*, 2012). Forest is structurally complex plant communities and its main characteristic features are their species richness. Species diversity is related to spatial environmental heterogeneity, such as variability in habitat conditions, altitudes and topography (Tang *et al.*, 2012).

Tree size distributions are useful indicators of the structure and dynamic of the tree population. Inverse J-shape distribution has been regarded as a proxy of population growth or dynamic equilibrium while a uni-model distribution, with comparatively fewer juveniles relative to adults has been taken as evidence of population decline. The sporadic type model is due to intermediate disturbance. Poor regeneration of the tree species were noticed in disturbed natural forest and removal of understory evergreen shrubs (Wangda *et al.,* 2009). Thus, Inverse J shape, uni-model and sporadic distribution are the indicator to assess the pattern of regeneration.

2.7. Conservation threat

T. sinense is a tertiary relic plant, primitive, endemic, monotypic species and vessel less angiosperm with peculiar remnant botanical features. It is confined in East Asia and is scarcely distributed (Gan *et al.,* 2012). The rapid destruction and fragmentation of natural habitats are the principal causes of species extinction throughout the world (Crooks & Sanjayan, 2006). The risk of extinction will increase especially for those that are already at risk due to factors such as slower life history trait, limited dispersal abilities, low reproduction rate, small population size and specialist and range-restricted species, limited climatic ranges, or occurrence on low-lying islands or near mountain tops. (Campbell *et al*., 2009). *T. sinense* conservation is of great concern for the world, because of their rarity and their phylogenetic traits.

CHAPTER THREE

Material and methodology

3.1. Study area

T. sinense is rare and found only at Lamperi in Toepisa block under Punakha district and Nobding in Dangchu block under Wangdiphodrang district. The total area of Toepisa block is 102. 79.4 Sq.km ranging elevation from 1826 m.a.s.l to 3309 m.a.s.l. Dangchu block has a total area of 171.23 Sq. km hectare and elevation ranging from 2475 m.a.s.l to 4117 m.a.s.l. harboring rich biodiversity of endemic plants as attitudinally lies in transitional zone of humid broadleaved to conifer forest zone.

3.1.1. Map of study area

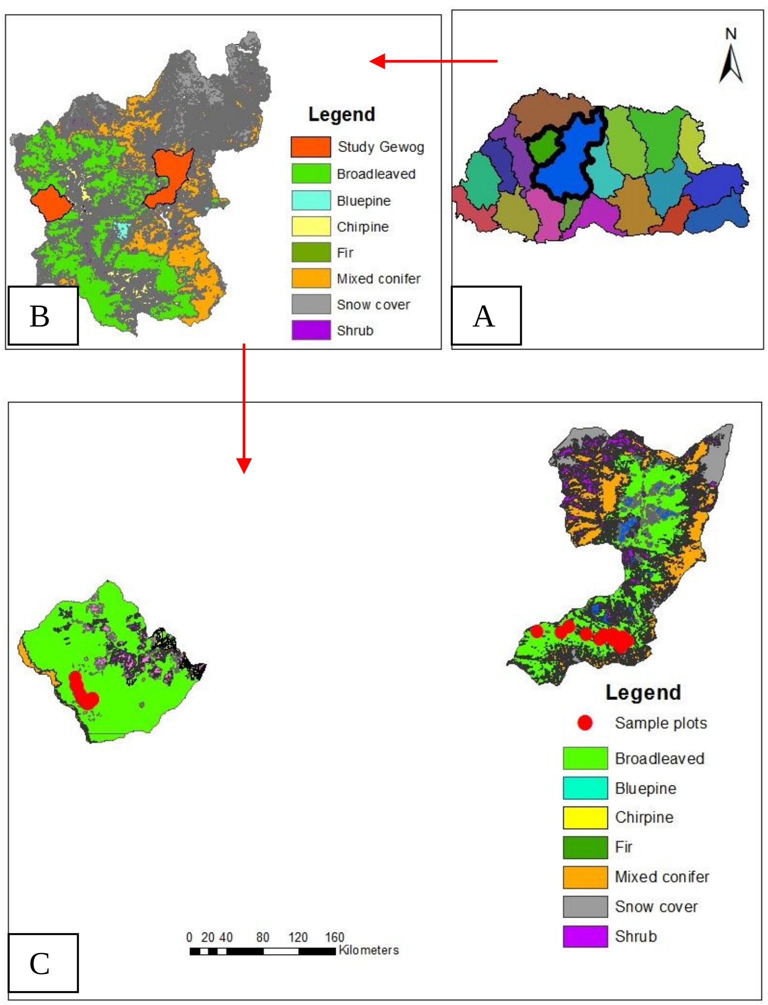

Figure 3.1. Map of study area

3.1.2. Climate

The climate data was gathered from Nobding meteorology station commencing from 1996 to 2012 and Thinley gang meteorology station from 2004 to 2015, for Lamperi as it is nearest available nearest station. Nobding has highest record of 24.79 °C in July, 2003 and lowest temperature of -2 °C in December, 2008. Similarly, the highest record of temperature in Lamperi is 29.09°C in the month of August, 2006 and lowest is -1.7 in December, 2008. The highest record of rainfall is 15.72 mm in July, 2010 for Nobding and 12.09 mm in July, 2010 in Lamperi. The monthly climatic condition is illustrated (Figure 3.2).

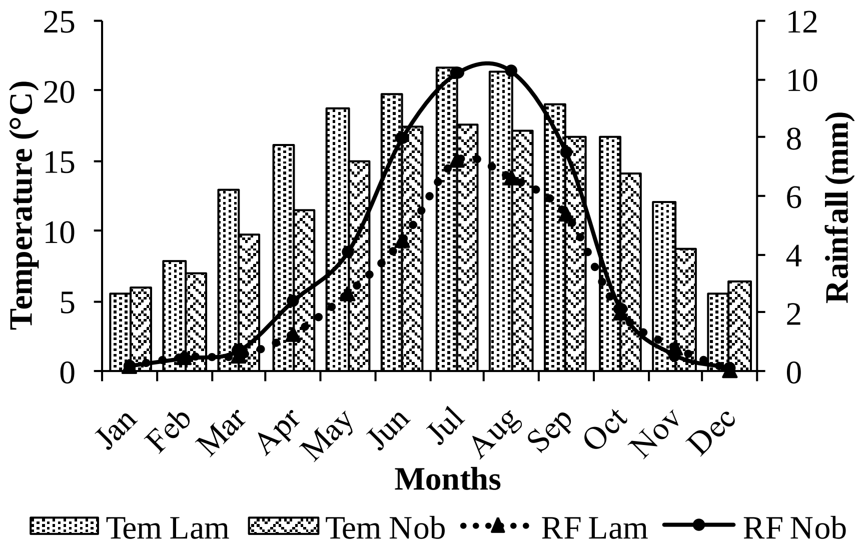

Figure 3.2. Monthly climatic condition over years (Department of Hydromet Service, MoEA)

3.2. Material required

The materials used in the field work are: GPS, Increment borer, Sunto clinometers, Compass, Diameter tape, Measuring tape, Digital hypsometer, transponder, bamboo tubes, Masking tape, Permanent marker pen.

3.3. Methods

Rare plant species are sparsely distributed across the landscape, appearing infrequently and confined to certain range. Meandering technique was carried out to maximize coverage of suitable habitat of species (Lancaster & Robson, 1998). Targeted samplings were done for coring and subsequently vegetation assessment was also done.

3.3.1. Tree core sample collection

Two cores from each tree were obtained along the contour line with code C1 (left) and C2 (right) referring from uphill. Another two cores were extracted along the slope with the code ID S1 (downhill) and S2 (uphill) which DBH ≥ 80 cm. After coring, samples were stored in bamboo tubes to dry naturally and core ID was given serially. The parameters like diameter at the base (db), diameter at breast height (dbh), height of the trees (ht) and other factors such as aspect, slope, and altitude were recorded.

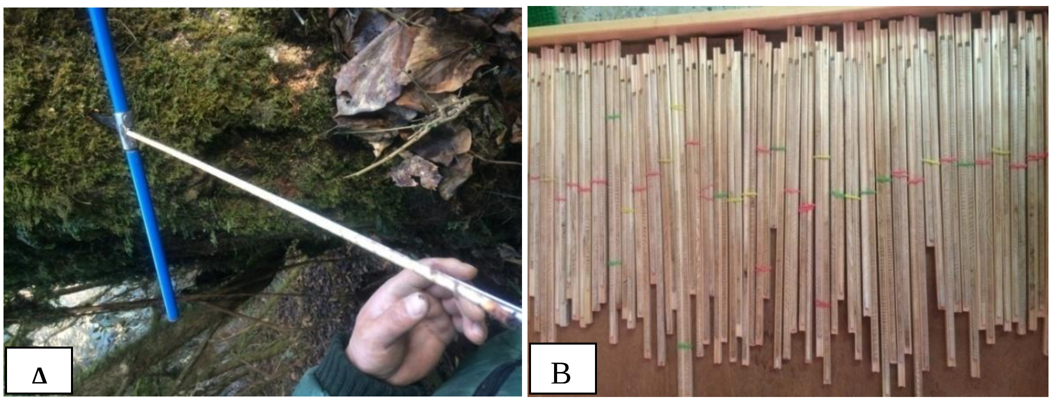

Figure 3.3. Extracting core (A) Sample after sanding (B)

3.3.2. Laboratory method

Core samples were mounted on applying fevicol glue, band with masking tape and dry for a day. Core samples were polish to half their size using belt sander machine to make sure the tree ring sequences are clearly visible. Then the sanding of samples with different grit of sand papers to obtained maximum visibility of ring.

3.3.3. Assigning of year against ring

Ten best samples were selected having both wider and narrow ring, maximum age for skeleton plotting. The ring width was counted from the peripheral part of the ring starting from the bark, after the bark one ring was count for year 2015 as there was no growth formed for 2016. While reaching at the fifth ring, marked one dot for 2010 and consecutive counting of every after ten rings. Two dots were marked for every after run into half century and three dots for one century.

3.3.4. Cross dating for skeleton plotting and Composite plotting

Skeleton plotting for ten samples was built to construct master chronology/composite plotting to serve as bench mark and to relate against the rest of samples. The intensity of narrowness and wider is compared to immediate neighbor ring. One grid box on graph paper denotes one year and commence from extreme right edge of graph paper maintaining interval of one decades corresponding from bark of the sample. Narrowest ring was marked with bar of ten small grid perpendicular to year assigned. Widest ring were marked ‘B’ and average ring was not given bar. Composite graph was drawn based on ten skeleton graphs to serve as master chronology as references to other samples cores. Ten graphs were arranged in sequence of same year and rating was done against all respective years. The other core samples were dated by referring to the composite sheet

3.3.5. Vegetation survey

Vegetation survey was conducted to examine the dominant associated species in *T. sinense* community. The plot sites were determined by existence of *T. sinense* stand and correspondingly laid around. The vegetation assessment was carried in 8 plots from Lamperi and 15 plots from Nobding. Tree diversity (Height ≥ 1.3 m) was recorded with DBH and height within quadrate of 20 m x 20 m. occasionally, clustered stand of *T. sinense* appeared within the quadrate. Sub plots of 2 m x 2 m in centre were laid to determine regeneration (Height < 1.3 m) and relative abundance of ground vegetation was recorded.

3.3.6. Soil sample collection

Soil samples were collected by setting small quadrate (0.5 m by 0.5 m) from *T. sinense* habitat site to obtain soil parameters to determine the preferred habitat of species. The samples were collected from different regime; from highest and lowest elevation of *T. sinense* habitat, clustered and scattered population of *T. sinense* habitat to examine the possession of different soil parameters.

3.4. Data Analysis

3.4.1. Core samples and ring width measurement

Core samples were measured for the annual rings count by using the J2X program. Tree ring Sequences were measured under a stereo microscope to apprecision of 0.001 mm using the computer based travelling stage in laboratory. These annual ring measurement data was verified by using COFECHA software program to eliminate error due to cross-dating.

3.4.2. Diversity

Species diversity index (*H*') was calculated by using Shannon and Wienner Diversity index where the species evenness (*J*') was calculated using Pielou's method (1969).

$H' = -\sum_{i=1}^{s} pi * pi \ln Pi$--------------Equation 1

Where; Pi= n_i/N

n_i= the number of individual in species *i*, the abundance of species *i*.

N= total number of all individuals.

S = the number of species which is also called species richness.

p_i = the relative abundance of each species. $J' = \frac{H'}{\text{Ln}\,(S)}$--------Equation 2

Where H' = Shannon wiener diversity index; S = Total number of species (species richness)

For the ground cover vegetation, volume (biomass) was used as a species abundance measure. Volume was calculated by multiplying the height of tallest individual by the percent coverage of each species (V=max Ht in cm*C %) ----------------Equation 3

3.4.3. Dominance

The RBA of each species was used as abundance of species and the dominant species in each plot were determined by dominance analysis (Ohsawa, 1984).

RD % = $\frac{\text{Volume of individual plant speceis}}{\text{Total volume}}$ X 100-----------Equation 4

3.4.4. Composition

Composition was analyzed running through pivotal table using species diversity. Composition for both species level and life form were analyzed.

CHAPTER FOUR

Result and Discussion

4.1. Habitat of tertiary relic plant *T. sinense*

T. sinense thrives in humid broad leaved of evergreen and deciduous forest up to transitional zone of mixed conifer in unstable habitats of frequent disturbances, steep slopes, rocky cliffs, stream margin, roadsides, and in bamboo coverage. These are the principal controlling factors of the distribution and survival of *T. sinense* in Bhutan as similar result is also reported by Tang *et al.* (2013) in china.

The habitat for phylogenetically isolated endemic plant is floristically heterogeneous responding to environment factors, topographic situation, and disturbance regimes. It is light demanding species; appearing to be stress tolerant and their regeneration depend entirely on disturbances with little or no competition from other species (Juan *et al.*, 2008). The main companion species of *T. sinense* communities in both sites are *Q. oxyodon* under fagaceae family in evergreen tree life form, *A. campbellii* and *A. sikkimense* under Acerceae family under deciduous tree life form. *Daphne bholua* Buch *et al*, and *Ilex dipyrena* Rehder are dominated species for the regeneration category in *T. sinense* habitat area. *Sarcococca saligna* Don under buxaceae and *Yushania mycrophylla* Munro *et al*, under gramineae family are the dominated ground cover species in *T. sinense* community area.

4.1.1. Aspect and slope

All 8 plots in Lamperi and 11 plots in Nobding face North East aspect. Most of the forest vegetation occurs on the habitats with northern exposures and in moderate slopes (Jiang *et al*., 2007). Rigg (1993) point out that, north facing slopes generally have less sunlight and in turn have higher moisture levels and greater vegetation establishment resulting in more organic matter. This is due to the high moisture towards northern aspect as per finding of Wangda *et al*. (2010).

It was found that, the average slope gradient is comparatively low in Lamperi than Nobding in *T. sinense* habitat area with average of 49% and 76% respectively. Topographic factors such as the orientation of the hill slope and the steepness of the slope affect the microclimate, vegetation establishment, water movement, and erosion (Birkeland, 1984).

4.1.2 .T. sinense plots location

T. sinense appears at highest elevation of 3038 m and lowest of 2696 in Nobding. Similarly, Lamperi has highest elevation record of 2845 m and lowest elevation of 2468 m of *T. sinense* growth. Its altitudinal distribution range was found to be 2500 – 2900 m in valley bottoms of the Himalayas as reported by Ohsawa (1987). The graph (Figure 4.1) depicts the plots distribution in two sites, the plots descent from high elevation in Nobding and ascent from low elevation in Lamperi. The altitude from 2700 to 2800 m is the prominent ranges of *T. sinense* habitat as ascertained by clustered population predominately with similar content of soil properties from both study sites.

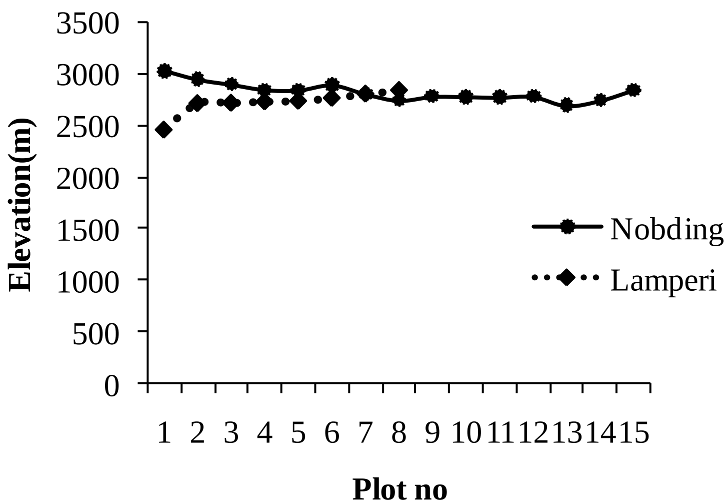

Figure 4.1. Location of study plots in the two sites

4.1.3. Soil factor

There are differences of soil properties between two sites (investigated in 4 plots) in *T. sinense* community, the content of moisture and organic carbon is relatively high in Lamperi as depicted (Figure 4.2). It is attributed owing to plain topography as a result of decomposition and accumulation of organic matter as reported by Walker *et al.* (2000).

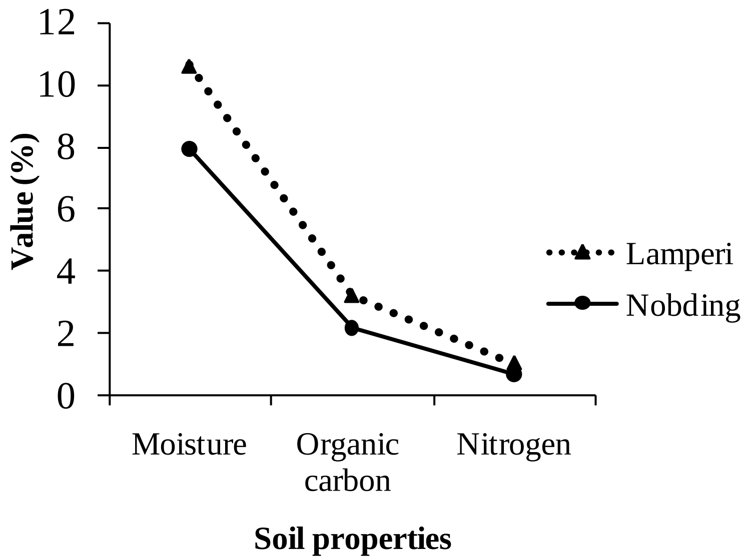

Figure 4. 2. Trends of soil moisture, organic carbon, nitrogen in two sites

Comparatively, Lamperi plots with cluster population of *T. sinense* has slightly higher soil properties like moisture, organic carbon, nitrogen, pH but low phosphorous than plot with clustered *T. sinense* in Nobding. Soil pH decrease down the elevation in both the study sites and same result was also reported by Rigg (1993). It is due to soluble salts such as chlorides of calcium and magnesium are transported down slope along with moisture (Birkeland, 1984). *T. sinense* density does not vary with changing soil properties. The highest elevation (Plot 1) has average of all soil characteristic favoring growth of 1 no of *T. sinense*. In contrast, lowest elevation (Plot 8) has highest moisture, highest organic carbon, and pH favoring 2 nos of *T. sinense* growth in Nobding (Table 4.1). In Lamperi, Plot 6 at elevation 2743 m has highest *T. sinense* density with all average soil properties except high pH. The general pattern of organic carbon trends to decline with increasing altitudes and lowest organic carbon thrive maximum number of *T. sinense* (plot 6) in Lamperi.

As reported by Kumer *et al.* (2012), the stocks of soil organic carbon is found to be decreasing with altitude and the decreasing trend of carbon might be attributed to the lower mineralization rate and net nitrification rate at the higher altitude. It has also reported that, the characteristic decline in vegetation with increasing altitude results in less accumulation of litter and low input of organic carbon in soils.

Table 4.1. Soil properties in varying population of *T. sinense* in two sites Nobding (Table A) Lamperi (Table B)

Table A

Plot No	Altitudes	No of TS	Moist (%)	OC (%)	N (%)	pH H2O	Avail P. mg/kg
P1	3038	1	5.71	1.37	0.47	6.85	7.5
P6	2898	2	9.2	2.4	0.8	6.86	25.0
P8	2748	2	11.1	3.1	1.0	6.91	21.5
P10	2784	3	5.7	1.9	0.5	6.55	45.5

Table B

Plot No	Altitudes	No of TS	Moist (%)	OC (%)	N (%)	pH H2O	Avail P. mg/kg
P1	2468	1	11.4	3.6	1.1	6.63	10.0
P2	2720	4	9.6	4.0	1.2	6.76	30.5
P6	2743	7	10.4	2.3	0.9	6.76	24.0
P8	2845	2	11.1	2.9	0.9	6.33	33.0

Stem density of *T. sinense* does not fluctuate with variation of nitrogen content in *T. sinense* community. There is negative correlation between stem densities of *T. sinense* and nitrogen content, ($r = -.257, p > .05$). Nitrogen content in the soil alone has no significant effect in the population density *of T. sinense* in the plot.

4.2. Floristic composition of major life form

In Nobding, a total of 19 tree species belonged to 14 families classified to 4 major life form of conifer, deciduous, evergreen tree and evergreen shrub were enumerated as associated species of *T. sinense*. *Q. oxyodon,* an evergreen tree life form has highest composition based on relative basal area. A total of 7 families with 10 species classified to 4 major life form of evergreen shrub, conifer, deciduous and evergreen trees were recorded in regeneration category. *D. bholua*, an evergreen shrub has highest composition based on relative density in *T. sinense* community area. Similarly, ground covers of 10 families with 14 species were recorded and are classified to 5 major life form as evergreen shrub, herb, fern, climbers and bamboo. *Y. mycrophylla* has the highest and dominated in *T. sinense* habitat area as also reported by Tang *et al*. (2013).

In Lamperi, 22 species belonging to 17 families classified to 5 life form of evergreen tree, deciduous tree, conifer tree, evergreen shrub and deciduous shrub were recorded. *Q. oxyodon* under evergreen tree life form has highest composition based on relative basal area. (Annexure 15). The regeneration survey revealed a total of 11 species within 9 families under 4 life forms from such as evergreen shrub, evergreen tree, deciduous shrub and deciduous tree. *I. dipyrena* was found most dominant composition. Correspondingly, 24 species belonging to 17 families classified to 5 life forms. *S. saligna* under evergreen shrub dominates the composition from *T. sinense* habitat area from 8 plots.

4.3. Structure of *T. sinense*

4.3.1. Height and DBH

The DBH growth has direct impact on height of tree as the parameters are commonly used to measures of tree growth and size. (Sumida *et al.*,2012). The relationship established (r =.410, p < .05) is positively correlated. Simple regression equation, (R^2=0.434, ŷ=0.28x+9.40) showed that only 43% of independent variable of height depends on DBH for its growth and rest 57 % remained unexplained. It further conveyed that when DBH is 0, height is already 0.28 m or increase in one unit of DBH raise height by 9.40 m. (Figure 4.3 A & B) in Nobding.

Similarly, there is positive correlation between DBH and height of *T sinense* in Lamperi where (r =.708, p =.001). The association of depending and independent variable is statically significant. Sumida *et al.* (2012) point out that, relationship indicates that the amount of leaves on a tree was an important factor in DBH growth and then height for the process of photosynthesis. The strength in simple linear regression equation, (R^2=0.501, ŷ=0.291x+2.654) explained that 50% of independent variable height is dependent on DBH and remaining 50% remained unexplained. It explained when DBH is 0, height was already in 0,291 or an increase in one unit of DHB will raise height by 2.654 m. (Figure 4.3 C & D).

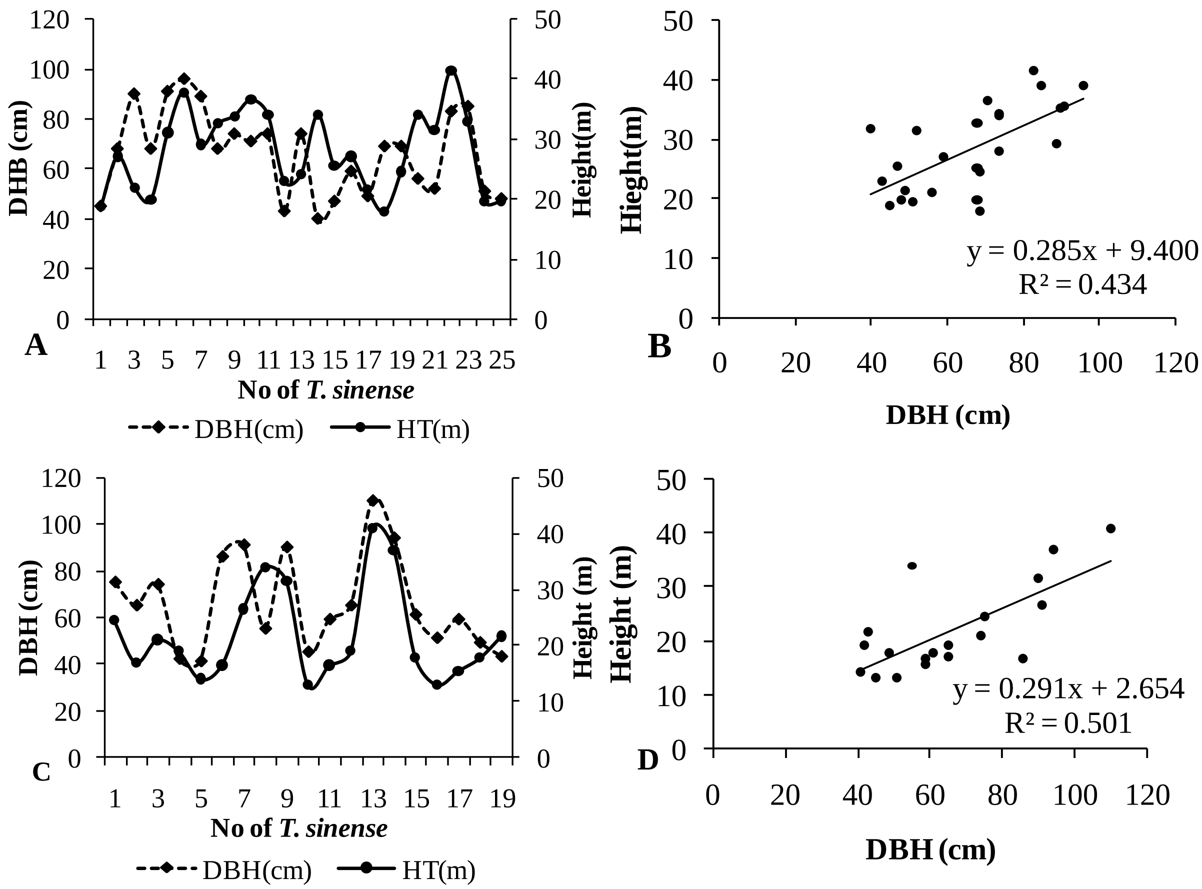

Figure 4. 3. Correlation between *T. sinense* DBH and Height for Nobding (A) Simple regression for Nobding (B) DBH and Height for Lamperi (C) Simple regression for Lamperi (D).

The unexplained attributes may be due to influential of environment factors like elevation, soil properties, topography, aspect, slope and competition from neighboring species. The anthropogenic disturbance causes disruption of forest structure and changes community composition which ultimately leads to disruption of tree population structure (Sahoo *et al.*, 2009).

4.3.2 Stem density and basal area

The growth patterns of all trees are not responding homogeneously in two sites. *T. sinense* stem density/plot trend to increase toward descending elevation (within differences of 100 m) with changes in stem density of other associate species in Nobding. Stem density of *T. sinense* respond arbitrary disparate with associated species especially in plot no 10, 11 and 12 (Figure 4.4

A). Similarly, there is dramatic variation in stem density of *T. sinense* with other associated species especially in plot no 2, 4 and 7 (Figure 4.4 B) for Lamperi. Many study revealed that neighborhood effects on individual tree growth are primarily negative, owing to competition for limiting resources (Burton, 1993)

The overall pattern of stem trends to decline with increase in DHB and height distribution in both study sites as similar finding is also reported by Sahoo *et al.* (2009) reasoning with increase competition for space and nutrients.

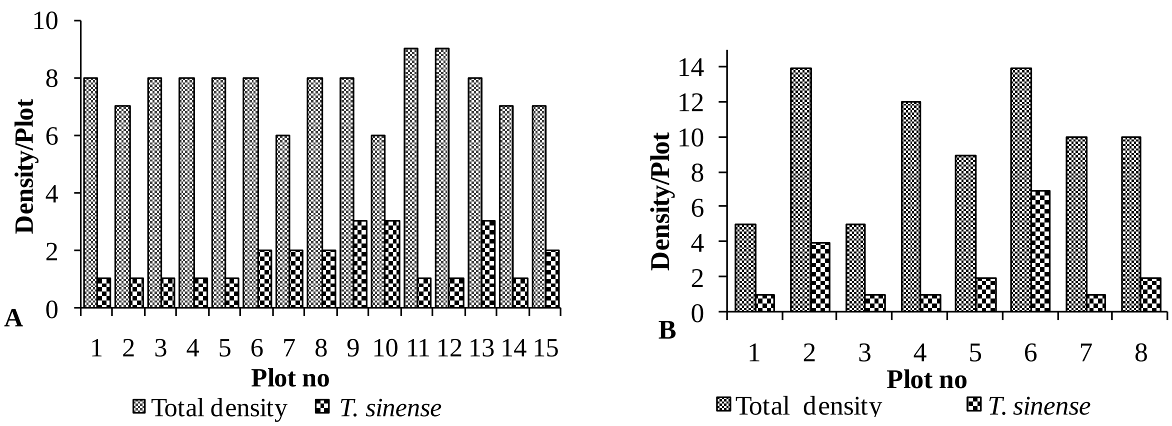

Figure 4.4. Comparative of stem densities of *T. sinense* with associate species, Nobding (A) Lamperi (B)

The trends of basal area for all plots in both sites are depicted (Figure 4.5 A & B). There are variation of basal area among plots due to differences in DBH and competition. Plot 5 comprise of 1 *T. sinense* with 8 associated stem density with lowest basal area as it lies in intense disturb area of excavated soil of road widening. Correspondingly, due to flooded area and excavated soil, same pattern of basal area variation results in plots 14 and 15 respectively as illustrated (Figure 4.5 A). Excessive disturbances factor activate to threaten the growth and survival of tertiary relic species than other associated species.

The highest basal area for associated species in Nobding is from plot 6 constituting 38,540 cm^2/plot and 13,459 cm^2/plot for *T. sinense*. Correspondingly, Plot 2 has highest basal area for associated species with 69,711.15558 cm^2/plot and plot 6 has highest basal area for *T. sinense* with 29,051.0 cm^2/plot in Lamperi. The overall average basal area in Lamperi is relatively higher than Nobding as it constitutes more stem density/plot and high DBH. The level of rainfall, snowfall, and temperature variation affects organic matter decomposition that affect accumulation of organic matter with elevation and contributing for variation in basal area and stem density (Walker *et al*., 2000).

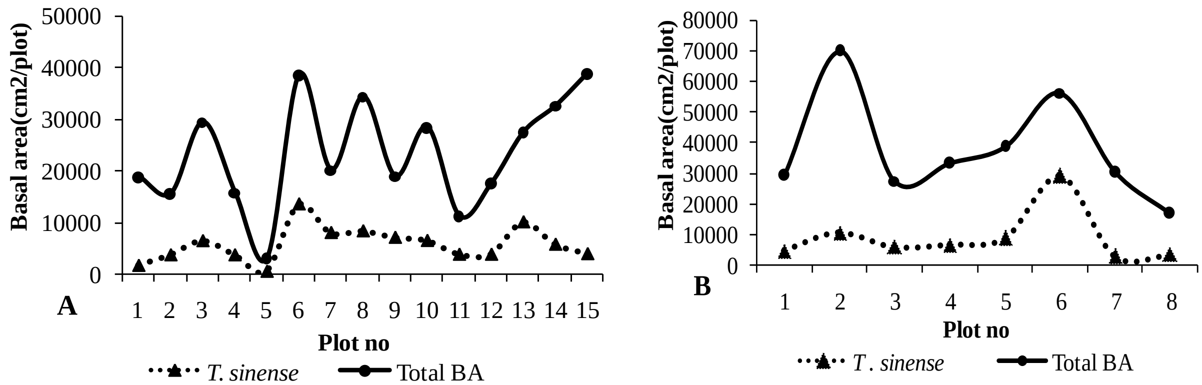

Figure 4.5. Relationship between basal areas of *T. sinense* with associated species, Nobding (A) Lamperi (B)

4.4. Dominant associate species of *T. sinense*

From the surveying of 23 plots, the main companion species of *T. sinense* are *Q. oxyodon, A. campbellii, A. sikkimense, Acer sterculiaceum* Franchetii *etal, Alnus nepalensis* D.Don, *Euonymus tingens I. diprena, Taxus baccata* Lindla, *Rhododendron grande* H. F. Tagg and *Tsuga dumosa* D.Don. The dominant species were determined using the relative basal area (RBA) of each species (Ohsawa, 1984). *Y. mycrophylla* and *S. saligna* featured dominated in under storey. The composition table for associated species segregated into life form for tree, regeneration and ground cover from two sites are appended (Annexure 3 & 4).

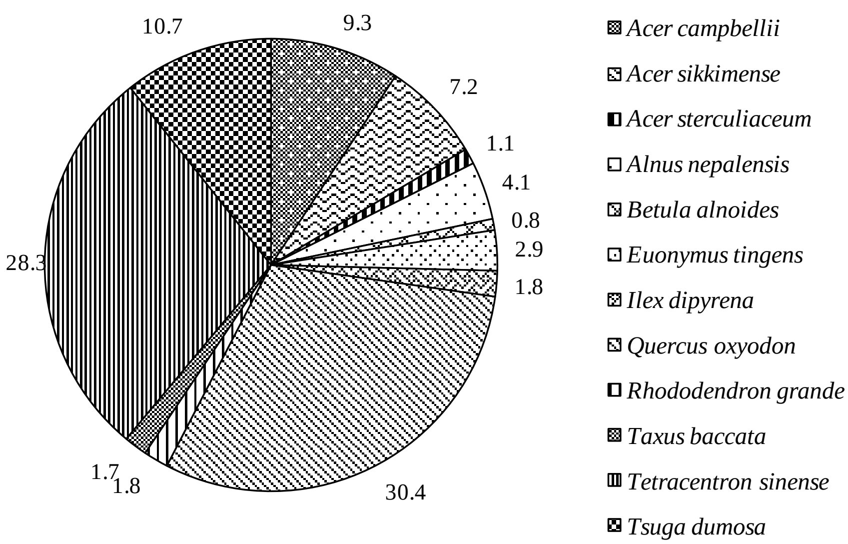

Figure 4.6. Tree dominance species in Nobding

Q. oxyodon under fagaceae family and evergreen tree life form, A. *campbellii* and *A. sikkimense* under Aceraceae under deciduous tree life form are the dominated companion species of *T. sinense* community in both study sites.

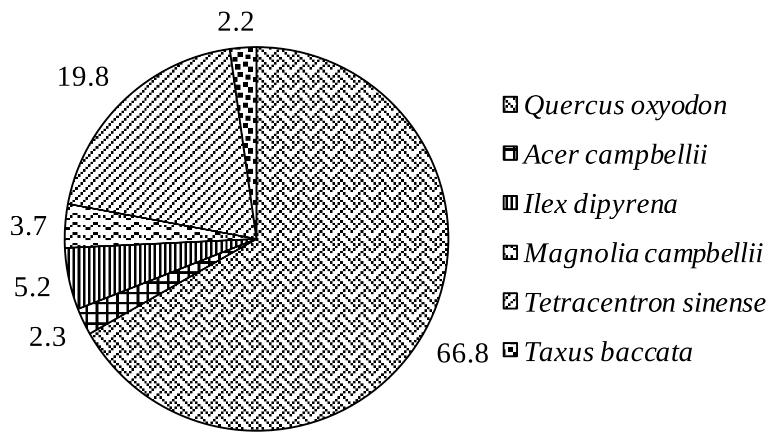

Figure 4.7. Tree dominance species in Lamperi

4.5. Regeneration modes of the tertiary relic deciduous trees

The study found out that, there was no regeneration in both the sites indicating the risk of future sustainability. The competitions from associated growing species further narrow the possibility of regeneration. *T. sinense* species is characterized by long life span with minutes wind dispersed seed as reproduction happen unstable habitat, steep terrain and disturbance sites lose the ability to profuse germination. The harsh environment factor for species habitat and low density of population during flowering and pollination is critical factor for making the poor or no regeneration traits of *T. sinense*.

Rare plant exhibit slightly higher self compatibility than common plant and lack of pollinator facilitate inbreeding depression and attributing for further rare and endangered species. (Saunders & Sedonia, 2006). It is reported by Xiaohong *et al.* (2013) that, pollinator insect for *T. sinense* exhibit nectaring behavior and not the potential pollinator. *T. sinense* depends on self pollination resulting in autogamous and geitonogamous selfing, causing inbreeding depression and reduction of genetic diversity which decrease the ability to adapt in changing environment. (Buza *et al*., 2000, Gaudeul & Bottraud, 2003). Establishment of forest species in any site depends on the ability of their seed to disperse, to germinate and to compete to survive (Cavallin & Vasseur, 2008).

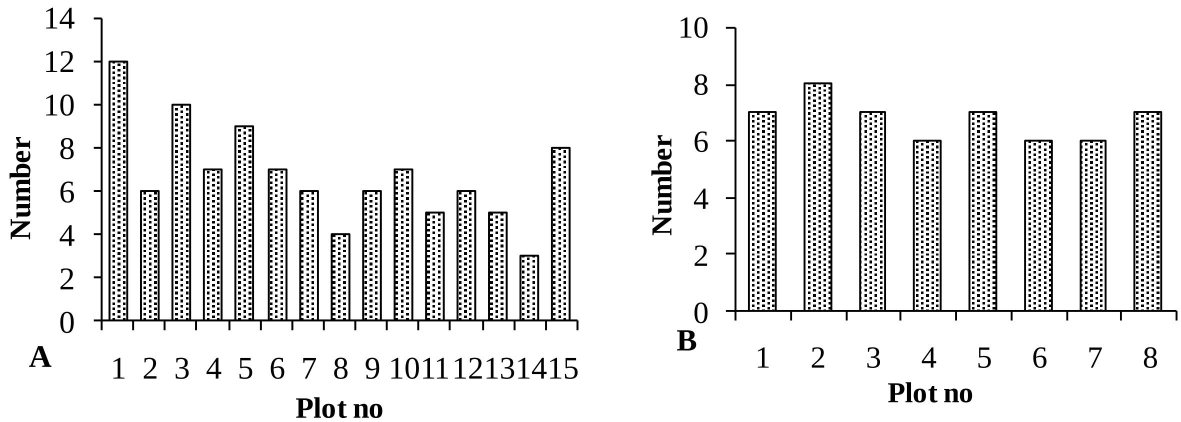

Figure 4.8. Regeneration status of associated species, Nobding (A) Lamperi (B)

The associate regeneration counts in Nobding fluctuate between the plots as location differs with accessible and inaccessible area. On contrary, regeneration in Lamperi has similar trend among plots as the area is exposed to same degree of disturbances factors.

4.6. Population structure and conservation strategies for relic species

The population of 44 stems was recorded from two study sites constituting basal area 15.66 m^2/hectare. The DBH class distribution ranges from 40 - 96 cm and height ranges from 17.8 - 41.2 m. In Lamperi, the highest DBH recorded was 110 cm and lowest was 41 cm for *T. sinense*. Conversely, the highest height was 41 m and lowest height was 13 m.

The chronology series in Lamperi revealed with suppressing and releasing in many occasions due to endogenous factors. (Figure 4.11 B). The area of frequent logging, along the roadsides, stream banks, steep slopes, landslide area and in depression are the prominent *T. sinense* inhabitant, but excessive disturbance hinder their growth. In both sites, the result portrayed that taxa have restricted in site specific geographical distributions and relatively small population sizes, which predisposes them to a high risk of extinction. During flowering and pollination in natural population, the decrease of population density and harsh environmental condition might be one of crucial reasons resulting in endanger for this species. Druary & Nisbet (1973) also emphasized on differential dispersal pattern of species adapted to grow at different point on stress gradient with different growth and survival.

The structure pattern of *T. sinense* in Nobding is uni-modal and sporadic in Lamperi site as depicted (Figure 4.9 A & B). The uni-model distribution is indication with comparatively fewer juveniles relative to adults has been taken as evidence of population decline and sporadic type model is due to intermediate disturbance (Wangda *et al.*, 2009). The variation of stand structure is due to differences in micro site factors and disturbance cause as also ascertained by annual mean ring chronologies (Figure 4.12). Tang & Ohsawa (2002) reported that, ancient relic plant survived in unstable site where there is less or no competition from other species.

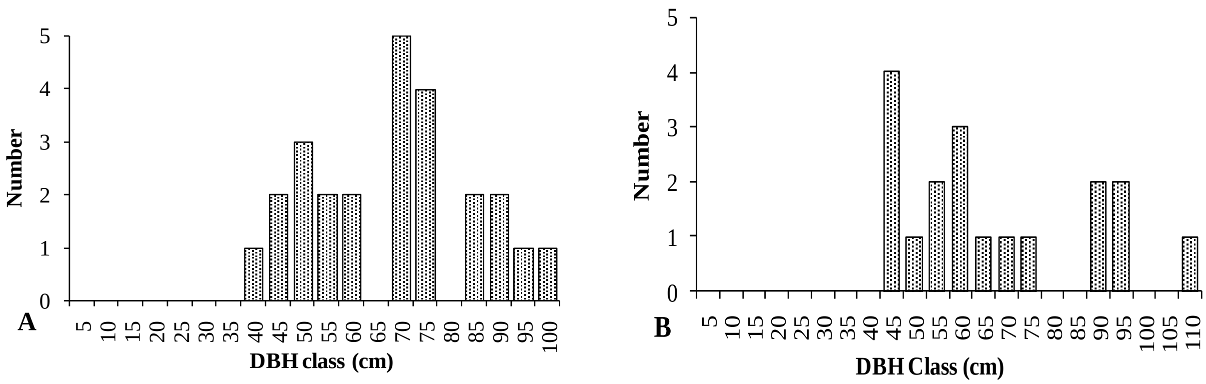

Figure 4. 9. Population structure of *T. sinense* in Nobding (A) Lamperi (B)

The reason of missing smaller recruitment may be due to grazing, leaving only matured trees in difficult area. Thus, it is pertinent to advocate the significant of endemic taxa not only due to unique in taxonomy, but more importantly, the manifestation it carry along, be it ecological, economic, evolutionary and, genetic diversity in landscape. Their conservation is of great concern in the world due to rarity and phylogenetic traits (Tang *et al.*, 2013). The protection of their habitat is crucial to enhance the regeneration reproduction and to adopt artificial means for their survival as they are at already in risk of extinction. It is significant to conserve *T. sinense* associated species in their natural habitat. It is vital to necessitate for enlarging its population and individual numbers promptly through artificial intervention as reported by (Lingling *et al.*, 2013.).

4.7. Species diversity, richness, evenness and dominance

In both sites, diversity of species was homogeneous with little differences. It is attributed as there is no huge variation of environment factors; elevation differences were negligible between plots to plots, aspect and slopes were found predominately similar, soil properties were similar. Tang *et al.* (2012) stated that, species diversity is related to spatial environmental heterogeneity, such as variability in habitat conditions, altitudes and topography. Human disturbances are also directly link with diversity with diversity decreases with increase in disturbance in any forest community as reported by Roa (1990). Diversity measure the community attributes which can determine stability, productivity and migration including different aspect of species richness evenness (Zang *et al*., 2012).

Table 4.2. Pearson's correlation with species diversity, richness, evenness and dominance Nobding(Table A) Lamperi (Table B)

Table A

Attributes variable	Diversity(H')	Richness(S')	Evenness(J')	Dominance(D)
Diversity(H')	1	.610*	.939**	.725**
Richness(S')	15	1	.304	.392
Evenness(J')	15	15	1	.701**
Dominance(D)	15	15	15	1

*. Correlation is significant at the 0.05 level (2 tailed).

**Correlation is significant at the 0.01 level (2 tailed).

Table B

Attributes variable	Diversity(H')	Richness(S')	Evenness(J')	Dominance (D)
Diversity(H')	1	.528	.876**	.873**
Richness(S')	8	1	.083	.264
Evenness(J')	8	8	1	.828*
Dominance(D)	8	8	8	1

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Diversity correspond positive correlation to evenness and dominance as similar result is also reported by (Stirling *et al*, 2005) as more interaction with competition and regulated by dispersal and migration. Richness showed negative correlation to evenness and dominance in both sites and same findings is reported by (Wilsey *et al*., 2005). Evenness and dominance in the community decline with increasing number of species as more species occupy with more variation in evenness and dominance.

4.8. *T. sinense* growth response with climatic factors

Annual ring width series was compared with available climate data from 1996 to 2011 for Nobding and 2004 to 2015 for Lamperi which is very short for climate related studies. The paucity of long meteorological records in Asia has been a matter of concern in the field of dendroclimatology (Cook *et al*., 2013). *T. sinense* is not responding to climatic factors and is may be due to low sensitivity towards climatic influences.

Table 4.3. Pearson's correlation with annual mean ring width and climatic factors, Nobding (Table A) Lamperi (Table B)

Table A

Variable	Ring width	Max Temp	Min Temp	Ave Tem	Rainfall
Ring width(mm)	1	.329	-.751**	-.445	-.319
Max Temp ((°C)	16	1	-.132	.326	.193
Min Temp (°C)	16	16	1	.669**	.535*
Ave Temp (°C)	16	16	16	1	.441
Rainfall (mm)	16	16	16	16	1

*. Correlation is significant at the 0.05 level (2 tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table B

Variable	Ring width	Max Temp	Min Temp	Ave Temp	Rainfall
Ring width(mm)	12	.329	.506	.467	.318
Max Temp ((°C)	12	12	.392	.963**	.282
Min Temp (°C)	12	12	12	.560	.543
Ave Temp (°C)	12	12	12	12	.377
Rainfall (mm)	12	12	12	12	12

*. Correlation is significant at the 0.05 level (2 tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Pearson's rho correlation indicates, *T. sinense* ring width is negatively correlate with climatic factors as depicted (Table 4.3 A & B). However, annual mean ring width showed positive correlation with minimum temperature (r = -.751, P < .01) in Nobding. It clearly informs that *T.*

sinense does not respond or does not record the climate signal. For climate tree relationship investigation, proper choice of old/mature and climate signal tree is essential (Fritts, 1976), but *T. sinense* being rare, all available population were examine through coring attributing for non signal of climatic factors. Hughes *et al.* (1982) also noted that radial growth responses may vary significantly with climatic, site conditions and the inherited capabilities of tree species.

Simple linear regression illustrate, there is negligible or no association between *T. sinense* annual mean ring width against the climatic factors. In Nobding, Annual ring width and minimum temperature has hightest relation ($\hat{y}$ = 4.67x+13.94, R^2 = 0.563) followed by minimum temperature in Lamperi ($\hat{y}$ = 2.117x+8.457, R^2 = 0.255). Thus, result revealed that, *T. sinense* have relatively more association with minumum temperarure in both sites than other climatic variable, suggesting that growth of *T. sinense* is hinder with increasing temperature. Increase temperature under climate change might increase evapo-transpiration and reduce soil moisture, further limiting plant growth (Yang *et al.*, 2003) and decreasing forest productivity, which is true for endemic *T. sinense*. Hollinger (1992) revealed that sufficient but not excessive heat is basic prerequisite for plant life and further supported by Laude (1974) temperature response is conditioned by level of other factors in environment.

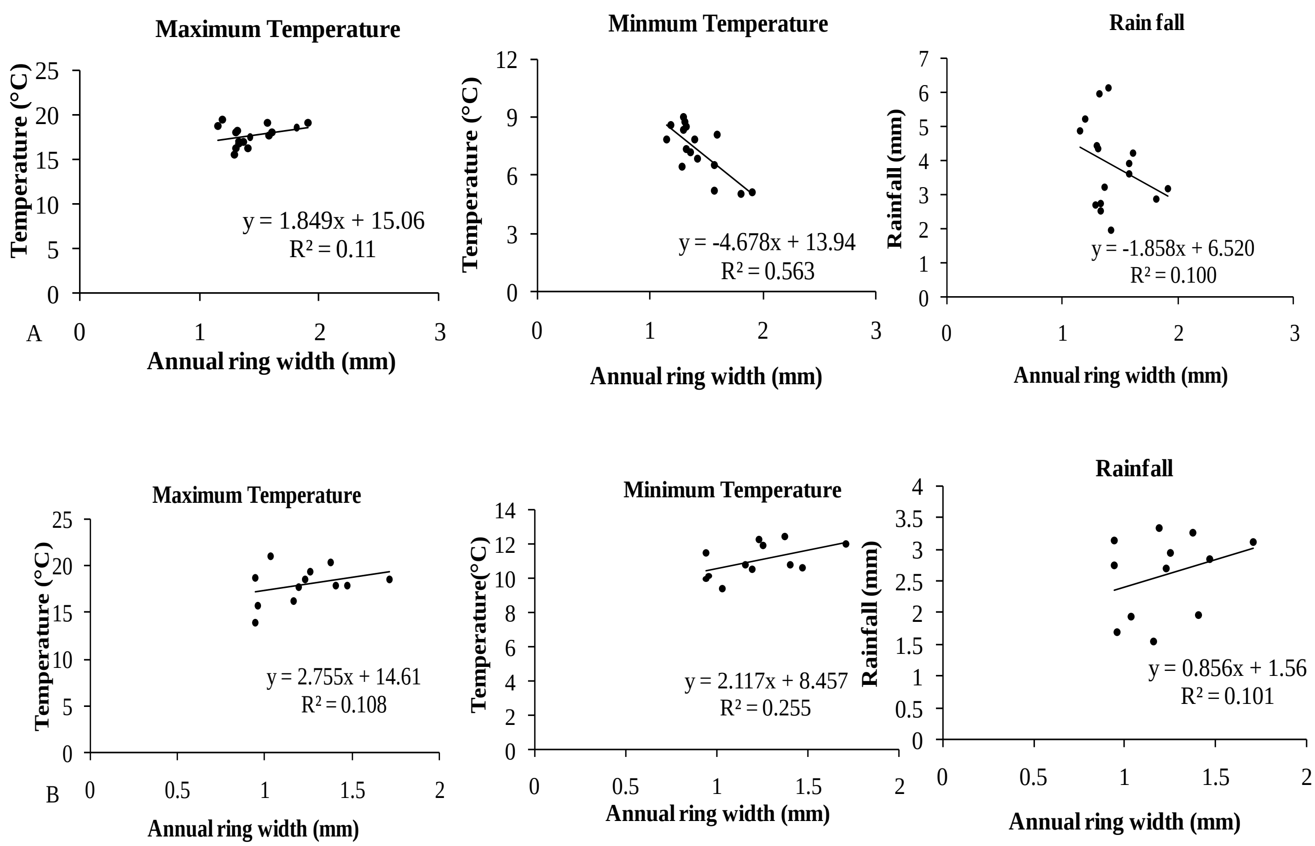

Figure 4.10. Simple linear regression between annual ring width and climatic factors for Nobding (A) Lamperi (B)

4.8.1. The influence of temperature on radial growth of T. sinense

T. sinense radial growth does not appear to have responded to the variation in temperatures, although it is not clear to draw result with limited climate data at one time study. The highest temperature recorded of 19.5 °C in 2003 with annual mean ring width of 1.19 mm which is lowest measurement. In contrast, Minimum temperature of 5.11 °C in 2011 measure longest measurement of 1.91mm ring width. The equivalent to highest temperature of 19.09 °C measure ring width of 1.57 mm in 2009, which is difficult to draw concrete results. There are many increases and decrease of radial growth with similar ranges of temperature such as 1998, 2001, 2002 and 2010 but ring width varies from 1.15 – 1.81 mm.

Whilst some higher temperatures coincide with years of lower growth and contrary, but it is not consistent. However, the trends does not appear to be clear with variation of temperature level with no significant relationship being discovered, this research coincides with Rebecca (2014) whose research showed minimal responsiveness to temperature. Way and Oren (2010) suggest increased temperatures increase radial growth, which does not particularly coincide with *T. sinense* radial growth. The same result was revealed from Lamperi site and is backed by statistical correlation depicted (Table 4.3 A & B).

4.8.2. The influence of precipitation on radial growth

Statistical analysis showed no significant relationship, suggesting that the annual precipitation levels had little or no effect on *T. sinense* radial growth. Highest rainfall of 6.13 mm measured 1.40 mm ring width in 2000 and lowest rainfall of 1.96 mm measured 1.42 mm ring width in 2007. Equally, some of the largest ring widths coincided with years of low precipitation and contrary. The maximum and minimum rainfall (3.1 & 1.6) mm in Lamperi results in same ring width (0.9 & 0.9) mm. Thus, it is hard to interpret as the trend appears is inconsistent. This does not coincide with research from various studies, which imply those years with low precipitation levels result in narrow rings (Bouriaud *et al*., 2004).

Although the climatic conditions are recognized as a major influencing factors affecting radial growth (Fritts, 1965), there still remained contradiction amongst research from different studies throughout the world related to many different species. The relationship between ring width and climate is complicated by variety of non climatic factors (Fritts, 1976). Aside than climatic factors, tree age, phytosociological position of tree, site differences and disturbance regimes also influence the radial growth, which may hold true for *T. sinense*. The site specific factors such as topography, soil type, forest thinning and ecological parameters like pest infestations on trees can modify the climate ring width relationship (Managave *et al.,* 2010).

4.9. Mean comparison of annual ring series in two sites

The growth patterns from annual mean ring width measurement in two sites are not similar. The paired sampled *t* test confirmed that, there is significant differences in radial growth performance *of T. sinense* for Nobding (*M* =1.74, *SD* =.664) and Lamperi (*M*=1.39, *SD* =.538) with *t* (275), *P* = 0.00.

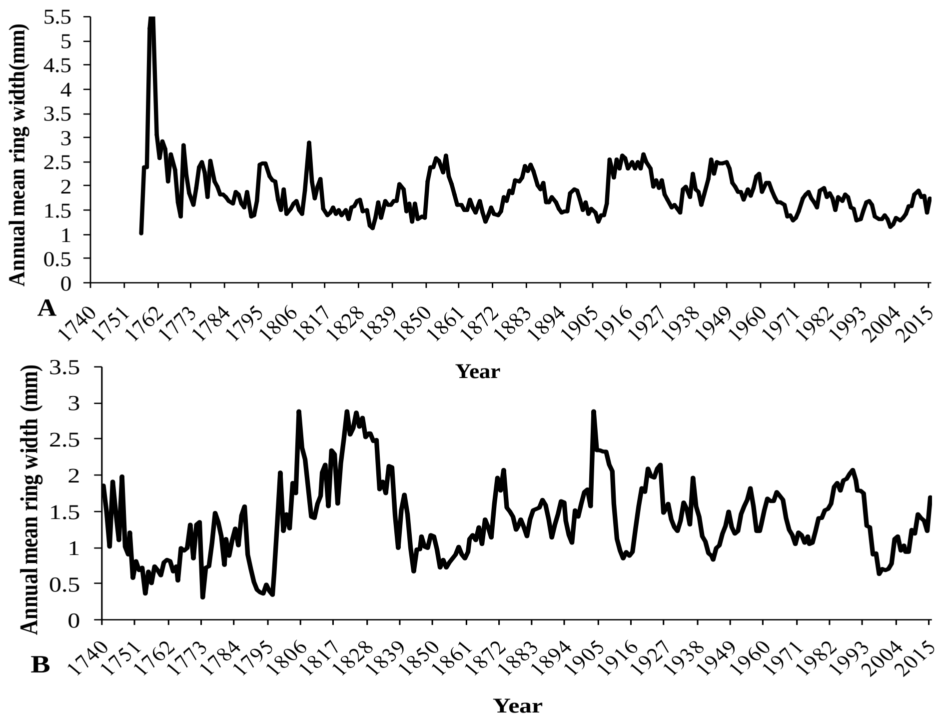

Figure 4.11. Growth performances of *T. sinense* in two sites, Nobding (A) Lamperi (B)

The result obtained from dated sample of 31 from Nobding showed 0.127 inter correlation series with average mean sensitivity of 0.261 and means annual length series of 150.3.Correspondingly, 13 dated samples from Lamperi showed 0.141 inter correlation series with average mean sensitivity of 0.300 and mean annual length series of 161.0. The weak intercorrelation among dated sample is attributed by differences in topographic gradients and micro site characteristic between plots.

Mean annual ring width from 1740 to 2015 (275) old year of *T. sinense* in Lamperi and from 1756 to 2015 (259) old year in Nobding was compared in (Figure 4.12). The ring pattern of *T. sinense* growth in Nobding is low degree of variation (complacent ring) and high degree of annual variation (sensitive ring) in Lamperi. The rampant disturbances in Lamperi by uncontrolled grazing, PWD camps, Park infrastructure development, and Wasabi pilot project might have attributed for disturbing factor for releasing and suppressing the ring patterns over the years. There is history of anthropogenic and similar finding is also reported by Wangda

(2006), where maximum height of tree showed slight decrease due to gradual sprawling into surrounding forests by increased human disturbance in Lamperi.

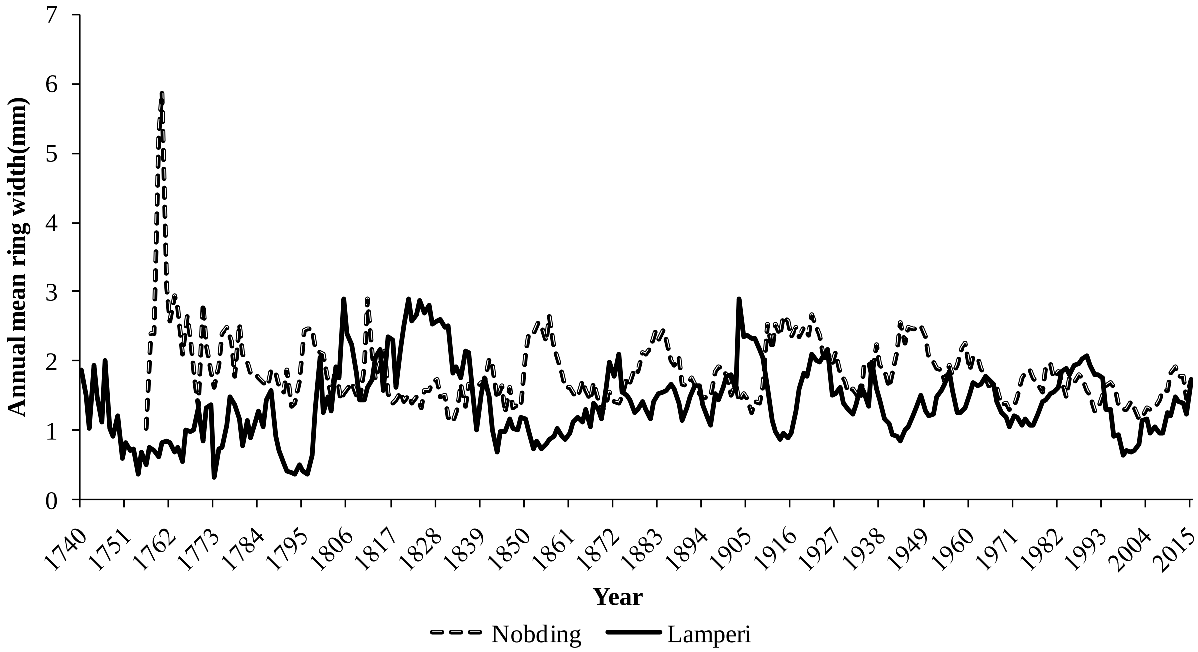

Figure 4.12. Comparative of annual mean ring width from two sites

The population of *T. sinense* and associated species per plot is relatively higher in Lamperi fluctuating even within the plots which enhance competition among the species, over the years, annual precipitation is comparatively low in Lamperi than Nobding, thus ring formation of *T. sinense* is wider and narrow. In contrast, habitat in Nobding is restricted to undisturbed area of steep slope in inaccessible area along the margin of stream and in valleys with good water table for moisture complacency with complacent ring formation over the years.

Coder (1999) reported that, water supply accounted for around 80% of variation in ring growth. Water is the most limiting ecological resource for most tree and forest sites. Tree ring response to climate is not necessarily limited to the growing season, but rather to the most influential conditions of water availability, which the tree may be put under (Hughes, 2002).

CHAPTER FIVE
Conclusion

Geographically, *T. sinense* is restricted species in cool humid evergreen and deciduous forest to transitional zone of mixed conifer in Bhutan. It occurs in unstable habitat such as steep terrain ranging from average slope gradient of 49% to 76%, and subjected to frequent anthropogenic influences of stream margin and roadsides. North East is predominate aspect of majority plots where *T. sinense* thrives. The prominent range of elevation is 2700 to 2800 m as clustered population was concentrated with similar properties of soil in these elevation ranges. The main dominated associated tree species of *T. sinense* are *Q.oxyodon, A. campbellii*, *A. sikkimense* based of relative basal area.

There is positive association between DBH and height of cored *T. sinense* and stem density/plot does not fluctuate with variation of nitrogen content in *T. sinense* community. The study showed no single regeneration and distribution pattern was uni-modal and sporadic structure for Nobding and Lamperi. *T. sinense* exhibit non response to climatic factors due to low sensitivity, but relatively respond with minimum temperature. Therefore, it signifies that relic species will not adapt with increasing temperature in climate change scenario. The radial growth pattern of *T. sinense* results significant differences between two sites with complacent and sensitive ring formation which is attributed by disturbance regimes and other environment factors. Sustenance of it genetic diversity is uncertain as the current trends of population structure is declining by habitat destruction coupled by low reproduction rate. In order to preserve the ancient genetic diversity of this phylogenetically distinctive and increasingly threatened species, protection of companion species in their habitat and artificial measures are crucial to revive the declining species**.**

There was no information about the area coverage and distribution pattern of relic species precisely in advance, systematic sampling could not be done and the study was done through targeted sampling. Lacks of long climate data hamper to relate the annual ring width for longer time scale. The findings of the study are based entirely on one time data collection confined in two study sites, and therefore the findings may not necessarily be generalized and apply in global context. Since, the smaller populations are rare, it is very important to clarify the cause of absence of recruitment of *T. sinense* through detail research with setting permanent observation plots for this species habitat in future.

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Annexure 1. Detail information in Nobding site

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
Elevation (m)	3038	2952	2903	2852	2848	2898	2811	2748
Slope %	85	65	90	75	75	97	95	75
Aspect	NE	SW	NE	NE	NE	NE	SE	NE
Total density (no)	8	7	8	8	8	8	6	8
TS density (no)	1	1	1	1	1	2	2	2
Max DBH (cm)	110	89	90	89	91	96	79	130
TS Max DBH (cm)	45	68	90	68	91	96	74	74
TS BA (cm^2/plot)	1,590.4	3,631.7	6,361.7	3,631.7	452.4	13,459.0	7,932.5	8,260.0
Total BA (cm^2/plot)	18,777.0	15,517.8	29,386.4	15,746.1	3,009.6	38,540.0	20,114.5	34,342.5
Max Ht (m)	32.5	24.8	31.2	24.8	23.5	34.5	34	48
TS max Ht (m)	18.6	26	21.8	19.6	23.4	24.6	33.8	36.1
Diversity (H')	1.39	1.19	1.8	1.54	1.76	1.3	1.15	1.2
Dominance (D)	2	2	4	3	5	3	2	2
Richness (S’)	7	7	8	8	7	8	6	8
Evenness (J')	0.71	0.611	0.86	0.74	0.9044	0.625	0.642	0.577

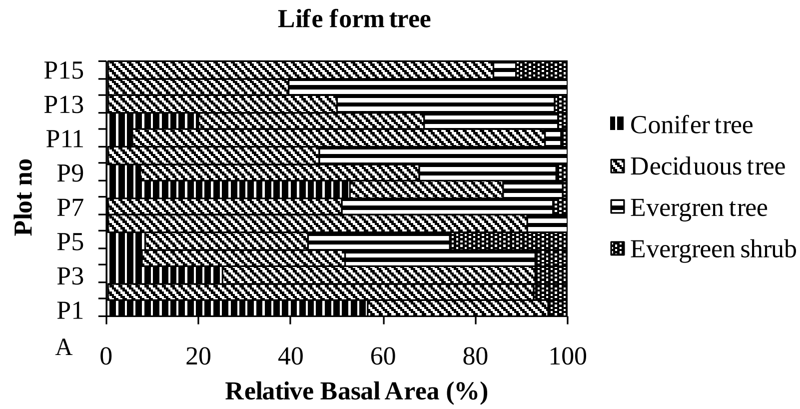
	Plot 9	Plot 10	Plot 11	Plot 12	Plot 13	Plot 14	Plot 15
Elevation (m)	2786	2784	2778	2786	2697	2746	2848
Slope %	50	60	85	70	55	75	83
Aspect	N	E	NW	NE	NE	N	N
Total density (no)	8	6	9	9	8	7	7
TS density (no)	3	3	1	1	3	1	2
Max DBH (cm)	74	71	69	69	83	89	92
TS Max DBH (cm)	74	59	69	69	83	85	48
TS BA (cm^2)	7,009.87	6,399.23	3,739.28	3,739.3	9,997.333	5,674.502	3,852.4

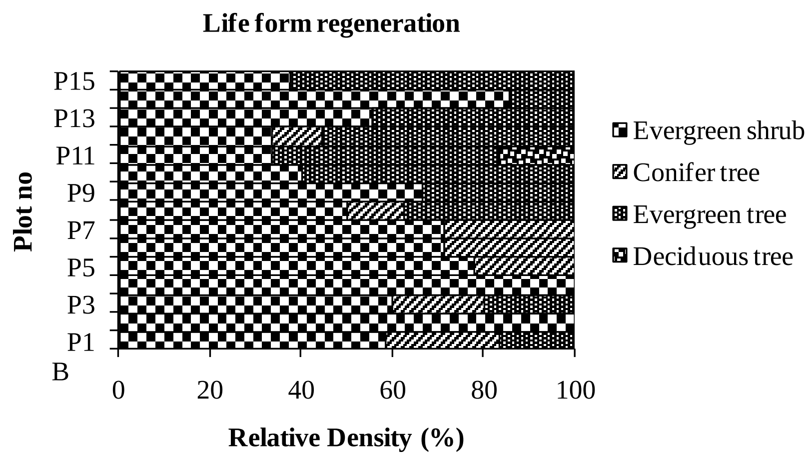
Total BA (cm^2)	18,866.37	28,424.3	11,136.5	17,521	2,7433.2	3,2525.11	3,8873
Max Ht (m)	34	34	21	32	43.5	49.3	45
TS max Ht (m)	34	25.5	17.8	24.5	41.4	32.8	19.8
Diversity (H')	1.44	1.2	1.89	1.8	1.54	1.3	1.1
Dominance (D)	3	2	3	6	3	4	1
Richness (S’)	8	6	9	9	8	7	7
Evenness (J')	0.692	0.669	0.723	0.819	0.74	0.66	0.565

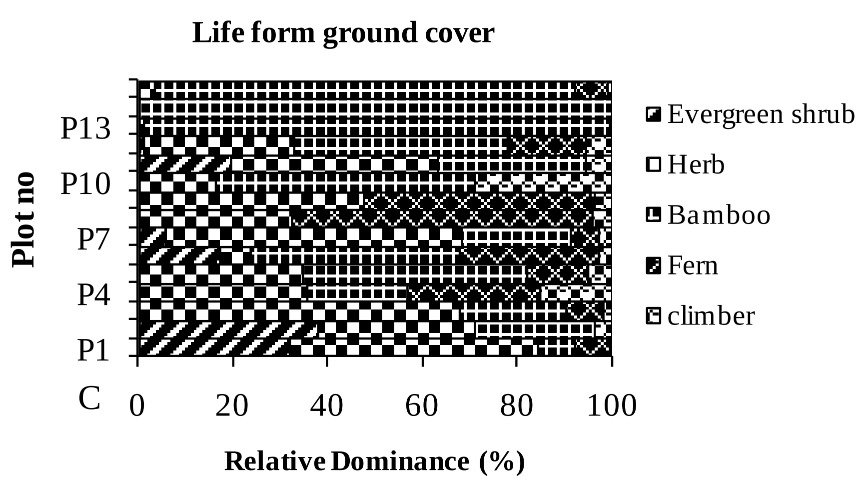
Annexure 2. Detail information in Lamperi site

	Plot 1	**Plot 2**	**Plot 3**	**Plot 4**	**Plot 5**	**Plot 6**	**Plot 7**	**Plot 8**
Elevation(m)	2468	2720	2724	2737	2743	2771	2811	2845
Slope %	75	55	25	75	60	50	15	40
Aspect	N	NE	E	N	N	N	E	N
Total density (no)	5	14	5	12	9	14	10	10
TS density (no)	1	4	1	1	2	7	1	2
Max DBH (cm)	75	130	120	91	130	110	110	70
TS Max DBH (cm)	75	74	86	91	90	110	59	49
Total BA (cm^2/plot)	29,028.68	69,711.2	27,411.2	33,160	38,357.7	56,031.88	3,0229	16,845.6
TS BA (cm^2/plot)	4,417.865	10,324.8	5,808.8	6,503.9	8,737.555	29,051.09	2,734	3,337.94
Max Ht (m)	32	41	25	42	34	41	26.5	23
TS Max Ht (m)	24.5	21	16.5	28	34	41	15.5	21.7
Diversity (H')	1	1.1	0.53	1.5	1.08	1.4	1.51	1.94
Dominance (D)	1	1	1	3	2	2	3	4
Richness (S’)	5	14	5	12	9	14	10	10
Evenness (J')	0.62	0.41	0.32	0.6	0.49	0.53	0.65	0.84

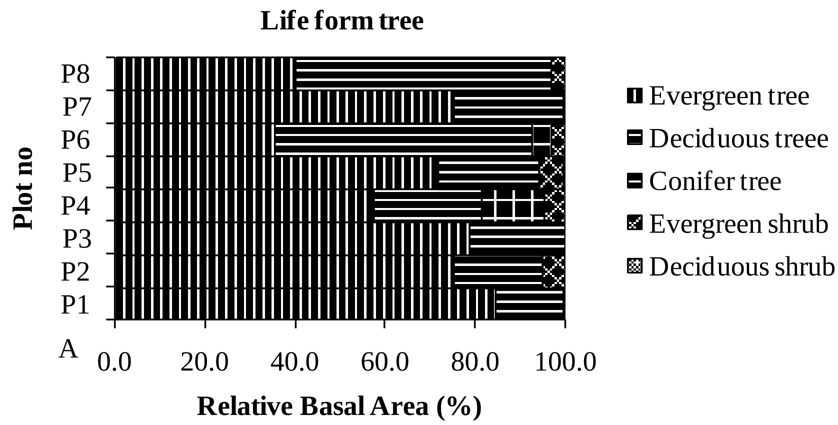
Annexure 3. Plot wise distribution of major life-forms tree layer (A) regeneration (B) and ground vegetation(C) *T. sinense* habitat area in Nobding

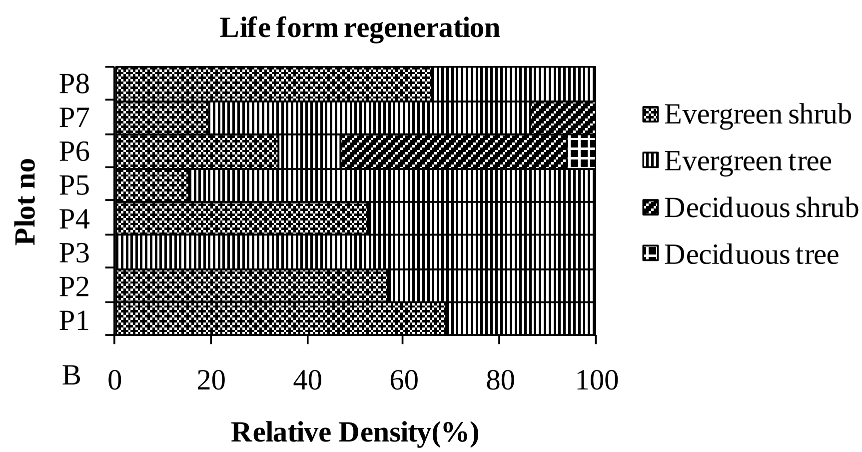


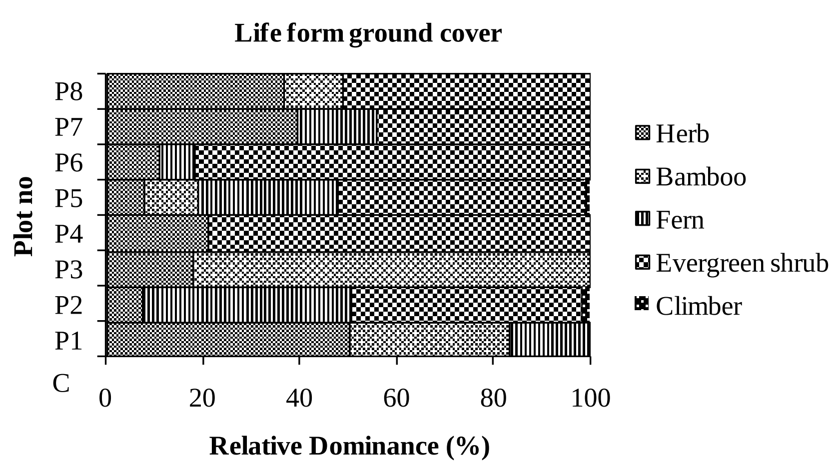




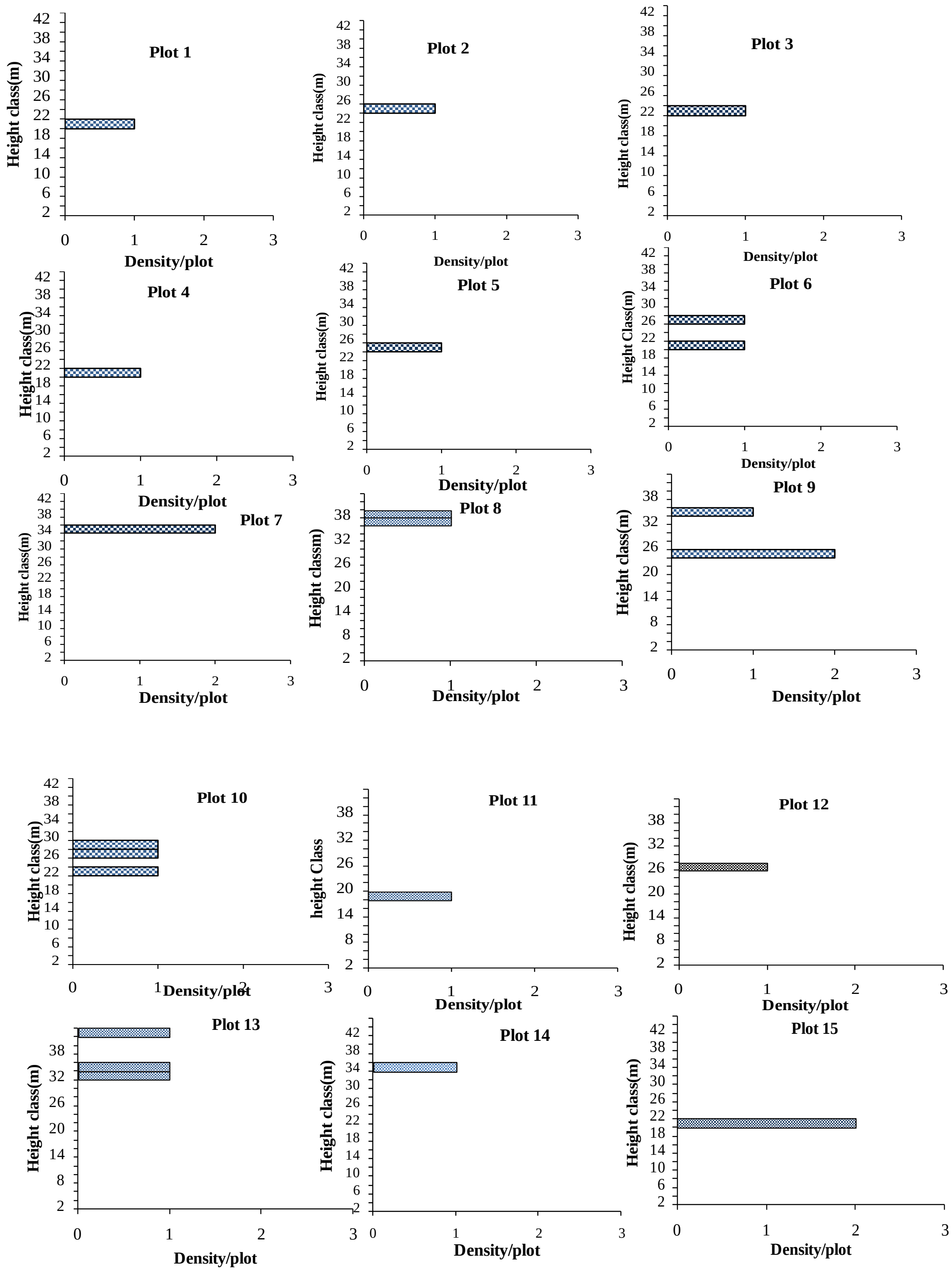
Annexure 4. Plot wise distribution of major life-forms tree layer (A) regeneration (B) and ground vegetation (C) in *T sinense* habitat area in Lamperi



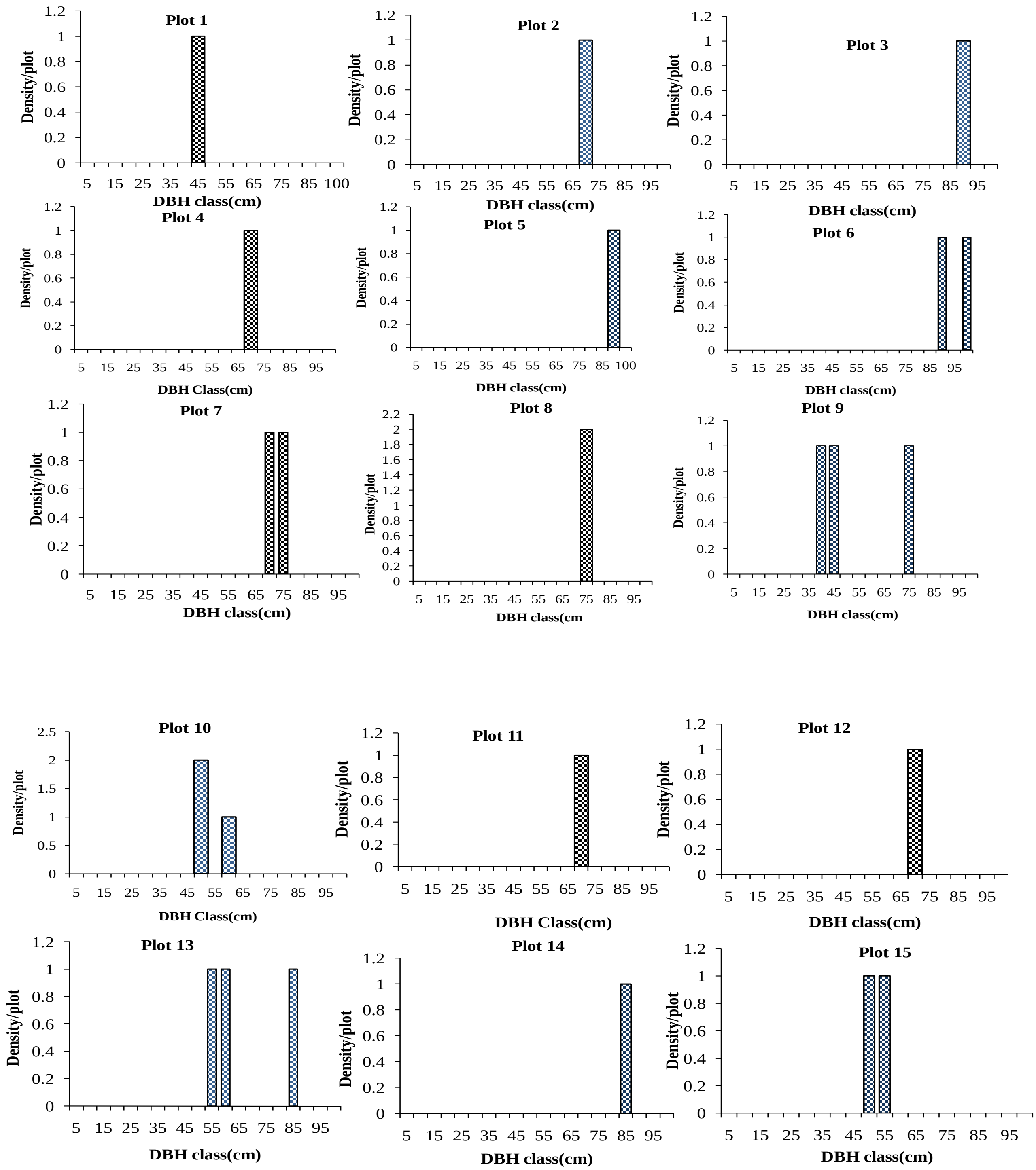




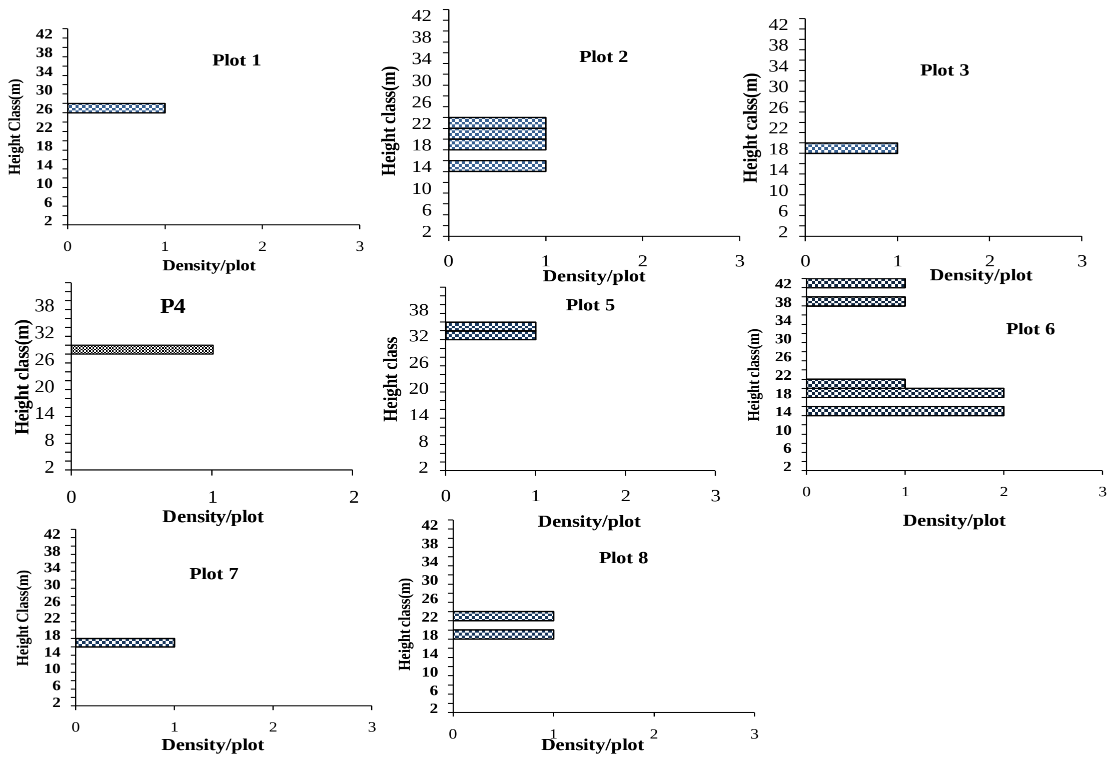
Annexure 5. Height class distribution for Nobding



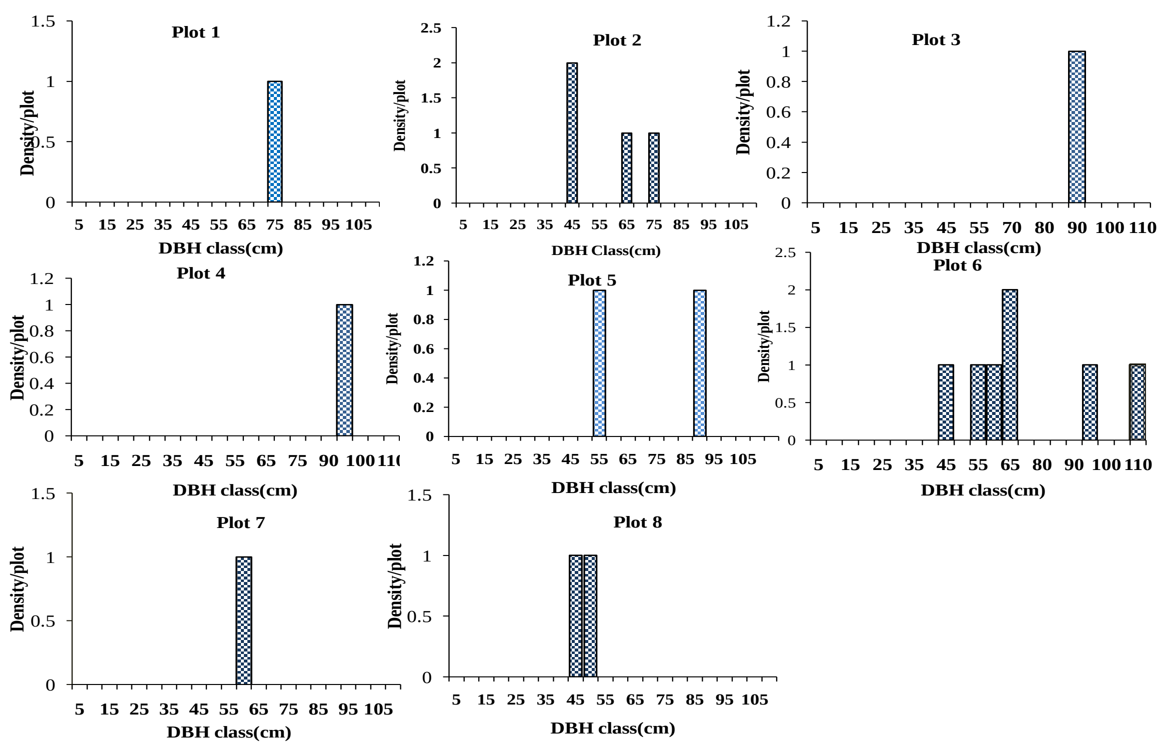
Annexure 6. Age class distribution in Nobding



Annexure 7. Height class distribution for Lamperi



Annexure 8. Age class distribution for Lamperi



Annexure 9. Format for tree ring sample collection

Plot No:…………………………………. Site Name/Location: …………………………………

Altitudes:………………………………. Aspect:…………………………………………………

Geo coordinates:……………………….. Slope %:……………………………………………..

Land use types/Forest types: ……………………………………………………………………….

Spp No	**DB (cm)**	**DBH (cm)**	**Height (m)**	**Aspect**	**Slope %**	**Geo coordinates**	**Core Id code**

Annexure 10. Format for Tree Inventory (Height ≥ 1.3 m)

Plot No……………………………………Location…………………………………

GPS coordinate………………………..Forest type……………………………….

Altitude………………………………..Aspect…………………………………….

Slope %.. Date………………………………………

Species No.	**Species**	**DBH (cm)**	**Height (m)**	**Remarks**

Annexure 11. Format for *T. sinense* regeneration Inventory (Height < 1.3 m)
Site No ……………………………… Plot No……………………………………

Location………………………………GPS coordinate……………………………

Forest type…………………………… Altitude…………………………………….

Aspect……………………………… Plot size…………………………………….

Slope %..Name of recorder………………………….

Species No.	**Species**	**DBH (cm)**	**Height (m)**	**Remarks**

Annexure 12. Detail of *T. sinense* in Nobding

Plot		DBH(cm)	DBH class	HT(m)	Ht class	BA
1	*Tetracentron sinense*	45	45	18.6	20	1590.431281
2	*Tetracentron sinense*	68	70	27	24	3631.681108
3	*Tetracentron sinense*	90	90	21.8	22	6361.725124
4	*Tetracentron sinense*	68	70	19.8	20	3631.681108
5	*Tetracentron sinense*	91	95	31	24	452.3893421
	Tetracentron sinense	96	100	37.8	26	7238.229474
6	*Tetracentron sinense*	89	90	29	20	6221.138852
7	*Tetracentron sinense*	68	70	32.5	70	3631.681108
	Tetracentron sinense	74	75	33.8	76	4300.840343
8	*Tetracentron sinense*	71	75	36.5	38	3959.192142
	Tetracentron sinense	74	75	34.1	36	4300.840343
	Tetracentron sinense	43	45	22.8	24	1452.201204
	Tetracentron sinense	74	75	24	24	4300.840343
9	*Tetracentron sinense*	40	40	34	34	1256.637061
	Tetracentron sinense	47	50	25.5	26	1779.523743
	Tetracentron sinense	59	60	27	28	2733.971007
10	*Tetracentron sinense*	49	50	21.4	22	1885.74099
11	*Tetracentron sinense*	69	70	17.8	18	3739.280656
12	*Tetracentron sinense*	69	70	24.5	26	3739.280656
	Tetracentron sinense	56	60	34	34	2463.00864
	Tetracentron sinense	52	55	31.4	32	2123.716634
13	*Tetracentron sinense*	83	85	41.4	42	5410.607948
14	*Tetracentron sinense*	85	85	32.8	34	5674.501731
	Tetracentron sinense	51	55	19.5	20	2042.820623
15	*Tetracentron sinense*	48	50	19.6	20	1809.557368
	25 trees					
	Max DBH	96	Max Ht	41.4	Total BA	85731.51883
	Min DBH	40	Min Ht	17.8		

Annexure 13. Detail of *T. sinense* in Lamperi

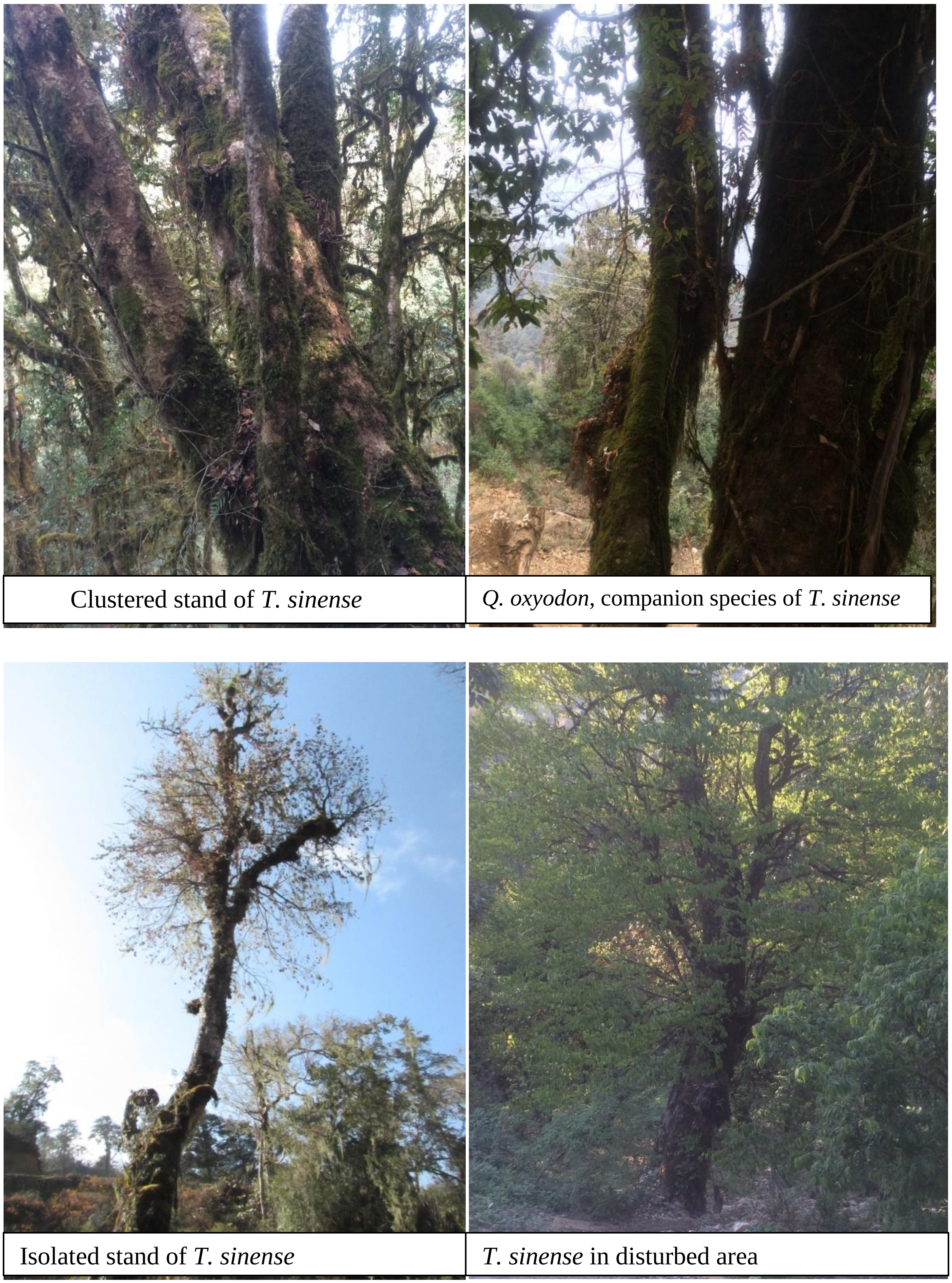
Plot		DBH(cm)	DBH class	HT(m)	Ht class	BA
1	*Tetracentron sinense*	75	75	24.5	26	4417.864669
	Tetracentron sinense	65	65	17	18	3318.30724
	Tetracentron sinense	74	75	21	22	4300.840343
	Tetracentron sinense	42	45	19	20	1385.44236
2	*Tetracentron sinense*	41	45	14	14	1320.254313
3	*Tetracentron sinense*	86	90	16.5	18	5808.804816
4	*Tetracentron sinense*	91	95	26.5	28	6503.882191
	Tetracentron sinense	55	55	34	34	2375.829444
5	*Tetracentron sinense*	90	90	31.5	32	6361.725124
	Tetracentron sinense	45	45	13	14	1590.431281
	Tetracentron sinense	59	60	16.5	18	2733.971007
	Tetracentron sinense	65	65	19	20	3318.30724
	Tetracentron sinense	110	110	41	42	9503.317777
	Tetracentron sinense	94	95	37	38	6939.778172
	Tetracentron sinense	61	65	17.8	18	2922.466566
6	*Tetracentron sinense*	51	55	13	14	2042.820623
7	*Tetracentron sinense*	59	60	15.5	16	2733.971007
	Tetracentron sinense	49	50	17.8	18	1885.74099
8	*Tetracentron sinense*	43	45	21.7	22	1452.201204
	19 Trees					
					Total	
	Max DBH	110	Max Ht	41	BA	70915.95637
	Min DBH	41	Min Ht	13		

Annexure 14. Tree composition with basal area in Nobding

Species	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	14	15
T. dumosa	51.6		4.5	7.4	8.4	0.0	0.2	52.6			5.3	19.6			
T. baccata	4.8		20.5						7.0						
A. campbellii	23.8	5.7	25.0	6.4	6.7	24.5	2.5	8.6	1.5	9.3	19.1	7.5	9.5	14.8	7.2
T. sinense	8.5	23.4	21.6	23.1	15.0	34.9	39.4	24.1	37.2	22.5	33.6	21.3	36.4	17.4	
A. sikkimense		57.6				31.5									
A. sterculiaceum			13.8												
E. tingens	7.0	5.9	7.3		13.6		8.6	0.5	22.1	2.9		2.4	3.9	7.2	10.4
A.nepalensis				14.6							28.8	7.9			66.2
B. alnoides										11.4	8.2	9.9			
R. grande	2.7	7.2	7.0	7.1	21.9				2.5					0.0	0.0
R. arboreum	1.4	0.1		0.0		0.2	3.3	1.3			1.6	2.1	2.9		1.5
D. bholua	0.3	0.1	0.2	0.0		0.0			0.1	0.0			0.0		
S. ramosissima					3.8										9.9
P. duthiei											0.0				
Q. oxyodon				41.4	30.7	4.6	45.9	11.2	28.9	54.0		27.2	33.0	48.7	
S. sumuntia						4.2		1.8	0.8						
I. dipyrena								0.0			3.2	2.0	10.8	11.8	4.7
M. nepaulensis											0.2				
V. negundo													3.3		
Grand Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Annexure 15. Tree composition with basal area in Lamperi

Species	P1	P2	P3	P4	P5	P6	P7	P8
Q. oxyodon	67.0365	70.3309	78.50778	50.94569	64.35696	28.27927	54.88581	2.056094
T. sinense	15.21897	14.81089	21.19137	19.6134	22.77914	51.84744	9.044142	19.81496
E. tingens	9.757373					0.022427		
S. sumuntia	7.492629	0.01014				0.358835		2.261237
D. bholua	0.494528	0.014646	0.183376		0.407465	0.138768	0.480657	2.44512
A. sterculiaceum		3.408105					4.157032	
I. dipyrena		2.816616		2.131634	2.631119	2.914132	12.09696	20.18329
A. campbellii		1.802634		2.579277		3.769168	5.261243	14.10359
P. duthiei		1.802634		4.263267	4.464282	2.283367	7.63335	9.441246
R. grande		1.408308		2.939286	2.106943	1.098932		
S. lucida		1.380142						
S. ramosissima		1.070314	0.045844	0.767388	2.701248	0.65179		
S. laureola		1.032008	0.071631	0.985288				
L. melastomacea		0.072105				1.533459		0.671377
L. ovalifolia		0.040559		0.037896	0.544652			
T. baccata				13.83193		4.240139		
A. nepalensis				1.904946				
P. formosa					0.00819			
M. himalaica						1.494211	0.691107	6.177605
A. sikkimense						1.368058	5.739302	
J. recurva							0.010393	
M. campbellii								22.84548
Grand Total	100	100	100	100	100	100	100	100



Clustered stand of *T. sinense*

Q. oxyodon, companion species of *T. sinense*

Isolated stand of *T. sinense*

T. sinense in disturbed area

Figure 4.13.*T. sinense* stand in different area