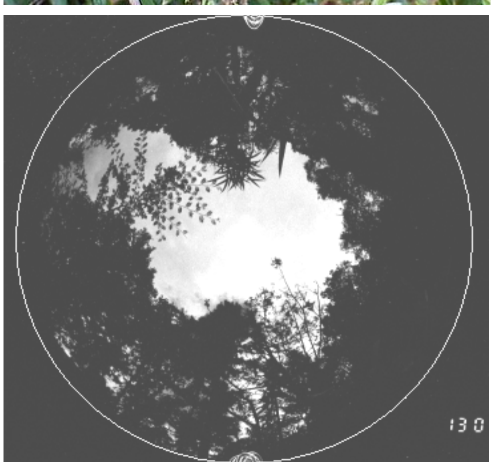
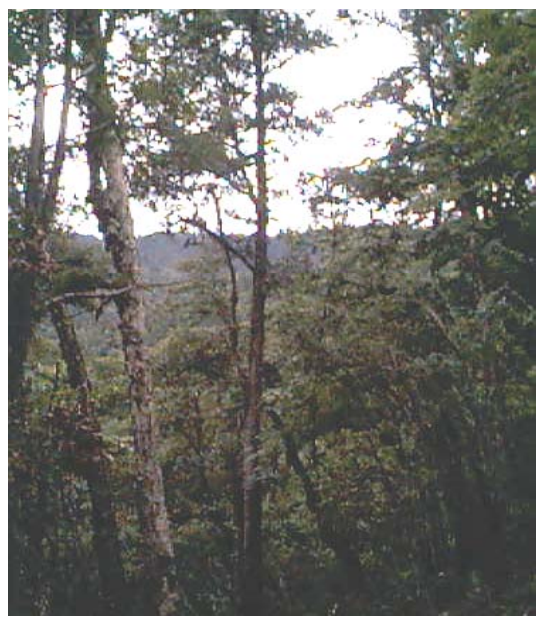
Regeneration of *Quercus semecarpifolia* Sm. in an Old Growth Oak Forest under Gidakom FMU- Bhutan



Sonam Tashi

MSc Thesis Forest Ecology and Forest Management **AV 2004-01**
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Sonam Tashi

FEM- 80326

Supervisor: Dr. Ir. Jan den Ouden

Key words: Oaks, *Quercus semecarpifolia*, Regeneration, Forest, Ecology, Management.

MSc Thesis Forest Ecology and Forest Management
Department of Forestry
Wageningen University and Research Centrum
The Netherlands
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Tashi Delek

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SUMMARY

The preference of oak trees for fuel wood during the cold winter months and the system of forest grazing being blamed for the lack of natural regeneration of *Quercus semecarpifolia* in the forest led to initiation of this study. The aim of the study was to understand the regeneration requirements of the species and to provide recommendations for silvicultural management of Oak Forest in Bhutan.

The study was initiated in 2000, at Chimithanka, Gidakom FMU Bhutan. A 9 hectare mixed broadleaved temperate forest was allotted for the study. 114 systematic plots of $2m^2$ each were set up to cover the entire accessible study area. Plot parameters such as slope, aspect, litter depth canopy openness and all regeneration were recorded. *Yushania microphylla* was recorded in cover categories; for *Q. semecarpifolia* the seedling was tagged and height measurement and survival followed through 2003. A record of all other species was also kept.

Another 12 plots of 10m X 10m with fenced and unfenced treatments were also set up to study the effect of grazing and canopy openness. During 2003, 16-quarter hectare inventory plots were carried out in the vicinity of the study area, to get an overview of the regeneration status of the forest, especially for *Q. semecarpifolia*.

The canopy openness was positively correlated with the height growth and the number of leaves on the seedling but did not have an influence on the presence of the seedling. However, canopy openness was negatively correlated with survival of the seedling.

The *Y. microphylla* cover was positively correlated with the presence, survival and height of *Q. semecarpifolia* seedling. *Berberis* and *Daphne* frequencies had a significant positive effect for the height increment and also positively influence the presence of *Q. semecarpifolia* seedling. The regeneration of *Q. semecarpifolia* seedling seemed to respond optimally to a soil pH of about 6, and it seemed to be favoured on gentle slopes rather than on steep slopes.

The findings imply that *Q. semecarpifolia* germination is not dependent upon the canopy openness, but survive better with more canopy cover for initial years of the seedling stage. For development into the next stage, canopy opening is a critical factor as the height growth and the numbers of leaf flushes responded positively to canopy openness. The oak seedlings in association with the facilitative shrubs seemed to escape certain amount of grazing pressure. Therefore, the key for the successful regeneration of the Oak Forest is the proper timing and amount of canopy opening, and to have controlled grazing to provide the right window of opportunity for oak seedling to establish into the next stage.

1.0 INTRODUCTION

Forests are dynamic ecosystems that change through time and space. The dynamic nature of forest has been recognised at least from the earliest observers who put their thoughts into writing. In temperate and tropical forest alike, two basic stages known variously as upgrading, building or aggregating versus downgrading, senescing degenerating, or stand decline are recognised (Barnes et al., 1998).

As part of ecosystem change, forest succession progresses in nearly infinite ways and is driven by many different factors along with simultaneously occurring processes. Trol, (1963) was the first one to emphasise, and explicitly describe succession as a landscape process involving all ecosystem components (Barnes et al., 1998). Grubb (1977) concludes that there seems to be almost limitless possibilities for differences between species in their requirement for regeneration, giving opportunities for replacement to plants of one generation, by those of the next. Although these traits and strategies are attributed to the species, they are intimately related to the site conditions that elucidate them (Barnes et al., 1998).

The vital characteristics in forest tree regeneration strategies include seed production, seed size, dispersal mechanisms, understory tolerance or shade tolerance, growth rate and longevity, tree crow architecture, resistance to insects and pathogens, biomass production, allocation of photosynthate and nutrient requirement (Barnes et al., 1998). Seed size is often used as a measure of parental investment in the individual offspring. Pioneer species usually produce large numbers, but small seeds to colonise ephemeral and unpredictable tree fall gaps, the resulting small seedling can grow quickly in the energy rich gaps (Gomez- Pompa and Varquez-Yanes, 1974). Non pioneers on the other hand produce large seeds, but few in number to provide sufficient reserves for the seedling to survive for a period of time under the energy poor understory (Foster, 1986).

The success of the natural reproduction depend on the completion of a long sequence of events (Wenger and Tsousdell, 1957), failure in any single link is fatal. If one attempts to set up detailed classification of the sets of ecological adaptations of the species, it can be found that each species of a given locality seem to have its own separate grouping. However, one species seldom exhibits exactly the same adaptations throughout its natural range (Smith et al., 1997). Different species, even among oaks adapt to gradients in resource availability and competition in different ways, including how they allocate their growth to stems, roots and leaves. (Loach, 1967; Gottschalk, 1985; Matsuda et al., 1989; Kolb and Steiner, 1990; Lathman, 1992; Pallardy and Rhoads, 1993; Walter et al., 1993;

Callaway and Mahall, 1996; Rice and Struve, 1997; Johnson, et al., 2002). Plants may have similar requirements and tolerance and occur together in recognisable communities, not because they react in the same way, but because they compete successively in various ways due to their difference in genetic make up and physiological responses (Barnes, et al., 1998). That enables them to utilise a site differently through their morphological and physiological responses to spatial, temporal and functional traits of the site. In fact one reviewer of competition theory (den Boer, 1986) states that coexistence is the "rule" and complete competitive exclusion the "exception" in the open systems of nature.

A germinating seedling will be dependent initially on seed reserves for all its energy and nutrient requirements. The rapid development of the root will allow the seedling to become anchored and to start taking up water and nutrients. Foliaceous cotyledons can begin to start photosynthesising and reduce the dependence on the seed reserve (Turner, 2001). Population studies have shown that a variety of sources of juvenile mortality may be important, depending upon the species, the site, and the time of study. Rates of survivorship increases as seedling becomes larger and older (Lieberman, 1996). Turner (1990), reports mortality of Malaysian rain forest tree seedlings to be ten times higher in the 10- 20 cm height class than those 30- 40 cm height class (Lieberman, 1996). A range of predators will attack the seedling, mostly for food and cause their death. At the earliest stages seed eating animals may eat their cotyledons and rob the seedling of its energy reserves. Herbivore mammals on the other hand, may eat the whole seedling before it becomes woody. Exclusion of mammals from the forest significantly reduces seedlings mortality rates (Osunkoya et al., 1992; Molofsky & Fisher 1993; Turner, 2001), and without browsing, growth rate and species composition of the natural regeneration are mainly determined by the light conditions (Ammer, 1996).

1.1 Problem Statement

The absence of natural regeneration of *Q. semecarpifolia* in Bhutan has been attributed to grazing by cattle and the microenvironment hindering the development of oak in old growth Oak forest (World Bank, 1995; Sangay, 1997). In eastern Bhutan where hardwood forests have not been subjected to systematic management and are under heavy grazing pressure, the growing stock is concentrated to the principal species of larger diameter classes. Thus, there is little representation in the seedling, sapling, and pole size trees except for few unpalatable species[1] (1996). Studies conducted by Riley (2002) also support the fact that herbivory of broadleaved seedlings is high, especially in *Pinus* dominated systems. Other reasons for the poor regeneration status of *Q. semecarpifolia* are erratic seed production, defoliation, acorn predation, decreased or increased fire incidence and extensive lopping (Singh & Singh, 1987; Andersson, 1991; Lorimer et al., 1994; Thandani and Ashton, 1995).

For the sustainable management of old growth Oak Forest in Bhutan, a thorough understanding of the ecology for the species is very important. The study is no doubt very complex, as many factors are involved in determining the regeneration of *Q. semecarpifolia*. Grazing has been confirmed as a main reason for poor natural regeneration of oaks by various researchers (Eiberle, 1967; Putman, 1986; Naiman, 1988; Huntley, 1991; Bryant et al., 1991; Sangay, 1997). This study will therefore limit its scope to understand the optimum environmental requirements for the species, like canopy openness, that influence the natural regeneration of the species (Crow, 1992).

Understanding the regeneration requirements for *Q. semecarpifolia* will enable the forest managers to adopt management systems to induce natural regeneration. Thereby rejuvenating the Oak Forest, which is vital for the livelihood of the local people. The species is used for fuel wood, timber, fodder for cattle, fencing posts, charcoal making and also for making farm implements like plough and handles for tools. Besides it harbours a rich faunal diversity and is important for watershed protection and bio-diversity conservation in general.

[1] Third Forestry Development Project. Mid term Review Mission. Nov.-Dec. 1996.

1.2 Research Objectives

Despite the fact that there are areas of old growth Oak Forest, there seems to be a general trend in the lack of natural regeneration in these forests (Saxena et al., 1984; Singh and Singh, 1987; Vetaas, 2000). This can lead to the degradation of the species from the forest of Bhutan, which is not desirable, as they are extremely useful to the local people. Thus to understand the regeneration requirements and propose recommendation to induce natural regeneration of the Oak Forest, has led to the formulation of the following objectives.

- To determine the status of *Q. semecarpifolia* regeneration in the study area
- To find out the effect of light quantity on the recruitment of *Q. semecarpifolia*
- To find out the effect of light quantity on the survival and height growth of *Q. semecarpifolia* seedling.
- To find out the effects of soil pH and the depth of litter layer for the regeneration of *Q. semecarpifolia*
- To come up with recommendation on the sustainable management schemes to induce natural regeneration of *Q. semecarpifolia* forest.

1.3 Hypothesis

The regeneration of *Q. semecarpifolia* in an old growth Oak Forest is dependent upon optimum gap size in the canopy, larger the gap size better the germination and survival of the seedling. The regeneration is also dependent upon the topography of the landscape. Regeneration is expected to be favoured on gentle slopes rather than on steep slopes. Germination is also expected to be favoured on ground with less litter depth than on thick litter layer.

2.0 SILVICS OF *QUERCUS SEMECARPIFOLIA* SM.

2.1 Taxonomy

Family: *Fagaceae*

Synonyms: *Q. aquifolioides* Rehd. and Wils. 1916
obtusifolia D.Don 1825.

Vernacular names: Brown oak, kharshu oak; Bjishi shing, oak of the Himalayas,

2.2 Habitat

Native range

The evergreen tree species ranges across the Himalayas from Bhutan, Nepal, India and is also found in Afghanistan, Pakistan, China, and Myanmar as a component of mixed forests, reaching 30m in height, but are seldom that tall in cultivation. It is naturally found in moist temperate forests of the western Himalayas within the elevation range of 2400-4000 m (CSIR, 1969; Baduni and Sharma, 1996; CABI, 2002).

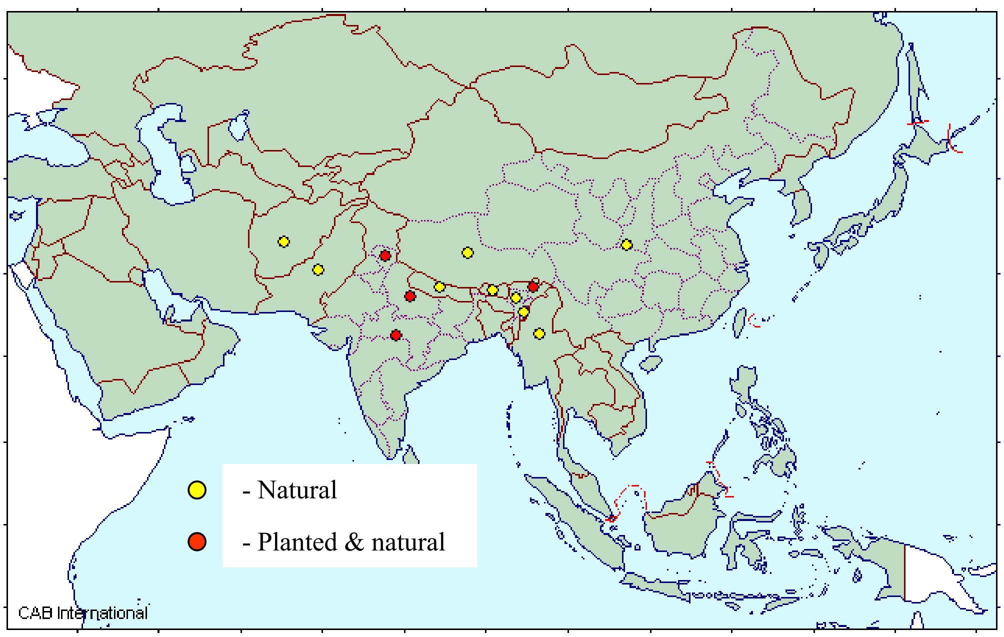


Fig.1. Distribution map of *Q. semecarpifolia*

Climate

This species prefers Mean Annual Rainfall of about 1000 - 2500mm and dry season not extending more than 4 - 6 months (CABI, 2002). The species can withstand absolute minimum temperatures of -15ºC, but grows well within mean annual temperatures of 5^{o}C - 17^{o}C; mean minimum coolest month: 4^{o}C - 9^{o}C; and with mean maximum hottest month of about: 16^{o}C - 23^{o}C, (CABI, 2002).

The oak occurs in regions of heavy snowfall and moderate rainfall. It does not extend into the dry inner Himalayan valleys (CABI, 2002).

Soils and Topography

Q. semecarpifolia prefers a good deep fertile loamy soil (Chittendon, 1951; Bean, 1981), with light to medium soil texture and free soil drainage (CABI, 2002). It usually grows both on deep rich moist soils in sheltered localities and on poor rocky ground on the crest of ridges.

Q. semecarpifolia is usually found on the moister southern slopes, which are more influenced by the monsoon (Puri et al., 1989). However, it is also often found as dominant species on north-facing slopes in the Himalayas, from 2400 - 3600m (Gamble, 1972; Bean, 1981). In China it grows right up to the tree line, where it becomes a thicket-forming shrub (Bean, 1981).

Associated forest Cover

Q. semecarpifolia can be found as pure stands especially along the tops and upper slopes of ridges (Troup, 1921), but can also be found with conifer species as a component of the cool temperate forest (Norbu, 2000). It is frequently mixed with spruce, silver fir, *Taxus baccata,* and in some localities with *Pinus wallichiana*. Among broad-leaved species, occasionally associates with it are *Pyrus* sp., *Prunus* sp. *Acer* sp. *Juglian regia* and with *Betula* sp. (Troup, 1921). There is often luxuriant herbaceous and shrubby undergrowth in the *Q. semecarpifolia* forest. The commoner shrubs are *Rosa* sp., *Rubus* sp., *Virbunum* sp., *Lonicera* sp., and dwarf bamboo, (Troup, 1921). Some other species associated with *Q. semecarpifolia* forest are *Rhododendron* sp., *Pieris* sp., *Myrsine* sp., *Berberis* sp. and *Daphne bholua.*

2.3 Life History

Reproduction and Early Growth

Flowering and fruiting

Q. semecarpifolia flowers are monoecious. The male catkin and female spikes appear with the new shoots, the former ripening and pollination taking place by the end of May-June. There is little or no growth in the young acorn until the following spring, when they commence growing rapidly as soon as the new shoot begins to appear. The acorns commence ripening by June and continue ripening during July, and at higher elevation even until August. The period between fertilization of the female flower and the ripening of the acorn is about thirteen months. The acorns may fall green, turning brown on the ground, while others turn dark brown before falling (Troup, 1921).

Seed Production and Seed Dispersal

Periodic seed crops of good seed years and lean seed years are noticed for this species. A twelve consecutive year record from Jaunsar, show that good to abundant seedling was recorded in four years and poor to moderate seedling in eight years (Troup, 1921).

Bears, wild boar, langur monkeys, squirrels and birds devour the acorns (Troup, 1921). There is a high likelihood that the caching activities of the squirrels, mice and birds are the primary dispersers of the seeds. There are about 100–140 viable seed/kg (CABI, 2002).

Seedling Development

Under natural conditions, germination takes place in profusion as soon as seed falls on exposed ground (CABI, 2002). Germination takes place early in the rainy season. The seedling continues to derive nourishment from the fleshy cotyledons for sometime and the remains of the cotyledons can be found even during the second season. The seedling as a rule produces in the first season nothing more than small leafless stems 5cm to 8 cm high, on which mere scales replace normal foliage leaves with buds in their axils, and normal leaves are produced first time only in the second season. However, under very favourable conditions, leaves can also be produced in the first season. Although the development of the stem is small, the taproot grows rapidly in length and thickness, enabling the seedling to establish itself. Many seedlings die down towards the end of the first season and often for a few years subsequently, sending up new and stronger shoots each year from the dormant collum buds, until they finally commence upward growth, when favourable conditions prevail. The growing season is short and followed by autumn drought and severe winter. Therefore the seedling soon after germination assumes the leafless form in preparation for the severe winter. The rate of growth of the seedling is very slow, averaging only about 5cm to 10 cm a year for those growing under natural condition (Troup, 1921) in cold climate. Young plants can tolerate reasonable levels of side shade (Huxley, 1992**).**

Vegetative Reproduction

Trees respond well to coppicing (Gupta, 1945; Gamble, 1972). This oak is a light demander and coppices and pollards well. However, coppice and pollard shoots are liable to be bent or broken by snow (Troup, 1921).

Sapling and Pole stage to Maturity

In favourable localities it can grow up to 24-30m tall and 60-70 cm in diameter. (CSIR, 1969; Baduni and Sharma, 1996), but height of 35m and diameters of 160cm DBH have been measured at Gidakom FMU, Bhutan. It is often stunted at its upper limit and on exposed ridges. It forms pure forests along the tops and upper slopes of ridges; however it does not form dense forests except in the pole stage (Troup, 1921).

Rooting habit

Q. semecarpifolia are sensitive to root disturbance and should be planted in their permanent positions whilst young (Bean, 1981). They have massive root system and are not liable to be easily thrown by wind (Troup, 1921).

Reaction to Competition

The oak is a light demander and fails to establish itself under shade. Older trees do not tolerate shade (Gamble**,** 1972). Heavy grazing prevents oak reproduction, but instances have been observed where light grazing has not had any appreciable effect on its establishment. Natural regeneration is often prevented from establishing itself by a dense growth of weeds and heavy undergrowth (Troup, 1921).

In many localities, the degradation of *Q. semecarpifolia* forest has occurred or is ongoing due to heavy lopping by cow herders and high grazing pressure and its inherently low regeneration and slow growth (Troup, 1921).

Damaging Agents

The acorns are usually infected and insects holes can be seen on the acorn, but if the embryo is not destroyed, then the acorn can still germinate (Troup, 1921). When the seedling is young, it is likely to be eaten by herbivore where forest grazing is still in practice.

2.4. Special Uses

The wood of this oak is very hard, of good quality but not much used as timber, though locally employed for building and agricultural implements. It is an excellent fuel and charcoal wood. *Q. semecarpifolia* oak is an important source of tannin (Pandey and Makkar, 1991). Cattle, Goats and sheep eat the seedling and leaves especially during the lean months (Singh et al., 1998).

2.5 Genetics

Hybridizes freely with other members of the genus like *Q. glauca* and *Q. lamellosa* (Huxley, 1992**).**

3.0 METHODS

3.1 STUDY AREA

3.1.1 Country Background Information

Bhutan is a small Himalayan country, with an area of 46,500 km^2 and a population of about 680,000 (RGOB, 2001). The country lies in the eastern Himalayas, surrounded by the Tibetan Plateau in the north, the Bengal and Assam Plains in the south, Arunachal Pradesh in the east and the Darjeeling and the Sikkim Himalaya to the west. The terrain is rugged, rising from 100 masl in the south, till 7550 masl to the north. Forest in Bhutan represents the single largest natural resource, about 72% of the county's land area (Norbu, 2000).

Table 1.Land cover in Bhutan

Category	Km ^{2}	% Total
Conifer forest	10,636	26.6
Broadleaf Forests	13,793	34.4
Mixed Forest	1,358	3.4
Scrub Forest	3,258	7.9
Pastures	1,564	3.9
Agricultural land	3,146	7.9
Snow and glaciers	2,989	7.5
Water spreads	304	0.8
Rock Outcrops	2,008	5.0
Others	1,020	2.5

Source: LUUP, 1994.

3.1.2 Climate and agro-ecological zones

Bhutan is divided into six agro-ecological zones: alpine, cool temperate, warm temperate, dry sub-tropical, humid sub-tropical and wet sub-tropical

Table 2. Agro-ecological zones of Bhutan

Agro-ecological zone	Altitude (m).	Temperature ^{0}C			Rainfall mm
		Max	Min	Mean	
Alpine	>3500	12.0	-1.0	5.5	<650
Cool temperate	2500 - 3500	22.0	1.0	10	650 - 850
Warm Temperate	1800 - 2500	26.0	1.0	13	650 - 850
Dry Sub-tropical	1200 - 1800	29.0	3.0	17	850 - 1200
Humid Sub-tropical	600 - 1200	33.0	5.0	20	1200 - 1500
Wet Sub-Tropical	150 - 600	35.0	12.0	24	2500 - 5500

Source: Dorji, 1995.

The climate is dominated by the monsoon, with high precipitation during June-September and a dry winter. Bhutan has a wide variety of climatic conditions influenced by topography, elevation and rainfall patterns. The great variation in rainfall within a relatively short distance is due to the effect of rain shadow and precipitation generally diminishes significantly from south to north (Wangdi, 2002).

Land use and agricultural enterprises are influenced by the diverse climate and topography related to altitude. In the higher altitudes, farming is dependent on livestock, temperate fruit crops and crops such as potato, buckwheat, wheat and barley. Further south, towards the sub-tropical areas, rice and maize dominate the farming system. Cash crops such as cardamom and citrus also find an important niche with livestock as an integral component in the overall farming system.

3.1.3 Site Location & Characteristics

An area of 9-hectare forest was allotted by the Department of forest, (DoF) to study the natural regeneration of *Q semecarpifolia* in 1999, at Chimithanka, Gidakom Forest Management Unit (FMU) under Thimphu Dzongkha (District) Bhutan. The site is at an altitude of 2800 to 3100 masl, and fall under the categorisation of cool temperate forest (Table 2). It is accessible by a forest road, maintained by the Forest Development Corporation (FDC) for harvesting and other management operation of the FMU.

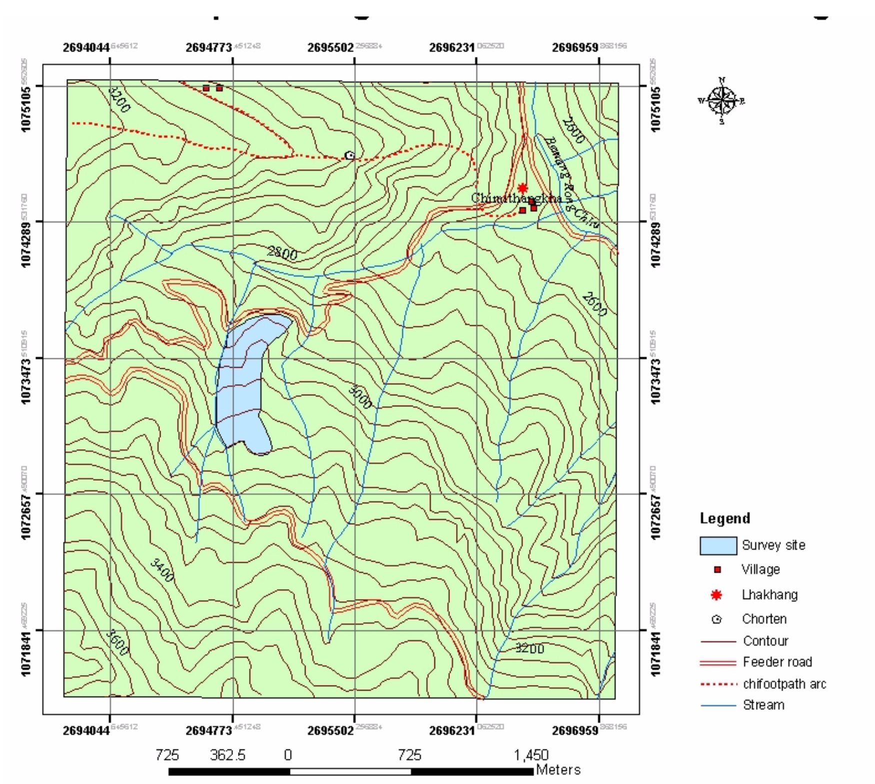


Fig.2. Location map of the regeneration trial site at Chimithanka

The forest has a north-westerly aspect with slopes ranging from 20% to 70 %. The average rainfall is about 720mm per annum[2] with most of the rainfall between July and September. The temperature can drop to as low as minus 8°C in winter and get as warm as 30 °C during the summer months. (Meteorological section DRDS, MoA). The soils in the study area are more or less similar throughout the site. The soils are acidic, well drained, very deep, dark greyish brow to yellowish brown silty clay loam to sandy clay

[2] Rainfall averaged for the year 1999 to 2001

loam texture with no mottles. The first and second soil horizons are found to be stable, probably due to very high organic matter content in the soil (5.5 to 6.8%). Despite the signs of heavy grazing, no soil erosion was noticed, this could probably be due to the thick litter layer and the relatively closed canopy which intercept the direct impact of rain fall and also reduced the surface flow damage to the soil (BSS/NSSC, 2003).

To carry out an inventory of the forest, 16 (50m x 50m) plots were set up in the vicinity of the 9 hectare study area allotted. The inventory sites were similar in vegetation composition and utilisation pattern by the local people.

The forest has been traditionally used for grazing by nomadic cattle population during summer months and by yak during the winter months. As common practice, firewood is extracted for local consumption. With the area becoming accessible by the logging road, there is tremendous pressure, especially from the capital city for the supply of fuel wood during winter months for house heating purposes.

The forest can be described as mixed broadleaved temperate mature forest with multi-layered structure, but with a clear delimitation between the 3 or so layers, that composes it. The dominant trees usually reach a height of about 30 to 35 m. *Quercus semecarpifolia* make up the majority of the dominant species, with some *Picea spinulosa* and *Tsuga dumosa* also dotted about as a component of the canopy species. The middle layer tree species usually reach a height of about 15m to 20m. *Betula* sp., *Acer* sp. *Rhododendron arboreum, Gambelia ciliata, Enkianthus deflexus* and *Ilex dipyrena* are some of the species that make up the middle tree layer. *Yushania microphylla, Pieris formosa* and *Daphne bholua* comprise the main species in the understory (Stierlin, 1999).

3.2 STUDY METHODS

3.2.1 Inventory

In the vicinity of the study area at Chimithanka, sites with northwest to northeast facing slopes, with altitude ranging from 2850 to 3100m and *Q. semecarpifolia* dominating at the canopy was selected. Eight plots of 50m X 50m were set up at relatively gentle slope ranging from 20 to 35 % slope, and eight other plots were set up at relatively steep slope ranging from 40 to 65 % slope. None of the plots were closer than 50 m to each other.

First one corner of the plot was chosen arbitrarily and then with the help of compass and measuring tape the other corners of the plot were set up. Horizontal distance was used to measure the dimension of the plots. The plots were then divided arbitrarily into smaller sections with the help of threads, so that there is less chance for double measurement and also less chance on missing out on some trees.

For *Q. semecarpifolia* all the trees above 1.3-m height were measured. For other species only DBH greater than 10cm at 1.3 m above ground, from the uphill side of the tree was recorded with a diameter tape in the 50m x 50m plot. When the tree was forked below 1.3 m, it was considered as two trees. Leaves and branch samples were collected for species that were not identifiable in the field, and taken to the local herbarium for identification.

Soil samples were collected from the topsoil horizon only, from four plots each of the two slope gradients. From each of the chosen plot, 10 soil samples about 1 kg each was randomly collected to cover the entire plot and then mixed thoroughly. A final sample of about only 1.5kg from the mixed soil was taken for analysis at the soil laboratory in Simtokha. The procedure was repeated twice in the same plot, to have two samples from each of the chosen plot. The final soil sample collected was air dried, pounded into fine granules and further sieved before it was taken to the soil laboratory for analysis.

3.2.2 Systematic plots

In the 9-hectare forest, systematic plots of $2m^2$ were laid out in the year 2000. A prominent permanent reference point was chosen at the edge of the area and then with the help of a hand held compass and measuring meter tape the first plot was laid out. After which a fixed compass bearing and a horizontal distance of 25 meters interval between each plot was chosen till the other edge of the plot. For the next transect, 90 degree was added to the previous bearing and a 25m horizontal distance was taken to locate the next transect. From the plot, the back bearing of the previous transect was used to set up the plots along the second transect. Thus the centres of each $2m^2$ plots were distanced by 25 m. The four corner of the plots were marked by 20 cm long wooden pegs that were especially chopped and painted, so it would be easily seen and be more durable. For the centre of the plot, a longer wooden peg (120cm) with the plot number marked on it was used. A total of 114 ($2m^2$ plots) was established in the accessible portion of the entire 9 hectare plot.

In each plot, the slope percentage was recorded with the clinometer and the aspect with a Suunto compass. *Y. microphylla* cover was estimated by subdividing the plots into smaller units and then estimating the total coverage in the plot. The percentage canopy openness was recorded by visually looking up into the canopy and making an estimate of the canopy opening. Every *Q. semecarpifolia* seedling found in the systematic plot were tagged with an aluminium tag in 2000, their actual height were measured since 2000. The aluminium tags were sometimes found to be uprooted and destroyed for some of the seedling, and also some of the seedling perished and new ones germinated, so it was difficult to actually keep an exact trend for all the seedling tagged in 2000. The regeneration data for all other species have been collected since 2000 in height classes.

Height class:

0 = < than 5 cm
1 = 6 -10 cm
2 = 11-15 cm
3 = 16-25 cm
4 = 26-50 cm
5 = 51-130 cm
6 > than 130 cm

With the help of Suunto compass, measuring tape and field records the plots were relocated for data measurement in 2003. The regeneration for the species was recorded by height classes, except for *Q. semecarpifolia* seedling where the actual height, the number of leaves and end shoot growth was measured.

For each of the plots, the depth of the litter layer was measured by gently pushing a garden shovel into the soil, away from any regeneration. The depth of the litter layer was then measured with a ruler in cm. The soil was put back as intact as possible. The pH of the soil was also measured with a Kelway soil pH meter for every plot.

For more reliable measurement of the canopy opening, rather than by visual estimates alone, hemispherical photographs were taken for each of the plots in 2003. During early mornings or late afternoon or when the sky was uniformly overcast, hemispherical photographs were taken with a Nikon camera with 8mm fish eye view lens. ISO 400 black and white film was used for the exposure, which was pushed up to 800-film speed for better contrast of the sky and the canopy. The camera was mounted on a self-levelling frame with a monopod. The camera focus was set to infinity, and the top of the camera was always oriented towards the north using a Suunto compass. Photograph was taken directly above the centre of the plot at a height of 50cm from the ground. The Global position and altitude was recorded with a Garmin GPS III Plus, at the centre of the 9-hectare plots.

3.2.3 Long term observation plots.

For long term monitoring of grazing dynamics, twelve 10m X 10m plots had been set up in the 9 hectare trail area in the year 2000. Six plots were fenced and the other six were unfenced. From the six fenced and the unfenced plots, three plots each have been further strategically set up in relatively open canopy and relatively closed canopy. For fencing a five strand barbed wire was used to fence the plots. For the unfenced plots, four corners of the plots were marked by erecting wooden poles. The fenced and the unfenced plots were further subdivided into 100 (1m x 1m) plots with wooden pegs for more convenient data collection and recording.

The regeneration data of the plots were measured from 2000, 2001, and 2002 and again in 2003. For *Q. semecarpifolia* seedling, the end- shoot growth, height and numbers of leaves were measured, whereas for the other species, the height was measured in classes as per the categorisation for the systematic regeneration plots.

3.3 DATA ANALYSIS

3.3.1 Procedure for developing hemispherical photographs

To obtain light variables for the systematic plots and the observation plots, the hemispherical photographs were processed. The negatives of the hemispherical photographs were developed at the photo studio. The negatives were then scanned using the Dimage scan Elite 5400 scanner and saved as BMP files. The software program Winphot 5, (recognises only BMP or PCX file formatted) was used to analyse the scanned images. After importing the photo files to Winphot 5, first the threshold for the picture was set, after which the picture needs to be aligned, that is to set the actual border of the image, which can be done manually. From the options menu, the location options for latitude of 27º 20′; longitude 89º30′, altitude 2990 masl; and time zone 6 were entered for the study area. From the same option menu, the sunshine option of 100 was specified. From the Calc menu of the program, calculation for the openness of the canopy in percentage, the photosynthetic photon flux density (PPFD) for direct and diffuse light above and below canopy was calculated thereafter by the program. (Adopted from Winphot 5)

3.3.2 Inventory plots

To get an overview of the structure of the forest on steep slope and on relatively gentle slope, the vegetation density, basal area per hectare and the density and basal area per ha for *Q. semecarpifolia* was estimated. The diameter distribution of the forest on the two categories of slope was also calculated, according to the grouping of species (Table 3). To test if there is a slope effect on the density and basal area of the forest and for *Q. semecarpifolia*, an ANOVA was performed.

3.3.3 Systematic Plots

The regeneration data for the systematic plots were entered and then accordingly the attributes for the plots like soil pH, litter depth, slope percentage, *Y. microphylla* cover, density for *D. bholua* and *Berberis* species in the plot, and canopy openness were entered. These factors were thought to have an effect on the likelihood of finding a *Q. semecarpifolia* seedling in the plot.

- *Y. microphylla* cover was categorised into four classes according to the area of the plot occupied by *Y. microphylla*

  0- nil
  1- 1 to 10%
  2- 11 to 25 %
  3- more than 25%

- For *Daphne bholua and Berberis species,* densities of the individuals were measured.
- Canopy openness was measured via hemispherical photographs.

a. Effect of different factors on the presence of *Q. semecarpifolia* seedlings

The *Q. semecarpifolia* seedlings were categorised as either present or absent for the systematic plot. Presence of the *Q. semecarpifolia* is defined as being present in the regeneration plots ($2m^2$) in any one of the years since the time of plot establishment.

A logistic regression was done to test the presence of *Q. semecarpifolia* with the other plot variables, such as Canopy openness, Slope, Soil pH, Litter depth, frequency of *Daphne* and *Berberis* and *Y. microphylla* cover.

b. Effect of Canopy Openness and Vegetation variable on the growth parameters of *Q. semecarpifolia* seedling

The plots with the presence of *Q. semecarpifolia* for the year 2003 were considered along with the attributes of the plots like canopy openness, *Y. microphylla* cover, *D. bholua* and *Berberis* sp. frequency for the analysis. These variables were used to test if they had an effect on the height growth, end shoot grow and number of leaves for *Q. semecarpifolia* seedling. First a collinear check was performed to see that the independent variables taken were not highly correlated with each other. Then a GLM multivariate analysis was performed to test the significance of each of the variables on the log transformed growth parameters. Log transformation improved the normality distribution for the growth parameters.

c. Effect of Canopy Openness on the survival of *Q. semecarpifolia* seedling.

To test the survival of the *Q. semecarpifolia* seedling, only the seeding tagged in the year 2000 were considered. If the seedling was again recorded during the measurement in 2003, it was considered as surviving, otherwise as dead.
A logistic regression was carried out to test the effect of different factors, such as canopy openness, *Y. microphylla* cover and height of *Q. semecarpifolia* seedling, on the survival after a collinearity check for the factors was done

3.3.4 Long term Observation plots

a. Comparison of *Q. semecarpifolia* seedling number due to effect of fencing in the Observation plots

After log transformation of the seedling count for each of the observation plots, an ANOVA was carried out to test for the effect of fencing and canopy cover on the number of *Q. semecarpifolia* seedling for the fenced and unfenced plots.

4.0 RESULTS

4.1 Comparison of inventory data for different slope gradient

From the inventory of the 16 quarter hectare plots, the diameter class distribution for the less than 10 cm diameter class is definitely lacking for *Q. semecarpifolia* (Fig. 1).

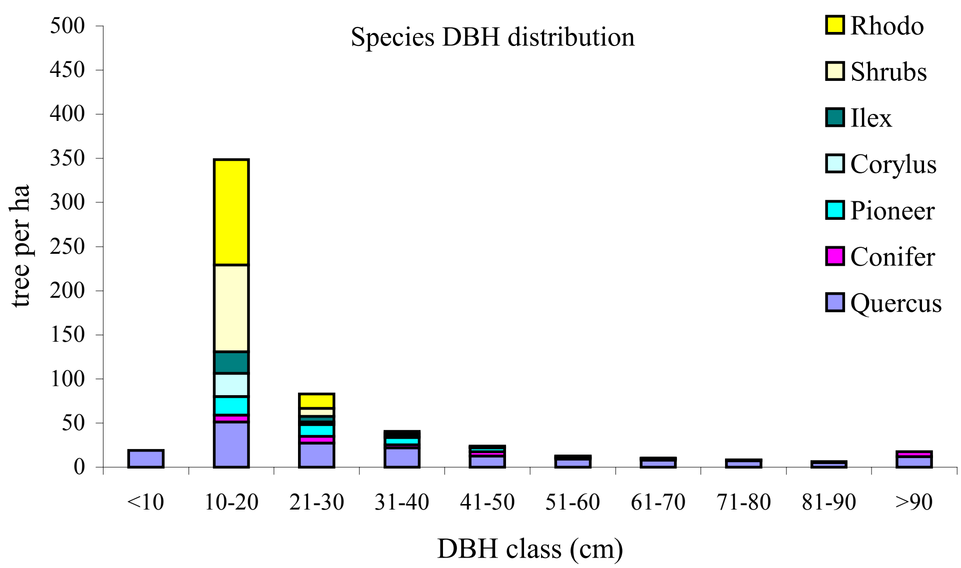


Fig.3. DBH class distribution for the 16 quarter ha inventory plots
Data for <10cm DBH collected only for *Q. semecarpifolia*

In the inventory of the sixteen 50m x 50m plots, there were 23 shrubs and trees species measured. To allow for better overview, the shrub species with basal area less than 0.5 m^2 per hectare were grouped together. The species in the same genus were also lumped together, and the pioneer species *Acer* sp. and *Betula alnoides* were taken together. All conifer sp. were also treated as one group. (Table 3)

Table 3 Grouping of vegetation categories

Grouping	Species
Quercus Species	*Quercus semecarpifolia*. *Quercus glauca*
Conifer	*Tsuga dumosa* *Picea spinulosa*
Pioneer	*Betula alnoides* *Acer* sp.
Corylus	*Corylus ferox*
Ilex	*Ilex dipyrena* *Ilex crenata*
Shrubs	*Prunus* sp. *Myrsine semiserrata* *Pieris formosa* *Gambelia ciliata* *Enkianthus deflexus* *Mallus baccata* *Hydrangea heteromalla* *Lindera* sp. *Sorbus microphylla* *Pyrus baccata* *Viburnum nervosum* *Lyonia ovalifolia*
Rhododendron species	*Rhododendron arboreum* *Rhododendron barbatum*

The projected area and the adjusted surface area of the plots were both used to separately compare the basal area and the density of trees in the inventory plots. The data for the projected area of the plots on relatively steep slope gradient, (40 to 65 %) had a basal area of 55 m^2 per hectare; density of 702 stems /ha of which, 157 trees were *Q. semecarpifolia* with a basal area of 29.8m^2. On relatively gentler slope (20 to 35 %) slope, the basal area was lower for the plots with 47m^2/ha and also had a lower vegetation density, 435 stems/ha. However, the basal area and density for *Q. semecarpifolia* was higher in gentle slopes, than the steeper plots, 32.8m^2/ha and 189 trees /ha respectively (Table 4).

ANOVA was carried out to test the effect of slope on the density and basal area of trees; and the basal area and density of *Q. semecarpifolia* in the inventory plots. Both the projected area and the surface area were used for the comparison. Test results for the projected area and for the surface area showed that there is no noticeable effect of slope on the density and basal area of *Q. semecarpifolia*; and on the basal area of all trees. However, the overall tree density is significantly higher on steep slopes.

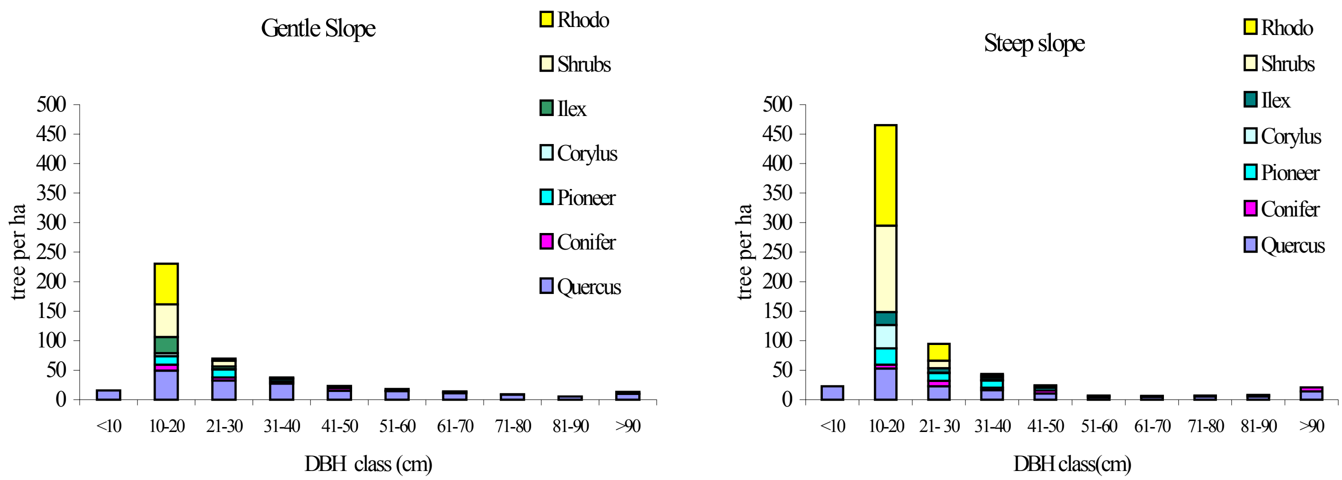


Fig.4. Species and DBH distribution on, a) gentle slope, 20 – 35%. b) Steep slope, 40- 65%

Data for <10cm DBH collected only for *Q. semecarpifolia*

Table 4. ANOVA on basal area and density of inventory plots

Slope	B A/ ha		Density / ha		Quercus BA/ha		Quercus density /ha	
	Projected area	Surface area	Projected area	Surface area	Projected area	Surface area	Projected area	Surface area
Steep slope (40-65%)	55 m^2	49 m^2	702	627	29.8 m^2	26.1 m^2	157	138
Gentle slope (20– 35%)	47m^2	46 m^2	435	422	32. 8 m^2	31.5 m^2	189	179
	P=0.278	P=0.620	P<0.001	P=0.004	P=0.568	P=0.254	P= 0.383	P=0.224

R Squared = 0.553 (Adjusted R Squared =0.521) for Projected area
R Squared = 0.455 (Adjusted R Squared = 0.416) for surface area

After inspection of the scatter graph, a linear line to best suit the range of data collected for vegetation density and the slope percentage was fitted. The linear regression for vegetation density and slope percentage resulted in significance at $p< 0.01$, with Adjusted $R^2 = 0.3925$.

Log (density) = 1.881+ 0.006247 *(Slope percentage)

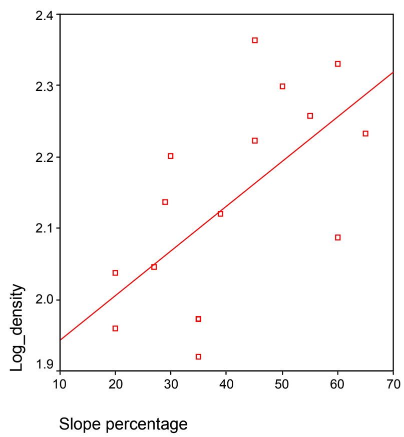


Fig.5. Relationship between slope and tree density (log scale)

ANOVA was done to see if there was an effect of density and basal area between the same tree species or grouped shrubs on the two categories of slopes. Significant difference was shown only for the basal area and density for the *Rhododendron* species, $P< 0.05$ for both parameters. For other species, no significant difference in density and basal area could be evident for the gentle and the steep slope plots.

Table 5. Comparison of vegetation density and basal area between the two categories of slope

Species	Density/ha		BA/ha ($m^2\ ha^{-1}$)	
	Gentle slope	Steep slope	Gentle slope	Steep slope
	Mean ± S.E	Mean ± S.E	Mean ± S.E	Mean ± S.E
Acer species	$35.44^a \pm 10.12$	$48.52^a \pm 15.08$	$1.84^a \pm 0.44$	$2.20^a \pm 0.68$
Betula alnoides	$16.00^a \pm 5.64$	$15.32^a \pm 2.80$	$2.00^a \pm 0.68$	$1.88^a \pm 0.52$
Corylus ferox	$14.68^a \pm 4.80$	$54.00^a \pm 16.04$	$0.20^a \pm 0.08$	$0.72^a \pm 0.24$
Ilex species	$37.16^a \pm 29.88$	$40.56^a \pm 18.96$	$0.76^a \pm 0.56$	$1.44^a \pm 0.68$
Shrubs	$20.32^a \pm 5.44$	$31.12^a \pm 7.32$	$0.48^a \pm 0.12$	$0.68^a \pm 0.12$
Conifer	$18.48^a \pm 4.20$	$26.32^a \pm 5.56$	$4.56^a \pm 1.12$	$8.08^a \pm 2.48$
*Q. semecarpifolia Sm**	$188.52^a \pm 19.32$	$156.00^a \pm 28.08$	$33.92^a \pm 3.36$	$29.96^a \pm 3.76$
Rhododendron arboreum✪	$74.00^a \pm 24.64$	$203.00^b \pm 59.00$	$1.20^a \pm 0.48$	$4.36^b \pm 1.40$

Species on different slope with the same letter are not significantly different (ANOVA $p> 0.05$)

* Includes one *Quercus glauca* ✪ Includes *Rhododendron barbatum*

Table 6. Population parameters of stem ≥10cm DBH for woody species in the 16-quarter hectare inventory plots

Species	Stem Density per ha ± S.E	Basal Area m^2/ha ± S.E	Density % per ha	DBH (cm) Mean ± S.E
*Q. semecarpifolia**	172.25 ± 67.98	31.94 ± 9.94	22.55	40.55 ± 3.02
R. arboreum	138.50 ±140.36	2.78 ± 3.32	18.13	14.04 ± 0.67
Myrsine semiserrata	78.00 ± 76.58	0.95 ± 1.05	10.21	11.83 ± 0.22
Pieris formosa	69.33 ± 59.04	1.04 ± 0.96	9.08	14.27 ± 2.01
Acer species	42.40 ± 35.55	2.03 ± 1.59	5.55	22.42 ± 1.68
Corylus ferox	40.89 ± 37.03	0.56 ± 0.53	5.35	12.69 ± 0.64
Ilex dipyrena	38.86 ± 63.60	1.10 ± 1.63	5.09	17.65 ± 1.14
Tsuga dumosa	25.87 ± 17.62	8.47 ± 7.76	3.39	47.90 ± 6.76
Prunus species	22.00 ± 21.54	0.82 ± 0.75	2.88	20.61 ± 1.49
Picea spinulosa	16.80 ± 16.20	2.89 ± 2.63	2.20	49.46 ± 4.86
Gambelia ciliata	16.00 ± 10.33	0.92 ± 0.90	2.09	22.26 ± 3.55
Q. glauca	16.00 ± 0.00	1.72 ± 0.00	2.09	34.00 ± 0.00
Betula alnoides	15.60 ± 8.32	1.93 ± 1.22	2.04	37.85 ± 4.40
Enkianthus deflexus	14.40 ± 11.03	0.18 ± 0.14	1.88	11.86 ± 0.46
Hydrangea heteromalla	13.50 ± 25.29	0.31 ± 0.61	1.77	16.67 ± 1.00
Lindera species	13.20 ± 7.32	0.49 ± 0.49	1.73	18.48 ± 2.23
Mallus baccata	12.00 ± 13.86	0.42 ± 0.63	1.57	15.86 ± 3.65
Lyonia ovalifolia	8.00 ± 0.00	0.08 ± 0.00	1.05	11.00 ± 0.00
Sorbus microphylla	6.40 ± 3.58	0.13 ± 0.07	0.84	16.10 ± 1.82
Viburnum nervosum	4.00 ± 0.00	0.03 ± 0.00	0.52	10.50 ± 0.29

* For *Q. semecarpifolia* all stems > than 1.3 m height were measured for DBH

4.2 Effect of different factors on the presence of *Q. semecarpifolia* seedling in the systematic plots.

A total of 39 plots were occupied by a *Q. semecarpifolia* seedling since the measurement started in 2000 on a total of 114 plots (2 m^2 each) set up in the trial area. The tallest seedling measured in 2003 was 41 cm with only four leaves and the end shoot being browsed. About 55% of the seedlings were below 10cm height and the other 45% ranged till a height of 41 cm tall.

A logistic regression was carried out for the presence of *Q. semecarpifolia* seedling in the systematic plots, with respect to the environmental and vegetation variables. Significant differences were obtained only for the *Y. microphylla* cover $P < 0.001$. The percentage canopy openness, soil pH and litter depth or the other vegetation frequency did not show any significant difference on the number of seedling found in the systematic plots laid out. The *Q. semecarpifolia* seedlings however seemed to prefer a soil pH of around 6 (Fig. 7), though not statistically significant.

Table 7. Presence of *Q. semecarpifolia* seedlings with respect to understory vegetation

Vegetation categorization	No of plots	Presence plots	Presence Percentage
No vegetation	8	0	0.0 %
Daphne & Berberis	3	0	0.0 %
Daphne only	10	1	10 %
Yushania and Berberis	3	1	33 %
Yushania only	34	12	35 %
Yushania & Daphne	39	15	38 %
Berberis only	2	1	50 %
Berberis, Daphne & Yushania	14	9	64 %
Total	**113**	**39**	**34 %**

Table 8. Result of logistic regression for the presence of *Q. semecarpifolia* seedling

Factors	Coefficient ±S.E	t-stat	P
Yushania cover %	1.259 ± 0.352	12.757	0.000
Litter depth	0.193 ± 0.135	2.043	0.153
Soil pH	0.945 ± 0.847	1.245	0.264
Canopy Opening %	0.191 ± 0.164	1.362	0.243
Daphne frequency	0.146 ± 0.101	2.112	0.146
Berberis frequency	0.354 ± 0.219	2.611	0.106
Slope	-0.005 ± 0.022	0.041	0.840
Constant	-8.588 ± 5.335	2.591	0.107
Model chi square (df)	25.784 (9)		
% correct Prediction	74.3 %		

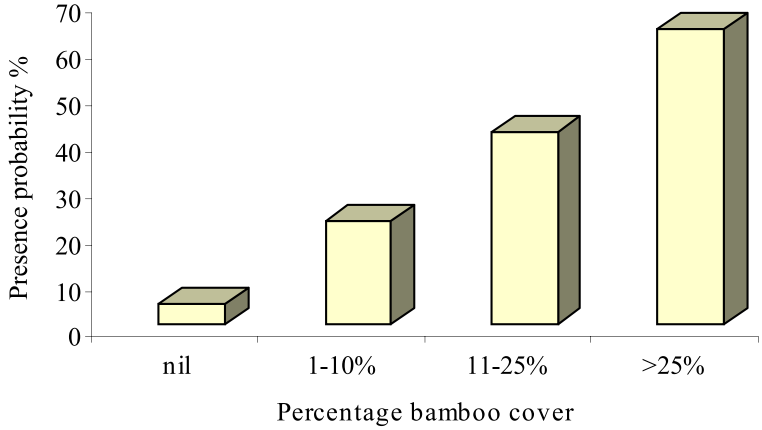


Fig.6. Presence percentage probability of *Q. semecarpifolia* seedling in the plot with respect to *Y. microphylla* cover

Log (p/(1-p)) = -8. 588 + 1.259 *(*Y. microphylla class)*

Predicted probability of the occurrence of *Q. semecarpifolia* with respect to the cover class of *Y. microphylla*

The results show that with increasing *Y. microphylla* cover, the probability of finding a seedling is higher. From Fig.6 a clear trend can be seen that the higher the coverage of *Y. microphylla*, the higher the probability of finding a *Q. semecarpifolia* seedling.

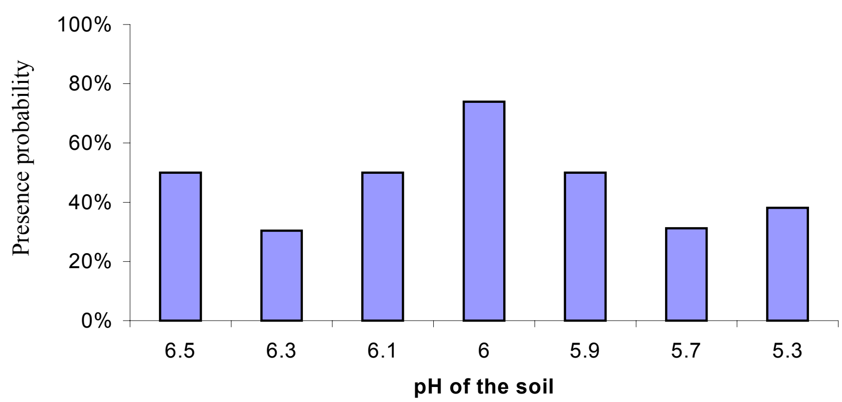


Fig.7. Presence of *Q. semecarpifolia* seedling with respect to soil pH

4.3 Effect of Canopy openness and *Y. microphylla* cover on seedling growth

The height of *Q. semecarpifolia* seedlings in the systematic plots ranged form 4cm to 41cm with about 50% of the seedling below 10cm height. The height of the seedlings averaged 11.98 ± 2.4 (S.D) cm, the annual end shoot growth averaged 2.9 ± 2.4 (S.D) cm, and the number of leaves averaged 5.41 ± 1.14 (S.D). The percentage canopy openness ranged form 4.5% to 29.4 %, and the data for *Y. microphylla* was collected as categories in the field.

A GLM multivariate analysis showed that the canopy openness had a significant positive effect on end shoot growth ($p<0.01$) and number of leaves on the seedling ($P<0.05$). The cover of *Y. microphylla* showed a significant positive effect for height of the seedling ($P<0.05$). The density of *Berberis* and *D. bholua* also showed a positive significant for the end shoot growth with $P< 0.05$ for both variables (Table 9).

Table 9. GLM Multivariate analysis for *Q. semecarpifolia* growth variables

Independent variables	Height increment	Number of leaves	Height of seedling
Canopy openness	P = 0.002	P = 0.039	P = 0.798
Y. microphylla cover	P = 0.136	P = 0.075	P = 0.048
Berberis density	P = 0.015	P = 0.296	P = 0.405
Daphne density	P = 0.018	P = 0.079	P = 0.124

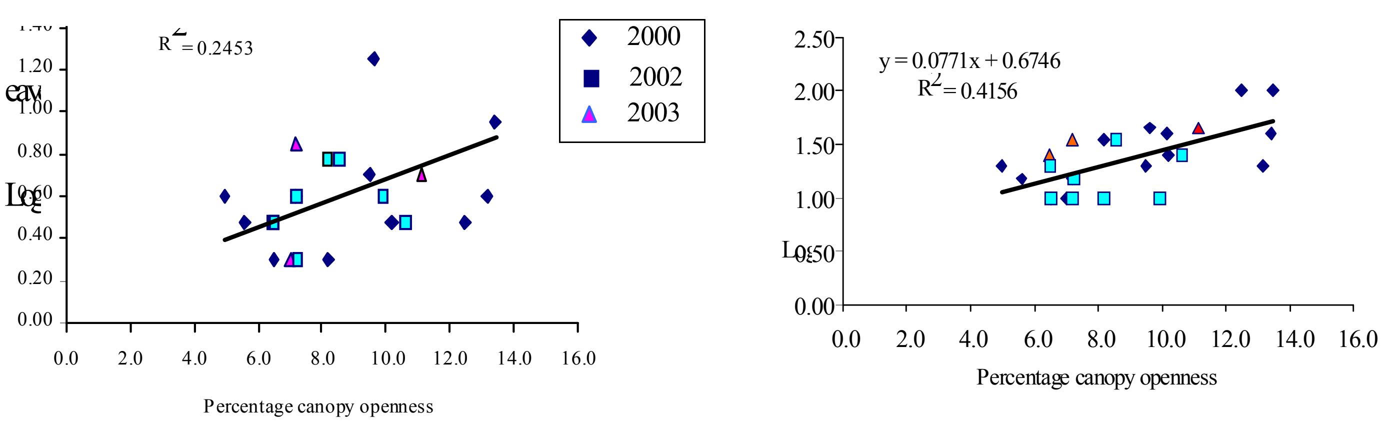


Fig.8. a). Log number of leaves. b) log end shoot growth of seedling with respect to percentage canopy openness in 2000/2/3 (simple linear regression analysis).

Table 10. Spearman's rho Correlations for the Growth parameters with plot variables

	Log height	Log no of leaves	Log height growth	*Y. Microphylla*	*Daphne*	*Berberis*	Canopy openness
Log height	1.000						
Log no of leaves	0.227	1.000					
Log height growth	0.596**	0.456*	1.000				
Y. Microphylla	0.072	0.101	0.140	1.000			
Daphne	-0.237	-0.241	-0.020	0.043	1.000		
Berberis	0.272	0.184	0.117	-0.045	0.173	1.000	
Canopy openness	0.508*	0.502*	0.692**	0.006	-0.255*	0.017	1.000

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

4.4 Effect of Canopy Openness, *Y. microphylla* and height of *Q. semecarpifolia* seedling on the survival.

The number of *Q. semecarpifolia* seedling counts in the 114 systematic plots of 2 m^2 each was greatest in the year 2000. A total of 54 seedlings were found occupying 29 of the plots, and since then the number of seedling has declined slowly through the years to about 28 seedling occupying 22 of the plots in 2003, including the new recruitment (Table 11). Of the 54 seedlings counted and tagged in 2003, only 20 seedlings survived till 2003.

A logistic regression was carried out to test the effect of different factors on the survival of *Q. semecarpifolia* seedling. The cover of *Y. microphylla* was significant for the survival of the seedling. With seedling height and canopy openness incorporated in the model, survival was also influenced positively by seedling height and negatively by canopy openness (Fig.9). A test of collinearity was performed to check that the factors incorporated into the model are not significantly correlated with each other to affect the result of the model.

Table 11. Trend of seedling count and plots occupied

Years	**2000**	**2001**	**2002**	**2003**
Total Seedling	54	36	29	28
Plots occupied	29	21	22	22
Percentage of plots occupied	25.4%	18.4%	19.3%	19.3%

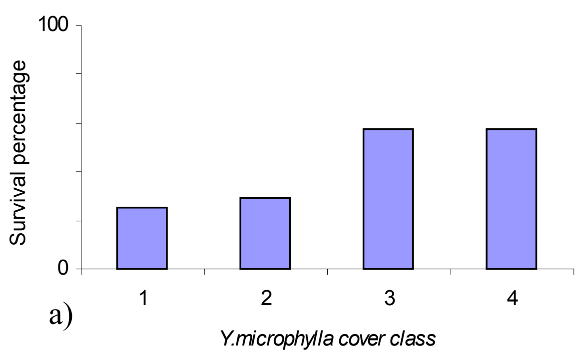
Table 12. Spearman's rho Correlations to check for collinearity between the variables

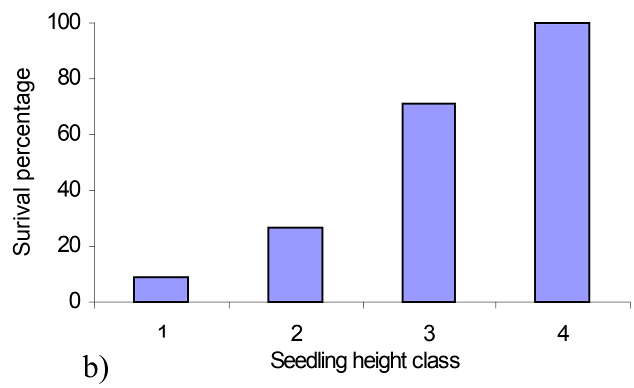
	Canopy Openness	*Y. microphylla* cover	*Berberis* frequency	*Daphne* frequency	Litter depth	Survival
Canopy Openness	1.000					
Y. microphylla cover	0.061	1.000				
Berberis frequency	-0.006	-0.138	1.000			
Daphne frequency	-0.266	0.156	0.108	1.000		
Litter depth	-0.203	-0.203	0.035	-0.146	1.000	
Survival	-0.146	-0.229	0.066	0.004	0.061	1.000

Non of the factors are significantly correlated with each other.

Table 13. Result of logistic regression for the survival of *Q. semecarpifolia* seedling

Factors	Coefficient ± S.E	t- stat	Sig.
Y. microphylla	1.012 ± 0.498	4.130	0.042
Canopy openness	-0.195 ± 0.097	4.022	0.045
Seedling height	2.175 ± 0.685	10.080	0.001
Constant	-4.871 ± 1.749	7.758	0.005
Model chi square (df)	21.695 (3)		
% correct Prediction	76.9%		





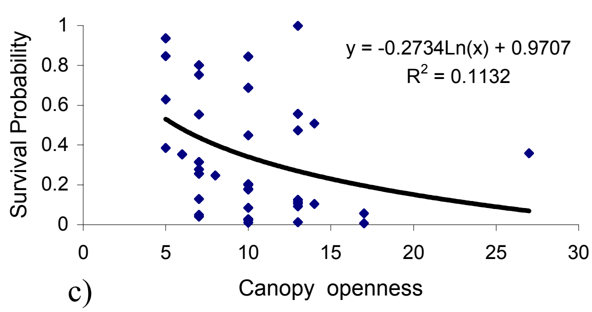


Fig.9. Percentage survival of *Q. semecarpifolia* seedling with respect to a) *Y. microphylla* cover b) seedling height and c) with canopy openness

4.5 Comparison of seedling number due to effect of fencing and canopy openness in the Observation plots

The seedling numbers in the observation plots show a high degree of variation. The highest number of *Q. semecarpifolia* seedling observed in 2003 was 107 seedling in the fenced-open canopy plot, but the mean highest number of *Q. semecarpifolia* seedling was observed in the fenced-closed canopy plots. The lowest mean and lowest number of seedling was observed in the unfenced-open plots. (Table 15)

Table 14. Number of *Q. semecarpifolia* seedlings under different treatments

Canopy	Fence	Number of *Q. semecarpifolia* seedling				Percentage canopy opening
		2000	2001	2002	2003	
Closed	Unfenced	0	1	5	5	6.60
Closed	Unfenced	1	4	3	4	6.27
Closed	Unfenced	43	33	41	40	5.63
Open	Unfenced	0	0	0	1	9.76
Open	Unfenced	12	10	7	10	22.31
Open	Unfenced	2	2	3	3	14.19
Closed	Fenced	4	4	5	4	9.43
Closed	Fenced	31	34	37	36	10.15
Closed	Fenced	39	52	93	85	8.40
Open	Fenced	0	3	2	2	17.36
Open	Fenced	0	1	0	2	22.37
Open	Fenced	43	60	112	107	9.16

Percentage canopy opening used for the calculation (Plot size of 10 m X 10 m)

Table 15. Number of *Q. semecarpifolia* seedlings under different treatments (2003).

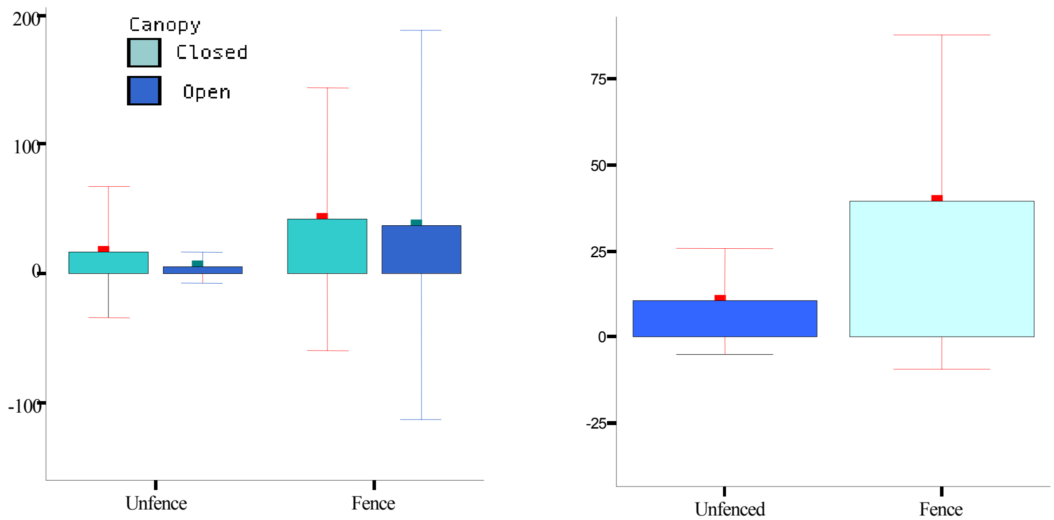
Treatment	Unfenced & Closed	Unfenced & Open	Fenced & Closed	Fenced &Open
No. of seedling				
Site 1	5	1	4	2
Site 2	4	10	36	2
Site 3	40	3	85	107
Total	**49**	**14**	**125**	**111**

An ANOVA was performed after log transformation of the seedling count data, to test the effect of fencing and the percentage canopy openness on the mean number of *Q. semecarpifolia* seedling. Although, when the mean seedling counts in the unfenced and fenced plots are graphed, there seems to be a difference, but statistically there is not enough evidence to prove that the fence or the canopy openness has an effect on the number of *Q. semecarpifolia* seedling in the plots.

Table 16. ANOVA for comparison of canopy openness and fencing

Treatment	Seedling count
Fence	P = 0.230
Percentage canopy opening	P = 0.172

(Adjusted R Squared = 0.105)



a) b)

Fig.10. Comparison of the effect of a.) fence and canopy openness b.) fence, on the mean number of *Q. semecarpifolia* seedling (2003) (Error bar show 95% CI of means; bar show means)

5.0 DISCUSSION

5.1 Plant density on slope

The size class diagrams may give a better indication of the long-term regeneration status of the forest than seedling counts (Vetaas, 2000). From the DBH distribution graph of the inventory plots (Fig. 1), it is evident that the regeneration for *Q. semecarpifolia*, which is the dominating species in the area, is definitely lacking in the 1cm to 10cm diameter class. However the discrepancy can be understood if one realizes that only one seed needs to survive to replace the mother tree (Oliver and Larson, 1990; Lorimer et al., 1994; Vetaas, 2000). It is apparent however that the regeneration of the *Rhododendron* species and other shrubby species is very good (Fig.1).

The density of trees on the steep slope is almost twice as much as that on the gentle slope. From the study on tropical rain forest, Clark et al. (2000) showed that on steep slopes with utisols, there were on average 44% more stem per hectare than on flat inceptisol plots and stem number per plot and basal area were significantly higher on slopes than on flat plots. Enoki (2003) also reported from the studies on subtropical evergreen broadleaved forest, that the stem density was higher in convex topography and steep slope. From this study, apparent difference in the density between the gentle slope site and the steep slope site is in the density of *Rhododendron arboreum*, which is consistent with the findings of Thomson et al. (1993), who reported that steep slope are an important factor favouring the spread of *Rhododendron*. The topographic variation in stem density may also be related to high stand turn over rates on the slopes because of the higher frequency of tree fall there (Poorter et al., 1994; Denslow, 1995). The canopy opening events such as tree fall, hurricane, or timber extraction commonly produce an increase in the density because a few large trees are eventually replaced by many small trees (Denslow, 1995).

In natural forest, neighbouring trees are the most important obstacles that reduce light intensity and change light quality (Harper, 1997; Endler, 1993; Umeki, 1995). For a tree on a slope, the crowns of the neighbouring trees on the upper side of the slope are situated at higher position than those of the same sized trees on the lower side of the slope. Thus the light environment is more favourable for both the trees on the upper and lower side of the slope, rather than if they were on a flat terrain with no slope difference. Almquista, et al. (2002) suggest that because of less light availability caused by smaller gap fraction and abundance, seedlings growing in low sites will have more difficulty reaching the canopy than those on ridges. Thus apart from a greater stand turn over rates on the steeper slopes, the side light availability could also be a factor for the greater density of *Rhododendron* species on the steep slopes.

The density of *Q. semecarpifolia* is not significantly different between the two slopes. However, it can be seen that the density is higher for relatively flat slope. Johnson et al. (2002) also report that on a given aspect, oak reproduction density is greatest on gentle slope and decreases with increasing slope gradient. The competitive success of Rhododendron on the steep slope could also be an influencing factor in the number of *Q. semecarpifolia* being greater on the gentle slopes, as species richness and regeneration layer decreases with an increase of Rhododendron thickets (Baker and Van Lear, 1998).

5.2 Effect of understory vegetation on presence of *Q. semecarpifolia* seedling

The environmental factors such as canopy openness and other site factors like litter depth, slope and soil pH did not seem to have a statistical significant influence on the presence of *Q. semecarpifolia* seedling. However, when the presence of the seedling is graphed with the soil pH the seedlings optimally respond to a pH of around 6 (Fig.7), which is consistent with the finding of Vetaas (2000), for *Q. semecarpifolia* seedlings.

Röhrig (1967) showed that one-two year old oak seedlings can grow in very low light (Welander et al., 1997). In another study by Grime and Jeffrey (1965), stated that the growth and survival of the young seedling under low light conditions could be attributed to the resources of the acorn. However growth rates under low light conditions are slow (Ovington and Macrae, 1960; Shaw, 1973; Lorimer et al., 1994). As only young seedlings were recorded in the study area, the dependence of the seedling on the acorn reserves for a few years could be a possible explanation, why the canopy openness did not have an influence on the amount of seedlings found in the systematic plots.

Vetaas (2000) report's that no clear relationship was found between the seedlings and the soil variables and that their survival may be more determined by external factors. Similarly in this study, soil did not seem to be an influencing factor for the presence of *Q. semecarpifolia* seedling. The soil report BSS/NSSC (2003) of the study area however, states that the soils are quite similar through out the site and are made up of the same parent material. (Appendix. 1a & 1b).

From studies by Putman (1986); Gill (1992) ungulates have been reported to retard or even totally prevent tree regeneration in forest landscapes, but then again Grubb et al. (1999) have reported instances where colonisation by woody species is observed even under heavy grazing pressure. Facilitation or associational resistances (Olff et al., 1999) where individuals of a browse resistant plant species have a positive effect on another species by protecting it against a high herbivory or grazing, is an example of a mechanism that enables plants to cope with grazing (Kuiters and Slim, 2003). This too, could be the case in this study, where the presence of *Q. semecarpifolia* seedling is significantly and positively correlated with the coverage of *Y. microphylla*. The cattle browse *Y. microphylla*, but it is only the leaves and the soft tender shoots that are browsed and not the tough stem. The tough stem could provide protection for the *Q. semecarpifolia* seedling against trampling and also against being easily spotted and eaten. Moreover, the presence of *D. bholua* and *Berberis* sp. along with the coverage of *Y. microphylla* has a higher presence percentage for *Q. semecarpifolia* seedling (Table 7), although the presence of *D. bholua* and *Berberis* species is not statistically significant. *Berberis* sp. being equipped with tough thorns could act as a fence and deter the cattle from grazing close to it and consequently if a *Q. semecarpifolia* seedling were growing within the *Berberis* bush, it would be protected from being easily browsed. In Borkener Paradies the occurrence of young oaks was also positively associated with the presence of Blackthorn shrub (Bakker et al., 2003). *D. bholua* has been cited as "plants deer don't like"(www.taoferbfarm). This was also evident in the trial site, as it is one of the few understory shrub species that remain evergreen throughout the year and nonetheless, thrive very successfully without being browsed excessively. Thus, they too seem to provide mechanical protection to *Q. semecarpifolia* seedling in their vicinity. Kuiters and Slim (2003) found that the density of woody regeneration was more than 20 times in patches with bramble compared to patches of open grass. Apparently bramble shrub acts as a successional facilitator in the grazed grasslands. From our study, the combination of the understory vegetation of *Y. microphylla*, *Berberis* and *D. bholua* has a positive effect and act as facilitators for *Q. semecarpifolia* seedling.

In an enclosure experiment, with weeding and not weeding treatment on the growth and survival of *Quercus petraea*, a short breach (2 days) of the fence that allowed the Sika deer inside the enclosure dramatically reflects the possibility of the facilitative effect of the shrubs to protect Oaks against browsing. 49% of the oak seedlings in weeded plots and only 11% in the un-weeded plots were browsed (Kelly, 2002).

Burrichter, et al. (1980); Pott and Hüppe (1993) and Bakker et al. (2003) report that oaks are usually found surrounded by thorny shrubs. It has been hypothesised that the thorny shrubs protect the palatable oaks and other tree species from grazers (Vera 1997, 2000; Bakker et al., 2003), an example of associational resistance (Olff et al., 1999; Bakker et al., 2003). The largest oak seedling recorded during the present study was found surrounded by the thorny *Berberis* species. This accentuates the fact that natural interplay of herbivore and plant defences may still be at work, and that associational resistance is an important mechanism for the regeneration of palatable trees in grazed systems (Bakker et al., 2003).

Photo1. *Q. semecarpifolia* seedling associated with *Berberis* sp. and *Y. microphylla*

5.3 Effect of Canopy openness and *Y. microphylla* cover on seedling growth

The canopy openness did not have a significant effect on the presence of the *Q. semecarpifolia* seedling; however, it was significantly and positively correlated with the height increment of the seedling and the number of leaves on the seedling. That is, as canopy openness increased the number of leaves and the height increment was higher. From studies by Suh and Lee (1998) report that the heights of oak seedlings in larger clear cuts were greater than those under canopies or in small gaps (Li and Ma, 2003). Similarly, Röhrig (1967) and Suner and Röhrig (1980) found a decrease in shoot length with increase in shade. Increased light levels generally result in greater height growth, greater root development and increased root/shoot ratio (Crow, 1988).

The significant increase in the number of leaves with increase in canopy openness from this study is also supported by the report of Welander & Ottosson (1998). They state that the light intensity during winter bud initiation in the previous year greatly determines the number of leaves developed in the first flush for *Q. robur* seedling the following year, and that the number of leaves that flush increases with light intensity. From studies by Crow (1992) report that the highest frequency of double leaf flushing always occurred in the no overstory treatment and the lowest frequency always occurred in the complete overstory treatment for *Q. rubra* seedlings.

The frequency of *D. bholua* has a negative influence on the end shoot growth of the seedling, which may be due to the fact that the frequency of *D. bholua* is negatively correlated with canopy openness, which means less light for the seedling and consequently less height growth.

The height increment for the seedling is positively correlated with the presence of *Berberis* and with the increase in cover of *Y. microphylla*. This could be due to the fact that *Berberis* and *Y. microphylla* protects the seedling from being browsed. Kelly (2002) reports that the height of the oak seedling is significantly taller in the unweeded plots than the weeded plots when grazing or browsing is present. This reflects that, lower portion of the seedling are browsed where there are other less palatable vegetation surrounding the seedlings.

5.4 Effect of Canopy Openness, *Y. microphylla* and height on the survival of *Q. semecarpifolia* seedling.

The percentage of canopy openness alone does not seem to satisfactorily explain the survival tend of *Q. semecarpifolia* seedlings. A study by Riley (2003) also did not find a significant difference between the clearcut and the understory seedling survival for two-year-old *Q. alba* seedlings. However the biomass growth and leaf area was much higher in the open sites, as was in this study.

The results of the logistic regression for the survival of the *Q. semecarpifolia* seedling show a positive influence with the percentage of *Y. microphylla* cover and a negative influence of the canopy openness. The results are consistent with studies by Li and Ma (2003) who report that the seedling survival and recruitment in the shade were significantly better than those in the open sites. Similarly, Callaway and D'Antonio (1991) reported that shrubs could have strong facilitative effects on the survival *of Q. agrifolia* seedling. Callaway (1992), reports that the presence of shrubs raised the survival of the 1-year *Q. douglasii* seedling from zero to 30-50% because of shade benefits and acorn protection from predation and herbivory (Li and Ma, 2003). Shrubs can also improve survival of oaks seedling by reducing heat or water stress and providing protection form herbivores (Crow, 1998; Callaway, 1992; Dubois et al., 2000, Li and Ma, 2003).

The height of the seedling had the strongest influence on the survival of the seedling. This is consistent with the finding of Collins and Battaglia (2002), where they report that the plant size, principally measured by maximum leaf length and stem height, was most strongly related to seedling survival through one or two seasons. De Steven (1994) also reports that seedling of 50 cm tall, among three common trees species on Barro Colorado Island, Panama showed annual survival or more than 80%. Survivorship appears to improve as seedlings get larger (Turner, 2001).

5.5 Comparison of seedling number due to effect of fencing and canopy openness in the Observation plots

Grazing and browsing from wild ungulates have always played a role in determining the structure and dynamics of the natural ecological systems and are a normal part of the natural, balanced ecological dynamics of woodland (Putman, 1996). However, when domesticated unchecked cattle population are allowed to graze freely in these woodlands, the balance of the system could be disrupted, especially when the forest is harvested. Riley (2003) reports that herbivory explained more of the variation in the growth of seedling than did all the other variables combined including light and water. Herbivores consumed 40% to 60% of the leaf area or stem in some plants (Riley, 2003). The effect of browsing and insect damage to the seedling can be heightened if the seedlings are unable to replenish lost tissues (Shaw, 1974; Crow, 1992; Fuchs, et al., 2000). Although from the study results, the effect of excluding the grazers by means of fencing did not seem to have statistically significant effect on the *Q. semecarpifolia* seedling count. The seedling count within the six fenced plots totalled 236 against only 63 seedlings in the other six unfenced plots. The statistical non-significance could be due to the large error variance in the data and the limited number of plots, but nonetheless, there is definite evidence that fencing does have beneficial advantages for the *Q. semecarpifolia* seeding (Fig.10 b). From a similar study by Adams et al. (2001) seedling height growth and shoot elongation were greater on fenced seedlings than on unfenced seedlings, suggesting that mammalian herbivory may be an important factor affecting seedling survival.

The numbers of *Q. semecarpifolia* seedlings under the open and closed canopy though not statistically different, are more in the closed plots. (Fig.10 a). This is especially true for the unfenced plots and is consistent with the findings from the systematic plots and furthermore confirms the possibility of associational resistance and the benefit of a shrub cover for survival of the seedling.

6.0 GENERAL FINDINGS AND SILVICULTURE OPTIONS

The regeneration requirements of *Q. semecarpifolia* is still very perplexing, because of the diverse interaction of spatial and temporal requirements of the species. The ecology of the species is still little understood for the different micro-sites that it could occupy. Nonetheless from the results of this study, some things are clearer and the following observation and silvicultural options have been made for the site.

It has been observed that *Q. semecarpifolia* starts to germinate as soon as the seed ripens and falls to the ground. In some instances the seed starts to germinate even when they are still on the tree. The radical develops rapidly after germination. However the epicotyl usually does not develop until the next spring, when conditions are more favourable (Troup, 1921). *Q. semecarpifolia* seedling shoots have been observed to die back to the ground and re-sprout from the roots during the following year. This way the seedling builds up a strong root system before it commences shoot growth, when conditions are favourable (Larsen, et al., 1998). Recurrent shoot die-back thus appears to be an important aspect of the evolutionary development and adaptive strategy of oak regeneration, especially for seedlings growing beneath the forest canopy (Johnson, et al., 2002).

Several authors have varying opinion on the occurrence of *Q. semecarpifolia;* some say it occurs on the south facing slopes while others have said that it occurs on north facing slopes. Yet, it has been observed that *Q. semecarpifolia* occur on both the aspects. However the regeneration strategy for these two aspects could be slightly different, for the species to become established, due to the differences in the moisture regime on the two aspects.

The north- facing aspects are usually more moist, than the south facing. The north facing aspect favours the regeneration of oak but also competing species. Successful regeneration of oaks partly depends on the species that oaks must compete with. Thus to develop a strategy to regenerate *Q. semecarpifolia,* the conditions of the site and the competing vegetation must be understood as the physiographic and climatic conditions of a particular site strongly influence the species present. Firstly, the germination and survival of the seedlings for a few years are favoured by the presence of a canopy cover, and other facilitative shrubs like *Berberis* and *Y. microphylla* as shown by the present study and also from report by Vetaas (2000). For further growth of the seedling, the report by Crow (1992) states that oak seedling requires multiple stem flushes and the frequency of multiple flushing is closely and positively correlated with light intensity. This is further confirmed by the findings from the present study where height growth and the number of leaves on the seedling were seen to be positively dependent upon the amount of canopy openness.

From these findings the Shelterwood system would apper to be the most appropiate system to regenerate the oak forest, as *Q. semecarpifolia* seem to be susceptible to strong light during the early seedling stage, but nonetheless require increasing light with growth and development of the seedling. To facilitate the regeneration of *Q. semecarpifolia,* it is imperative that there is plenty of advance regeneration (Thadani and Ashton, 1995) and that the forest is excluded from grazing for a period of time till the oak seedling outgrow from being grazed by cattle.

After a good seed crop, and plenty of advance regeneration in the forest, the canopy should be partially removed to facilitate the growth of the oak seedlings. A cautious amount of canopy removal about 30-40 % oppenness is recommended as the *Q. semecarpifolia* seedling is susceptible to stong light as show by this study. As it is almost definite that the canopy openness will also facilitate the growth of other shrubby vegetation, mechanincal weeding should be praticed at least once a year. This would give the oak seedling a bettter chance of survival from the competing weeds and also rodents that take shelter in the thickets and gnaw the oak seedling to their death. During weeding the facilitative benefit of some of the shrubs as shown from this study for the survival of the oaks must be recognized, especially if exclusion of grazing cannot be guaranteed.

The second cut should be planned when the seedling have grown relatively tall, about 50cm high or when there is less likelihood of facing competition for light from other shrubby species, but are still flexible enough to resist breakage during harvesting. At least 15 to 20 % of the original stand should be left standing for further seed production, seedling protection and for bio-diversity conservation in general. Once the oaks have reached the pole stage the remaining trees can either be harvested or left standing for aesthetic or as snag trees for wildlife habitat.

7.0 CONCLUSION

From the study results, it is clear that for initial germination and survival of the seedling for a few years, the association of the seedlings with other shrubs, like *Berberis* a thorny shrub and *Y. microphylla* seems to be very important. As the shrubs seems to provide safe habitat for the seedling from being browsed and also from being scorched and desiccated from the sun, as well as protecting them from frost damage during the cold chilly night in autumn and spring.

Canopy openness did not have an influence on the presence of the *Q. semecarpifolia* seedlings, however it did have a positive influence on the height growth and the number of leaves. The canopy openness was negatively correlated with the survival of the seedling, which makes it quite complicated for straightforward management. The findings imply that *Q. semecarpifolia* germination is not dependent upon the canopy openness, but survive better with more canopy cover for initial years of the seedling stage. For development into the next stage or for release from the seedling stage, canopy opening is a critical factor as the height growth and the numbers of leaf flushes are dependent upon the canopy openness. The oak seedlings in association with the facilitative shrubs can escape certain amount of grazing pressure. Therefore the key for the successful regeneration of the Oak Forest is the proper timing and amount of canopy opening, and to have controlled grazing to provide the right window of opportunity for oak seedling to establish into the next stage.

The slope and the topography of the landscape did not seem to have an influence on the regeneration. However, from the inventory of the 16-quarter ha plots the density of *Q. semecarpifolia* is higher on the gentle slopes, which is consistent with the finding of Johnson, et al. (2002). Hence, relatively flatter slope seemed to benefit regeneration, which could be due to the acorn not rolling of the area when it falls to the ground, or the caching preference of birds and mice, who bury the acorn for future use.

The soil survey carried out by BSS/NSSC (2003) report that the soil is more or less similar in the whole study area. Though, the soil analysis for the systematic plots was not carried out, the pH of the soil was measured for every plot. *Q. semecarpifolia* seedlings seem to prefer a soil pH of around 6, which is consistent with the finding of Vetaas (2000), for *Q. semecarpifolia* seedlings. The litter depth did not seem to have any significant effect on the presence or the survival of the *Q. semecarpifolia* seedling.

8.0 RECOMMENDATION / RESEARCH NEEDS

The natural regeneration of *Q. semecarpifolia* is still very perplexing. To further supplement the present study and literature available some more experiments needs to be done. Firstly, the present study should be continued to follow the dynamics of the seedling. The oak seedlings should be all tagged and growth parameters measured for a few more years. This could probably shed some more information on how the seedlings react to the canopy openness and competition from the facilitating shrubs with time.

For the Oak seedling, there seems to be a need for shade in the initial years for it to survive, but during later stages need more light to grow and develop into the next phase. As these thresholds are not yet understood from this study. Further experiments need to be set up to determine the optimum amount of canopy openness to favour seedling survival and growth.

As every winter there are occasional forest fires, especially in the *Pinus* dominated mixed forest. It would be worthwhile to set up experimental plots in these areas, to see if the regeneration of *Q. semecarpifolia* is favoured by the reoccurrence of forest fire. Experimental plots need to be set up on both southerly and northerly facing aspects, to try and determine if aspect has an effect on the regeneration of the species. It would be interesting to find out the effect of forest fire on the regeneration of *Q. semecarpifolia* for the two aspects.

The amount of advanced regeneration is quoted as an important strategy in the regeneration of oaks. This should be studied thoroughly to understand how and when advance regeneration could establish into the next growth phase.

In other parts of Bhutan, (Gangchey-Babesa area) where the soil is very shallow and rocky, the same species is found stunted and does not grow more than a few meters tall. It forms a shrub like forest and dominates other vegetation. Seed production and germination did not seem to be a problem in these poor areas, where the species does not grown into a tree but remains a shrub. The study of seed production and growth from these acorns of stunted forest, to see if they can grow into normal tall trees when grown in a better environment would be interesting.

The Forest Development Corporation (FDC), after harvesting operation, usually sets up forest plantation. It would be interesting to study the effect of canopy openness, fencing and weeding on the survival and development of *Q. semecarpifolia* seedling in these plantations.

If these studies can be carried out successfully, it would definitely shed more light on the regeneration requirements and developing silvicultural options for this less understood important species.

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Appendix 1:

Summary of soil sample data from the systematic plots

a.) Topsoil sample data analysis from the systematic plots

											Exchangeables							(Element/CEC) x 100				Cation Ratios		Cation Ratios	
Series	Site No.	Depth	pH	pH	pH	Avail P	Avail K	Org C	Total N	C:N	meq / 100g							Mg	K	Al	BS				
			H2O	KCl	diff	ppm	ppm	%	%		Ca	Mg	K	Na	TEB	Al	CEC	Sat%	Sat%	Sat%	%	Ca/Mg	Rating	Mg/K	Rating
ND	PT069	0 - 27	4.80	3.80	1.00	1.28	39.84	6.00	0.39	15	0.31	0.60	0.22	0.05	1.18		25.19	2	1		5	0.52	Ca deficient	2.73	Mg sli deficient
	Site Mean		**4.80**	**3.80**	**1.00**	**1.28**	**39.84**	**6.00**	**0.39**	**15.38**	**0.31**	**0.60**	**0.22**	**0.05**	**1.18**		**25.19**	**2.38**	**0.87**		**4.68**	**0.52**	Ca deficient	**2.73**	Mg sli deficient
	Site Rating		V.Acid	ND	ND	V Low	ND	V High	Mod	Mod	V Low	Low	Low	V Low	V Low		High	V Low	V Low		V Low				
ND	PT070	0 - 27	4.74	3.79	0.95	0.07	45.48	6.80	0.55	12	0.26	0.57	0.28	0.04	1.15		3.58	16	8		32	0.46	Ca deficient	2.04	Mg sli deficient
	Site Mean		**4.74**	**3.79**	**0.95**	**0.07**	**45.48**	**6.80**	**0.55**	**12.36**	**0.26**	**0.57**	**0.28**	**0.04**	**1.15**		**3.58**	**15.92**	**7.82**		**32.12**	**0.46**	Ca deficient	**2.04**	Mg sli deficient
	Site Rating		V.Acid	ND	ND	V Low	ND	V High	High	Good	V Low	Low	Low	V Low	V Low		V Low	ND	V Low		V Low				
ND	PT071	0 - 23	4.81	3.76	1.05	0.43	70.05	6.70	0.45	15	1.32	1.31	0.42	0.03	3.08		9.41	14	4		33	1.01	Ca sli deficient	3.12	OK
	Site Mean		**4.81**	**3.76**	**1.05**	**0.43**	**70.05**	**6.70**	**0.45**	**14.89**	**1.32**	**1.31**	**0.42**	**0.03**	**3.08**		**9.41**	**13.92**	**4.46**		**32.73**	**1.01**	Ca sli deficient	**3.12**	OK
	Site Rating		V.Acid	ND	ND	V Low	ND	V High	Mod	Mod	V Low	Low	Mod	V Low	Low		Low	ND	V Low		V Low				
ND	PT072	0 - 18	5.55	4.47	1.08	0.73	65.16	5.00	0.41	12	2.34	0.96	0.42	0.02	3.74		22.25	4	2		17	2.44	Ca sli deficient	2.29	Mg sli deficient
	Site Mean		**5.55**	**4.47**	**1.08**	**0.73**	**65.16**	**5.00**	**0.41**	**12.20**	**2.34**	**0.96**	**0.42**	**0.02**	**3.74**		**22.25**	**4.31**	**1.89**		**16.81**	**2.44**	Ca sli deficient	**2.29**	Mg sli deficient
	Site Rating		V.Acid	ND	ND	V Low	ND	V High	Mod	Good	Low	Low	Mod	V Low	Low		Mod	V Low	V Low		V Low				
ND	PT073	0 - 20	4.82	4.00	0.82	0.73	45.33	6.70	0.52	13	1.49	0.50	0.34	0.01	2.34		29.78	2	1		8	2.98	Ca sli deficient	1.47	Mg deficient
	Site Mean		**4.82**	**4.00**	**0.82**	**0.73**	**45.33**	**6.70**	**0.52**	**12.88**	**1.49**	**0.50**	**0.34**	**0.01**	**2.34**		**29.78**	**1.68**	**1.14**		**7.86**	**2.98**	Ca sli deficient	**1.47**	Mg deficient
	Site Rating		V.Acid	ND	ND	V Low	ND	V High	High	Good	V Low	Low	Mod	V Low	V Low		High	V Low	V Low		V Low				
	Overall for topsoils		**4.94**	**3.96**	**0.98**	**0.65**	**53.17**	**6.24**	**0.46**	**13.54**	**1.14**	**0.79**	**0.34**	**0.03**	**2.30**		**18.04**	**7.64**	**3.24**	**0.00**	**18.84**	**1.48**	Ca sli deficient	2.33	Mg sli deficient
	Overall rating for topsoils		V.Acid	ND	ND	V Low	ND	V High	Mod	Good	V Low	Low	Mod	V Low	V Low		Mod	V Low	V Low		V Low				

b.) Subsoil sample data analysis from the systematic plots

											Exchangeables							(Element/CEC) x 100				Cation Ratios		Cation Ratios	
Series	Site No.	Depth	pH	pH	pH	Avail P	Avail K	Org C	Total N	C:N	meq / 100g							Mg	K	Al	BS				
			H2O	KCl	Diff	ppm	ppm	%	%		Ca	Mg	K	Na	TEB	Al	CEC	Sat%	Sat%	Sat%	%	C/Mg	Rating	Mg/K	Rating
ND	PT069	27 - 61	5.20	3.80	1.40	0.02	20.51	3.80	0.22	17	0.26	0.73	0.18	0.04	1.21		18.58	4	1		7	0.36	Ca deficient	4.06	OK
		61 - 116	5.52	3.92	1.60	2.14	8.02	1.80	0.12	15	0.26	0.50	0.13	0.06	0.95		14.77	3	1		6	0.52	Ca deficient	3.85	OK
		116 - 143	5.79	4.03	1.76	0.59	4.36	1.30	0.10	13	0.26	0.43	0.13	0.05	0.87		15.20	3	1		6	0.60	Ca deficient	3.31	OK
	Site Mean		**5.50**	**3.92**	**1.59**	**0.92**	**10.96**	**2.30**	**0.15**	**15.09**	**0.26**	**0.55**	**0.15**	**0.05**	**1.01**		**16.18**	**3.38**	**0.90**		**6.22**	**0.49**	Ca deficient	**3.95**	OK
	Site Rating		V.Acid	ND	ND	V Low	ND	Mod	Low	Mod	V Low	Low	Low	V Low	V Low		Mod	V Low	V Low		V Low				
ND	PT070	27 - 61	5.25	4.10	1.15	0.05	6.48	3.40	0.32	11	0.09	0.12	0.09	0.02	0.32		25.06	0	0		1	0.75	Ca deficient	1.33	Mg deficient
		61 - 103	5.68	4.28	1.40	0.69	2.39	1.60	0.19	8	0.09	0.15	0.08	0.05	0.37		13.06	1	1		3	0.60	Ca deficient	1.88	Mg deficient
		103 - 130	5.64	4.72	0.92	0.01	1.05	1.40	0.15	9	0.09	0.03	0.08	0.01	0.21		17.67	0	0		1	3.00	OK	0.38	Mg deficient
	Site Mean		**5.52**	**4.37**	**1.16**	**0.25**	**3.31**	**2.13**	**0.22**	**9.46**	**0.09**	**0.10**	**0.08**	**0.03**	**0.30**		**18.60**	**0.60**	**0.47**		**1.77**	**0.90**	Ca deficient	**1.33**	Mg deficient
	Site Rating		V.Acid	ND	ND	V Low	ND	Mod	Mod	V Good	ND	V Low	V Low	V Low	V Low		Mod	V Low	V Low		V Low				
ND	PT071	23 - 40	5.06	4.01	1.05	0.14	19.66	3.60	0.24	15	0.43	0.48	0.15	0.03	1.09		19.69	2	1		6	0.90	Ca deficient	3.20	OK
		40 - 116	5.60	4.05	1.55	0.17	11.28	0.80	0.08	10	0.26	0.95	0.12	0.06	1.39		11.72	8	1		12	0.27	Ca deficient	7.92	OK
		116 - 132	5.76	4.12	1.64	0.20	47.20	0.30	0.03	10	0.26	0.77	0.36	0.06	1.45		10.21	8	4		14	0.34	Ca deficient	2.14	Mg sli deficient
		132 - 153	5.82	4.06	1.76	0.16	56.40	0.20	0.02	10	0.43	1.60	0.35	0.06	2.44		11.86	13	3		21	0.27	Ca deficient	4.57	OK
	Site Mean		**5.56**	**4.06**	**1.50**	**0.17**	**33.64**	**1.23**	**0.09**	**11.25**	**0.35**	**0.95**	**0.25**	**0.05**	**1.59**		**13.37**	**7.89**	**2.07**		**13.04**	**0.44**	Ca deficient	**3.20**	OK
	Site Rating		V.Acid	ND	ND	V Low	ND	Mod	V Low	Good	V Low	Low	Low	V Low	V Low		Low	V Low	V Low		V Low				
ND	PT072	20 - 45	5.43	4.32	1.11	0.18	13.19	2.90	0.20	15	2.16	0.17	0.11	0.06	2.50		15.24	1	1		16	12.71	Mg deficient with P inhibition	1.55	Mg deficient
		45 - 140	5.54	4.47	1.07	1.29	4.98	1.60	0.12	13	0.60	0.21	0.06	0.02	0.89		11.99	2	1		7	2.86	Ca sli deficient	3.50	OK
	Site Mean		**5.49**	**4.40**	**1.09**	**0.74**	**9.09**	**2.25**	**0.16**	**13.92**	**1.38**	**0.19**	**0.09**	**0.04**	**1.70**		**13.62**	**1.43**	**0.61**		**11.91**	**7.78**	Mg deficient with P inhibition	**1.55**	Mg deficient
	Site Rating		V.Acid	ND	ND	V Low	ND	Mod	Low	Good	V Low	V Low	V Low	V Low	V Low		Low	V Low	V Low		V Low				
ND	PT073	20 - 63	5.07	4.27	0.80	0.28	8.73	2.30	0.20	12	0.26	0.06	0.09	0.01	0.42		6.56	1	1		6	4.33	OK	0.67	Mg deficient
		63 - 90	5.82	4.44	1.38	0.43	6.14	1.20	0.13	9	0.43	0.14	0.13	0.05	0.75		6.56	2	2		11	3.07	OK	1.08	Mg deficient
		90 - 140	5.78	4.50	1.28	1.38	9.24	1.00	0.12	8	0.61	0.14	0.16	0.01	0.92		6.56	2	2		14	4.36	OK	0.88	Mg deficient
	Site Mean		**5.56**	**4.40**	**1.15**	**0.70**	**8.04**	**1.50**	**0.15**	**9.69**	**0.43**	**0.11**	**0.13**	**0.02**	**0.70**		**6.56**	**1.73**	**1.93**		**10.62**	**3.92**	OK	**0.67**	Mg deficient
	Site Rating		V.Acid	ND	ND	V Low	ND	Mod	Low	V Good	V Low	V Low	Low	V Low	V Low		Low	V Low	V Low		V Low				
	Overall for subsoils		5.53	4.23	1.30	0.55	13.01	1.88	0.15	11.88	0.50	0.38	0.14	0.04	1.06		13.67	3.01	1.20		8.71	2.71	Ca sli deficient	2.14	Mg sli deficient
	Overall rating for subsoils		V.Acid	ND	ND	V Low	ND	Mod	Low	Good	V Low	V Low	Low	V Low	V Low		Low	V Low	V Low		V Low				

ND – No Data or Not Recorded

Ratings Source: Soil Survey Handbook for Bhutan, BSS, NSSC Semtokha, Ministry of Agriculture Bhutan

Appendix 2

Result of the topsoil analysis from the Inventory plots.

										Exchangeables						(Element/CEC) x 100					Cation Ratios	
Plot no.	Sample No.	pH H2O	pH KCl	pH Diff	Avail P ppm	Avail ppm	Org C %	Total N %	C:N	meq / 100g Ca	Mg	K	Na	TEB	CEC	Mg Sat%	K Sat%	BS %	C/Mg	Rating	Mg/K	Rating
11	1	4.74	3.73	1.01	0.46	66.21	11.10	0.56	20	0.38	0.53	0.78	0.09	1.78	38.12	1	2	5	0.72	Ca deficient	0.68	Mg deficient
	2	4.82	3.78	1.04	0.38	58.81	9.60	0.52	18	0.12	0.39	0.40	0.04	0.95	35.54	1	1	3	0.31	Ca deficient	0.98	Mg deficient
	Site Mean		**3.76**	**1.03**	**0.42**	**62.51**	**10.35**	**0.54**	**19.14**	**0.25**	**0.46**	**0.59**	**0.07**	**1.37**	**36.83**	**1.24**	**1.59**	**3.67**	**0.51**	Ca deficient	**0.83**	Mg deficient
	Site Rating	**V.Acid**	**ND**	**ND**	**V low**	**ND**	**V high**	**High**	**Mod**	**V low**	**V low**	**Mod**	**V low**	**V low**	**High**	**V low**	**V Low**					
10	1	4.65	3.61	1.04	1.21	128.13	13.00	0.71	18	2.89	1.10	0.69	0.08	4.76	40.01	3	2	12	2.63	Ca sli deficient	1.59	Mg deficient
	2	4.51	3.52	0.99	0.91	78.13	13.00	0.79	16	1.45	0.74	0.42	0.09	2.70	37.46	2	1	7	1.96	Ca sli deficient	1.76	Mg deficient
	Site Mean		**3.57**	**1.02**	**1.06**	**103.13**	**13.00**	**0.75**	**17.38**	**2.17**	**0.92**	**0.56**	**0.08**	**3.73**	**38.74**	**2.36**	**1.42**	**9.55**	**2.29**	Ca sli deficient	**1.59**	Mg deficient
	Site Rating	**Ext Acid**	**ND**	**ND**	**V low**	**ND**	**V high**	**High**	**Mod**	**Low**	**Low**	**Mod**	**V low**	**Low**	**High**	**V low**	**V Low**					
9	1	4.70	3.62	1.08	1.19	83.70	10.60	0.67	16	1.70	0.73	0.47	0.04	2.94	33.57	2	1	9	2.33	Ca sli deficient	1.55	Mg deficient
	2	4.45	3.45	1.00	1.17	104.12	4.30	0.98	4	1.11	0.63	0.53	0.06	2.33	42.62	1	1	5	1.76	Ca sli deficient	1.19	Mg deficient
	Site Mean		**3.54**	**1.04**	**1.18**	**93.91**	**7.45**	**0.83**	**10.10**	**1.41**	**0.68**	**0.50**	**0.05**	**2.64**	**38.10**	**1.83**	**1.32**	**7.11**	**2.05**	Ca sli deficient	**1.55**	Mg deficient
	Site Rating	**Ext Acid**	**ND**	**ND**	**V Low**	**ND**	**V high**	**High**	**Good**	**V low**	**Low**	**Mod**	**V low**	**V low**	**High**	**V low**	**V Low**					
8	1	4.34	3.57	0.77	1.39	81.19	12.30	0.61	20	0.21	0.46	0.40	0.08	2.50	38.24	1	1	7	0.46	Ca deficient	1.15	Mg deficient
	2	4.52	3.60	0.92	1.19	96.38	10.50	0.71	15	1.18	0.60	0.49	0.02	0.89	34.75	2	1	3	1.97	Ca sli deficient	1.22	Mg deficient
	Site Mean		**3.59**	**0.85**	**1.29**	**88.79**	**11.40**	**0.66**	**17.48**	**0.70**	**0.53**	**0.45**	**0.05**	**1.70**	**36.50**	**1.46**	**1.23**	**4.55**	**1.21**	Ca sli deficient	**1.15**	Mg deficient
	Site Rating	**Ext Acid**	**ND**	**ND**	**V low**	**ND**	**V high**	**High**	**Mod**	**V low**	**Low**	**Mod**	**V low**	**V low**	**High**	**V low**	**V Low**					
6	1	4.45	3.59	0.86	1.68	65.83	14.10	0.76	19	1.86	0.83	0.44	0.07	2.50	39.87	2	1	6	2.24	Ca sli deficient	1.89	Mg deficient
	2	4.33	3.44	0.89	1.93	68.50	11.60	0.88	13	0.57	0.66	0.40	0.08	0.89	35.87	2	1	2	0.86	Ca deficient	1.65	Mg deficient
	Site Mean		**3.52**	**0.88**	**1.81**	**67.17**	**12.85**	**0.82**	**15.87**	**1.22**	**0.75**	**0.42**	**0.08**	**1.70**	**37.87**	**1.96**	**1.11**	**4.38**	**1.55**	Ca sli deficient	**1.89**	Mg deficient
	Site Rating	**Ext Acid**	**ND**	**ND**	**V Low**	**ND**	**V High**	**High**	**Mod**	**V low**	**Low**	**Mod**	**V low**	**V Low**	**High**	**V low**	**V Low**					
5	1	4.60	3.58	1.02	2.45	94.51	7.90	0.66	12	1.90	0.68	0.44	0.09	2.50	24.30	3	2	10	2.79	Ca sli deficient	1.55	Mg deficient
	2	4.68	3.57	1.11	6.90	225.50	8.50	0.72	12	3.23	1.18	1.01	0.03	0.89	29.53	4	3	3	2.74	Ca sli deficient	1.17	Mg deficient
	Site Mean		**3.58**	**1.07**	**4.68**	**160.01**	**8.20**	**0.69**	**11.89**	**2.57**	**0.93**	**0.73**	**0.06**	**1.70**	**26.92**	**3.40**	**2.62**	**6.65**	**2.77**	Ca sli deficient	**1.55**	Mg deficient
	Site Rating	**V.Acid**	**ND**	**ND**	**V low**	**ND**	**V high**	**High**	**Good**	**Low**	**Low**	**High**	**V low**	**V low**	**High**	**V low**	**V Low**					
4	4.42	5.00	3.87	1.13	3.07	160.37	13.00	0.65	20	8.17	1.98	0.90	0.04	2.50	34.88	6	3	7	4.13	OK	2.20	Mg sli deficient
	2	5.54	3.39	2.15	3.14	68.00	13.10	0.81	16	2.27	1.28	0.37	0.04	0.89	37.99	3	1	2	1.77	Ca sli deficient	3.46	OK
	Site Mean		**3.63**	**1.64**	**3.11**	**114.19**	**13.05**	**0.73**	**18.09**	**5.22**	**1.63**	**0.64**	**0.04**	**1.70**	**36.44**	**4.52**	**1.78**	**4.76**	**2.95**	Ca sli deficient	**2.20**	Mg sli deficient
	Site Rating	**V.Acid**	**ND**	**ND**	**V low**	**ND**	**V high**	**High**	**Mod**	**Mod**	**Mod**	**High**	**V low**	**V low**	**High**	**V low**	**V Low**					
3	2	4.61	3.64	0.97	0.87	64.46	7.50	0.51	15	0.11	0.27	0.38	0.10	2.50	28.30	1	1	9	0.41	Ca deficient	0.71	Mg deficient
	2	4.65	3.67	0.98	0.90	57.34	6.20	0.44	14	0.37	0.33	0.35	0.09	0.89	26.48	1	1	3	1.12	Ca sli deficient	0.94	Mg deficient
	Site Mean		**3.66**	**0.98**	**0.89**	**60.90**	**6.85**	**0.48**	**14.40**	**0.24**	**0.30**	**0.37**	**0.10**	**1.70**	**27.39**	**1.10**	**1.33**	**6.10**	**0.76**	Ca deficient	**0.71**	Mg deficient
	Site Rating	**V.Acid**	**ND**	**ND**	**V low**	**ND**	**V high**	**Mod**	**Good**	**V low**	**V low**	**Mod**	**V low**	**V low**	**High**	**V low**	**V Low**					

Ratings Source: Soil Survey Handbook for Bhutan, BSS, NSSC Semtokha, Ministry of Agriculture Bhutan

Appendix 3

Light environment in the Systematic Regeneration Plots

Plot no.	Canopy Openness %	PPFD Above Canopy		PPFD Below canopy		LAI	MLA
		Direct	Diffused	Direct	Diffused		
D2.	7.01	21.74	21.31	1.31	1.97	2.57	13.00
D3.	4.97	21.74	21.31	2.61	1.68	3.29	46.83
D4.	7.86	21.74	21.31	1.83	2.39	2.65	35.73
D5	7.57	21.74	21.31	2.53	2.31	2.67	26.45
D6.	9.42	21.74	21.31	1.33	3.72	3.05	67.26
D7.	14.48	21.74	21.31	2.99	4.74	2.07	49.40
D8.	9.62	21.74	21.31	4.31	3.52	2.65	59.80
D9	8.54	21.74	21.31	3.89	2.53	2.81	50.66
D10.	7.85	21.74	21.31	3.39	2.71	2.69	51.40
D11.	9.92	21.74	21.31	1.99	2.36	2.27	9.65
E2.	6.34	21.74	21.31	0.94	1.72	2.71	21.17
E3.	8.94	21.74	21.31	2.10	2.46	2.35	27.40
E4.	7.78	21.74	21.31	1.03	2.52	2.55	42.15
E5.	6.96	21.74	21.31	0.70	2.08	2.75	10.61
E6.	9.02	21.74	21.31	1.53	2.25	2.39	9.55
E7	15.06	21.74	21.31	6.60	5.09	2.04	56.12
E8.	17.15	21.74	21.31	8.55	7.62	3.26	85.91
E9.	13.29	21.74	21.31	4.35	3.54	2.00	25.92
E10A.	24.10	21.74	21.31	9.85	8.47	1.49	85.91
F1.	15.82	21.74	21.31	3.18	3.95	2.10	9.55
F2.	10.96	21.74	21.31	3.35	3.56	2.24	46.83
F3.	10.42	21.74	21.31	2.99	3.35	2.26	42.74
F4	10.14	21.74	21.31	6.15	4.2	3.64	78.46
F5.	12.54	21.74	21.31	8.51	5.22	2.77	81.20
F6.	8.35	21.74	21.31	3.18	3.47	2.96	67.47
F7	6.30	21.74	21.31	2.75	2.14	3.03	46.49
F8.	8.83	21.74	21.31	1.93	2.06	2.41	9.55
F9.	14.28	21.74	21.31	4.04	3.16	2.04	9.55
F10	5.41	21.74	21.31	0.82	1.75	3.23	47.84
G2A.	20.80	21.74	21.31	5.71	7.71	1.71	80.44
G3A.	15.85	21.74	21.31	4.44	5.87	1.95	69.77
G4.	15.56	21.74	21.31	5.04	4.22	1.80	9.55
G5.	7.16	21.74	21.31	2.14	1.91	2.52	16.67
G6.	7.29	21.74	21.31	2.09	2.19	2.66	38.57
G7.	13.39	21.74	21.31	2.18	3.46	1.97	9.55
G8.	13.73	21.74	21.31	3.07	3.73	2.08	9.55
G9	13.43	21.74	21.31	2.23	3.74	2.04	28.83
H1	14.47	21.74	21.31	3.70	3.51	1.90	9.55
H2.	7.07	21.74	21.31	1.17	1.86	2.94	9.55
H3.	5.45	21.74	21.31	0.91	1.17	3.46	9.55
H4.	13.17	21.74	21.31	4.36	3.91	1.93	18.99
H5.	26.97	21.74	21.31	11.61	9.62	1.37	85.91
H6.	18.79	21.74	21.31	2.84	6.48	1.68	65.25
H7	10.44	21.74	21.31	5.09	3.60	2.44	56.96
H8	9.80	21.74	21.31	1.49	2.12	2.30	9.55
H9	14.31	21.74	21.31	4.15	3.42	1.95	23.07
I1	7.38	21.74	21.31	2.67	2.40	2.91	40.45
I2	8.20	21.74	21.31	2.97	2.82	2.68	45.36
I3	6.82	21.74	21.31	2.03	2.28	2.83	45.20
I4	5.22	21.74	21.31	1.55	1.69	3.17	42.89
I5	6.58	21.74	21.31	3.12	2.15	2.80	36.93
I6	9.14	21.74	21.31	4.50	3.08	2.87	32.02
I7	23.08	21.74	21.31	3.95	7.23	1.39	56.12
I8	19.09	21.74	21.31	3.43	5.67	1.66	35.61
I9	6.47	21.74	21.31	3.42	1.95	2.87	28.65
J1	9.50	21.74	21.31	1.68	2.98	2.26	37.93
J2	10.34	21.74	21.31	3.01	3.69	2.39	56.12

Plot no.	Canopy Openness %	PPFD Above Canopy		PPFD Below canopy		LAI	MLA
		Direct	Diffused	Direct	Diffused		
J3	13.56	21.74	21.31	2.69	4.13	2.27	14.87
J4	24.52	21.74	21.31	7.32	8.89	1.53	85.91
J5	13.50	21.74	21.31	6.30	4.91	2.17	65.85
J6	13.48	21.74	21.31	3.93	3.51	1.94	9.55
J7	8.75	21.74	21.31	3.77	2.57	2.41	29.54
J8	12.52	21.74	21.31	4.28	3.31	2.18	9.55
K0.	13.70	21.74	21.31	4.79	5.22	2.35	71.51
K1	8.22	21.74	21.31	3.84	3.02	2.84	59.09
K2	10.97	21.74	21.31	3.74	4.45	3.09	72.61
K3	29.40	21.74	21.31	7.83	10.43	1.33	85.91
K4	10.54	21.74	21.31	2.51	2.71	2.41	9.55
K5	16.53	21.74	21.31	7.05	4.57	2.40	9.55
K6	9.51	21.74	21.31	3.16	2.56	2.31	32.74
K7	19.29	21.74	21.31	6.46	6.89	1.85	72.17
L0	9.08	21.74	21.31	4.13	3.10	2.49	47.84
L1	7.31	21.74	21.31	1.07	2.14	2.77	10.86
L2	16.82	21.74	21.31	6.30	5.95	1.98	61.25
L3	8.34	21.74	21.31	2.74	2.56	2.60	15.52
L4	11.12	21.74	21.31	1.97	2.98	2.12	9.67
L5	9.91	21.74	21.31	1.94	2.62	2.32	9.55
L6	9.47	21.74	21.31	1.54	2.63	2.33	9.55
L7	12.6	21.74	21.31	3.87	3.23	2.20	9.55
M0	5.60	21.74	21.31	3.15	2.06	3.45	58.02
M1	6.59	21.74	21.31	2.02	2.36	2.95	52.73
M2	8.77	21.74	21.31	1.36	2.61	2.59	34.92
M3	8.08	21.74	21.31	2.10	2.35	2.59	27.24
M4	16.82	21.74	21.31	3.18	4.98	2.78	9.55
M5	8.87	21.74	21.31	1.90	2.70	2.59	31.82
M6	10.07	21.74	21.31	2.64	2.39	2.24	9.55
N1	5.88	21.74	21.31	1.18	1.96	3.14	43.95
N2	6.90	21.74	21.31	2.45	2.29	3.16	41.43
N3	7.23	21.74	21.31	1.95	2.43	2.82	37.43
N4	8.18	21.74	21.31	2.18	2.54	2.89	9.55
N5	8.56	21.74	21.31	2.62	2.63	2.51	31.42
N6	8.10	21.74	21.31	2.48	2.15	2.33	9.55
O1	10.62	21.74	21.31	3.61	3.52	2.29	51.03
O2	8.19	21.74	21.31	2.87	2.76	2.86	41.43
O3	11.00	21.74	21.31	3.65	3.12	2.45	9.55
O4	12.48	21.74	21.31	2.38	4.11	2.10	42.45
O5	8.80	21.74	21.31	2.07	2.77	2.56	39.50
P1	10.16	21.74	21.31	4.20	3.08	2.24	34.92
P2	13.02	21.74	21.31	3.85	3.61	1.89	19.35
P3	13.41	21.74	21.31	8.29	5.47	2.34	77.49
P4	8.48	21.74	21.31	4.95	2.97	2.68	54.49
P5	6.49	21.74	21.31	1.87	2.08	2.83	36.57
Q1	9.54	21.74	21.31	1.31	3.43	2.99	56.33
Q2	8.99	21.74	21.31	2.71	2.64	2.68	32.33
Q3	9.58	21.74	21.31	2.53	2.89	2.54	31.42
Q4	10.29	21.74	21.31	2.84	2.64	2.13	12.99
R1	5.19	21.74	21.31	2.08	1.85	3.50	58.22
R2	4.94	21.74	21.31	2.66	2.01	3.52	60.34
R3	5.51	21.74	21.31	2.51	1.71	2.95	36.93
R4	5.48	21.74	21.31	1.34	1.58	2.89	16.06
S1	5.54	21.74	21.31	2.44	1.99	3.42	53.90
S2	4.51	21.74	21.31	3.64	2.05	4.20	63.69
S3	7.27	21.74	21.31	1.45	1.84	2.50	9.55
S4	5.58	21.74	21.31	1.22	2.08	3.28	53.11

Appendix: 4

Inventory plot attributes

Plot no	Solpe %	Av.soil depth (cm)	Quercus density/ ha	Ba/ ha	BA of *Quercus* / ha	Den/ha	Density of *Quercus* /ha
1	20	40	48.00	44.28	31.42	356.93	188.27
2	20	100	57.00	58.48	42.01	427.53	223.57
3	25	90	26.00	46.45	23.74	365.40	101.07
4	27	100	38.00	41.98	23.50	428.65	146.75
5	29	85	70.00	41.95	26.25	525.81	268.66
6	30	80	31.00	38.97	29.12	609.20	118.77
7	35	120	51.00	36.93	26.69	354.92	192.56
8	35	115	53.00	58.41	49.99	313.38	200.11
9	39	115	60.00	28.68	18.04	491.89	223.59
10	45	115	12.00	58.76	24.64	844.61	43.88
11	45	115	66.00	42.33	18.76	610.60	241.32
12	50	100	38.00	49.23	31.59	711.99	135.96
13	55	70	22.00	31.16	15.42	634.42	77.11
14	60	120	28.00	69.66	40.25	734.01	96.04
15	60	115	58.00	46.75	27.47	418.45	198.94
16	65	120	27.00	65.64	33.37	573.54	90.56

Appendix : 5

Data Collection format for Inventory plots

Date:	Aspect:
Plot no.	Slope %
Soil depth1:	Soil depth2:
	Altitude:

Tree no.	Species	DBH(cm)	Remark

Appendix 6

Data Collection format for Systematic plots

Date:

Plot	REGENERATION				Soil Parameters	
No.	Species	Height	end shoot	no. of leaves	soil pH	litter depth

End shoot growth and number of leaves measured only for *Q. semecarpifolia* seedlings

Appendix 7

Data Collection format for Observation plots

Location:
Canopy Cover:
Treatment:
Soil pH:
Date:

Plot #	Species	Height	end shoot ht.	no. of leaves

End shoot growth and number of leaves measured only for *Q. semecarpifolia* seedlings