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Is Chir Pine Displacing Banj Oak in the Central Himalaya? Socioeconomic Implications for Local People and the Conservation of Oak Forest Biodiversity

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Is Chir Pine Displacing Banj Oak in the Central Himalaya? Socioeconomic Implications for Local People and the Conservation of Oak Forest Biodiversity

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ABSTRACT

Various studies have suggested that chir pine (*Pinus roxburghii*) is replacing banj oak (*Quercus leucotrichophora*) in the Central Himalaya. Five sites with three different types of forests (banj oak, chir pine and mixed oak-pine) were sampled to compare the diversity of their vegetation and to assess the impact of this ongoing conversion on biodiversity. Soil samples collected from oak and pine forests were analyzed and compared. In addition, dendrochronology was used to obtain age estimates of chir pine and to understand the growth response of this species to precipitation. Also, samples of ectomycorrhizal fungi were collected in the form of fruiting bodies and root tips of banj oak and chir pine for DNA analysis, to identify the species associated with these forest types. Since these forests are heavily exploited by local people, social surveys were carried out to understand the dependency of the local people on these forests and their awareness and opinions relating to the current situation of the banj oak degradation, its consequences for them and the reasons behind it.

Analysis of tree rings of chir pine indicated a positive cool season precipitation response in earlywood and a negative response to warm season precipitation in latewood, which indicate that an increase in summer rainfall associated with anthropogenic climate change could adversely affect the chir pine. Banj oak does not form reliable annual rings, so we do not have any information regarding the potential impact of climate variability or change on banj oak growth.

Overall, banj oak forests were found to be richer in terms of soil fertility, tree and shrub diversity as compared to the chir pine forests. Tree ring data suggested that the mixed forest at Jakholi site was actually an oak forest that got encroached upon by the chir pine. Based on the

observations, data and results obtained during this study, it can be concluded that the banj oak forests are declining and chir pine is displacing banj oak in the Central Himalaya.

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DEDICATION

This dissertation is dedicated to my mother Mrs. Usha Nautiyal, who has been there for me like a support system upon which I could always rely. She always kept my happiness and needs above her own, and whatever I am today is because of her sacrifices. She is the best manager I have ever known. I hope I can reach to her level someday.

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CHAPTER 1. INTRODUCTION

"Nature holds the key to our aesthetic, intellectual, cognitive and even spiritual satisfaction." E.O. Wilson (1984).

This quote by E.O. Wilson precisely summarizes the importance of nature, but as rightly said by Dalai Lama (XIV), "Human use, population, and technology have reached that certain stage where mother Earth no longer accepts our presence with silence." There are more than 7 billion people on the earth, and it greatly exceeds the sustainable limit where humans could live in harmony with their natural ecosystems.

Homo sapiens is considered to be the most intelligent species on this planet. However, in order to accommodate their huge population, humans have used their intelligence in their own self interest only and have modified and/or adversely affected the majority of natural ecosystems. Hardin (1968) has beautifully explained how treating something as a common asset can lead to its overexploitation by giving various examples in his famous paper, "The tragedy of the commons." Humans treat their natural resources as a common asset which if they don't use then someone else will, and therefore, no one takes the responsibility of not contributing to their overexploitation. This irresponsible overexploitation by humans has resulted in a decline in global biodiversity. Numerous species have become extinct, several are on the verge of extinction and many are or will become extinct even before we can identify and describe them. Habitat loss, invasive species, overharvesting, pollution and climate change are the major threats to biodiversity (Reece et al 2014), and, ultimately, in most cases, these threats are outcomes of disturbances caused by the human beings and overpopulation of people.

Most of the time, the major focus is on conservation of those organisms which are already threatened and therefore need protection in order to survive. Also, often the efforts are initiated when it is already too late to maintain a sustainable population size of the organism. In addition, the conservation process cannot be successful until a holistic approach is followed which includes not only the detailed knowledge about the threatened organism but also its ecosystem. In other words, since an organism is part of an ecosystem, unless we create a healthy ecosystem, we cannot ensure the success of conservation efforts.

Ecosystem balance is delicate, although usually a small level of disturbance can be managed without much impact, yet any form of major disturbances can result in modifying the natural processes that can lead to the deterioration of the balance that existed prior to the disturbance. A single major disturbance can have a huge impact on the ecological balance, because, in ecosystems, one component or process is not exclusive of the others; instead, they are intertwined. Therefore, if any disturbance causes imbalance in one component of the process, that can lead to further chain reaction of imbalances. If these disturbances are removed soon, then the ecosystem can recover; however, in the case of long term heavy disturbances, the ecosystems can get completely modified, and often the changes are almost irreversible. One such example is represented by the grasslands of the Himalayas, which, under natural conditions, used to be limited to the alpine meadows only, are now a common feature of the Himalayan region. This also happened due to various human disturbances such as deforestation, grazing, burning and harvesting of forest vegetation, which resulted in the conversion of forests into grasslands (Singh and Singh 1992).

Usually, the invasive species are exotic, and they are not a natural component of the intruded ecosystems. Various natural components of ecosystem remain in a kind of balance and harmony. However, the ecosystems often fail to manage the invasive species, since they are foreign to the ecosystems, and, therefore, the invasive species take over the ecosystem by replacing the naturally occurring components, which results in modifications in the natural forms of the ecosystems. Many times, disturbances facilitate the establishment of invasive species by creating favorable conditions for them. For example, degraded sites can provide more suitable conditions for the hardy invasive species as compared to the native vegetation; also, the invasive species are better competitors than the native vegetation, which gives them an additional advantage over the native vegetation. Due to the deforestation and degradation of hill slopes, an invasive shrub *Lantana camara* (native to tropical South America) has established itself in a large area of the entire outer Himalaya, mainly up to an elevation of 1500 m (Singh and Singh 1992). In fact, this invasive species has become the dominant shrub in many forests of the region.

Invasive species are the second largest (habitat loss being the first) threat to biodiversity (Reece et al 2014) as they replace the native vegetation and/or change ecosystems, which adversely affects the native flora and fauna. What if a native species becomes invasive? Most people argue that it is always an exotic species that becomes invasive, and it is usually the case. According to the National Oceanic and Atmospheric Administration (NOAA 2014), "An invasive species is an organism that causes ecological or economic harm in a new environment where it is not native." However, is it appropriate to limit the definition to alien or exotic species? What if a native species is acting like an invasive species? Such invasion by a native species is taking place on a grand scale in the Central Himalayas, where an early succession pine species is replacing a late succession oak species (Figure 1). At elevations of 1000-1800 m for chir pine (*Pinus roxburghii* Sargent) and 1500-2100 m for banj oak (*Quercus leucotrichophora* A Camus) are the dominant species in the Central Himalayas (Singh and Singh 1992). Several studies (Singh and Singh 1992, Singh and Bisht 1992, Singh et al 1984,

Figure 1. A degraded banj oak forest invaded by chir pine

Saxena and Singh 1984, Singh and Singh 1986, Ralhan and Singh 1987) have suggested that chir pine is replacing banj oak, although under natural succession it should be the reverse. This reverse succession is not natural, but rather due to various forms of human caused disturbances such as lopping, logging, fire and grazing. There are other examples as well where a native species started acting like an invasive species, e.g. juniper and mesquite in North America. However, in their cases, both of these species are encroaching grasslands and other areas outside their natural range. Yet, in the case of chir pine (an early succession species), it is encroaching banj oak forests (a late succession species), which is leading to the opposite of natural succession. Therefore it makes the problem even more complicated since the presence of chir pine is unavoidable as it is a natural part of the ecosystem in the region. Also, without detailed observation, it is difficult to differentiate between a mixed forest due to natural succession process and a mixed forest due to chir pine encroachment.

The purpose of this research project was to determine whether the banj oak populations at the study sites are declining or not and to understand the causes and consequences of the ongoing conversion of banj oak forests into chir pine forests.

Listed below are the components covered under this research project-

1. Vegetational sampling was done to compare and contrast between the composition of banj oak and chir pine forests at different strata. Also the DBH (Diameter at breast height) size classes were recorded along with seedling and sapling count to understand the regeneration and age structure of these two types of forests. The purpose of this component was to estimate the extent of changes/damage that will be caused to the vegetational diversity if the banj oak forests get replaced by chir pine forests. Also, the size classe distribution and seedling/sapling count could be helpful

in predicting the fate of studied populations. Although, several studies have suggested the decline in banj oak population, there are not many which include actual research data to support this trend. The current study not only involves five different study sites which were located at considerable distance but also a reasonably large area of sampling (15 plots of 0.1 ha), which should ideally increase the reliability of the data obtained and conclusions based on the data. Most of the studies done in the study region include smaller sampling plots since, due to hilly terrain, it is very difficult to conduct sampling in larger plot sizes. In addition to sampling, the general condition of forests and different signs of disturbances have been reported in this study.

2. Soil samples were analyzed in terms of different soil parameters to compare the fertility of the two types of forests. This could be helpful to understand the impact on soil fertility in the event of banj oak displacement by chir pine forests.
3. Tree cores were collected from chir pine trees for age estimations. This was done to understand whether the chir pine trees were naturally occurring or they were an outcome of human interference. None of the studies done so far includes use of dendrochronology for this purpose. Banj oak doesn't form reliable annual rings; therefore the age estimation could not be done for the banj oak trees present at the study sites.
4. Dendroclimatology was used as a tool to interpret the growth response of chir pine to precipitation. This was done to understand possible impact of predicted anthropogenic climate change on the growth of chir pine. For this component, earlywood and latewood rind width measurement were done to study the impact of winter and summer precipitation (respectively) on the tree ring growth. This is the

first study from India that involves earlywood and latewood measurements. The studies done prior to this one (in India) include only total ring-width measurements.

5. Ectomycorrhizal fungi play a crucial role in the life cycle of host trees. In exchange of photosynthates, they assist the host plant to absorb more water and minerals from the soil and also provide some level of protection to the host root tissues. Banj oak as well as chir pine make ectomycorrhizal associations. Therefore, ectomycorrhizal fungi sampling was done in form of fruiting bodies as well as root tip collections which were used for DNA analysis in order to identify the fungal species. Along with molecular analysis, morphological identification was also done for the fruiting bodies. None of the studies from India, prior to the current study, includes the use of root tips for the identification of associated mycorrhizal fungi. In addition, general fungal diversity of banj oak and chir pine forests was recorded with the help of photographs.
6. Social surveys were conducted to understand the dependencies of local people on banj oak and chir pine forests. Also a variety of questions were asked to assess the awareness among local people regarding ongoing changes in the forests of the region.

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CHAPTER 2. BACKGROUND INFORMATION REGARDING THE STUDY REGION AND THE CURRENT STUDY

The traditional plate tectonic model suggests that India occupied a central location in Gondwana throughout the Paleozoic era and most of the Mesozoic era. The supercontinent started to break up in the Middle Jurassic era (~170 mya). First, South America-Africa drifted away from Madagascar-Seychelles-India-Antarctica-Australia. Then, ~132 mya (based on marine magnetic anomaly data) in the early Cretaceous, Australia and Antarctica started to separate away from India-Madagascar. In the late Cretaceous, about 90-85 Mya, India-Seychelles drifted away from Madagascar, and the subcontinent started migrating rapidly towards north, which led to the eventual collision of the subcontinent with Asia about 55-50 Mya (Ali and Aitchison 2008). This collision between India and the Eurasian plate resulted in a lot of pressure and ultimately the formation of the Himalayas.

The Himalayan arc covers a span of more than 2500 km from east to west and the degree of latitudinal expanse of the Himalayan arc is about ten degrees (between about 27-38º N) (Singh and Singh 1992). According to Singh and Singh (1992), the Himalayas can be divided into four latitudinal regional belts. The southernmost zone consists of the Shiwalik mountains, which show a sudden rise in elevation to 500-1200 m from the alluvial plains, and the width of the zone is about 10-15 km. Towards the north of the Shiwaliks is the Lesser Himalayan zone, with a width of about 70-80 km and an elevation of 2000-3000 m above mean sea level. To the north of the lesser Himalayas is the Greater Himalayan zone, with a breadth of about 70 km and elevations of 5000 to >6000 m. The Greater Himalayas include snow-covered peaks and glaciers, which are the source of major rivers in the region and supply water to >1 billion people. The northernmost zone is the Thethyan or Tibetan, with an elevation of more than 6000 m.

The Himalayas are very rich with respect to both diversity and endemism. In fact, they have been listed as one of the biodiversity hotspots of the world. At the same time, these mountains are the youngest major mountains and are very fragile due to the nature of their composition. Earthquakes are a reoccurring phenomenon, as these mountains lie in a seismic zone. As a result, various factors together make these mountains very prone to landslides and erosion. Besides the natural disturbances, humans have also greatly influenced the Himalayan ecosystem, which has been inhabited by humans for centuries.According to Encyclopedia of earth (2014), the Himalayan mountain range covers an area of about 750,000 km^2 and includes all the world's mountain peaks higher than 8000 m. Not only are they the loftiest mountains but the Himalayas are also home to some rare and charismatic animals like the tiger, snow leopard, leopard, musk deer, bear, elephant, and vultures. Also, they are rich in endemic plants. Out of about 10,000 species estimated from the Himalayan hotspot, 3160 species are endemic.

Various scientists have suggested different ways of recognizing sub-divisions for the Himalayas. Some of them divide the Himalayas into the Eastern and Western Himalayas, where the Kumaun-Garhwal Himalaya, Northwest Kashmir and Northern Pakistan are grouped under the Western Himalayas, and the remaining Himalayan region, which includes the northeastern Indian states of West Bengal, Assam, Arunachal Pradesh, Southeast Tibet, Northern Myanmar, Nepal and Bhutan. is listed under the Eastern Himalayas.

However, Validya and Bhatia (1980) (as mentioned in Singh and Singh 1992) suggested three main sub-divisions of the Himalayas—Western Himalaya, Central Himalaya and Eastern Himalaya. As can be seen in (Figure 2), the Garhwal and Kumaun Himalayas are located under the Central Himalayas. The study sites for this research project were located in the Garhwal region of the Uttarakhand state of India.

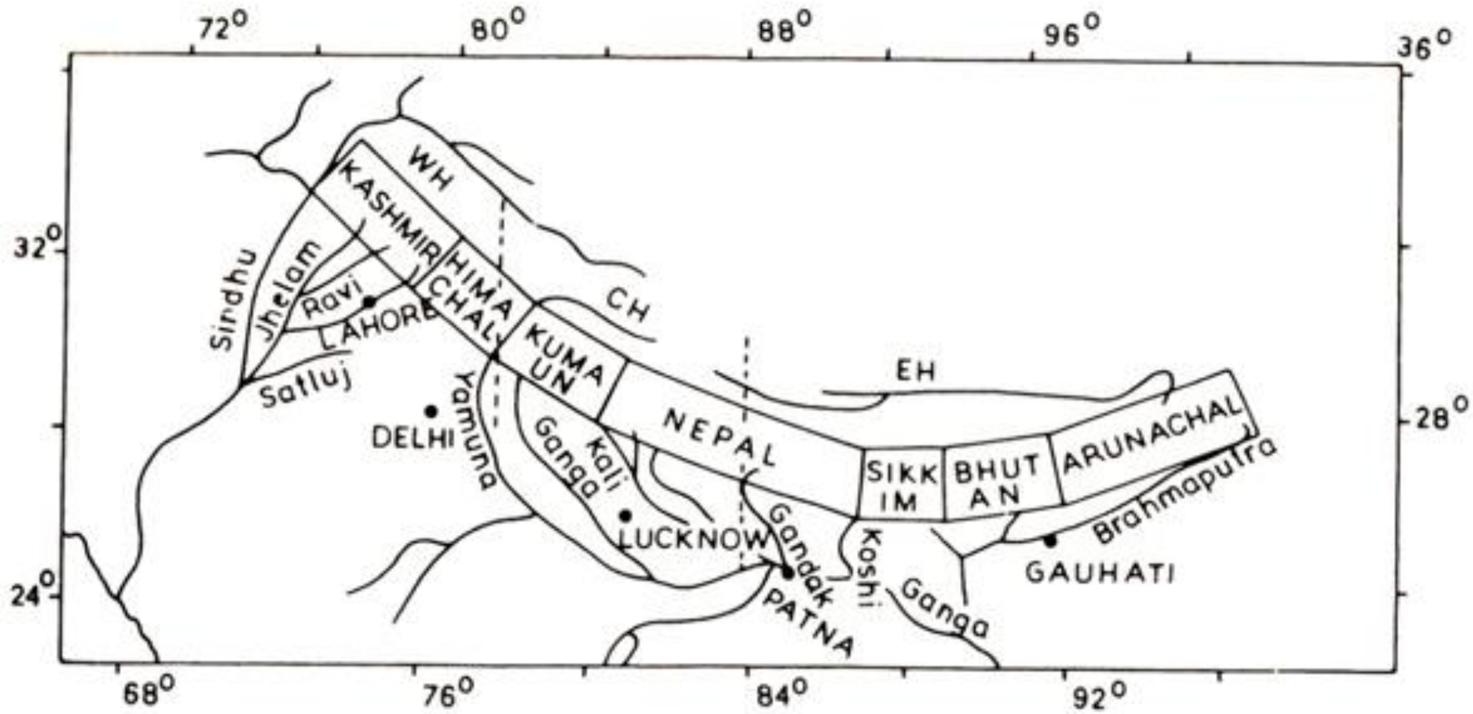

Figure 2. Subdivisions of the Himalaya, as given by Validya and Bhatiya (1980). Source: Singh and Singh 1992.

According to Singh and Singh (1992), the outer ranges of the Central Himalaya lie between 300 m (foothills) to 3600 m elevation. They also mentioned that most of the woody communities are present in the outer ranges. The common forest communities of these ranges are: sal (*Shorea robusta*), sal-chir pine (*Pinus roxburghii*); tun (*Toona ciliata*), chir pine-mixed broadleaf, chir pine, banj oak (*Quercus leucotrichophora*); chir pine, banj oak, tilonj oak (*Q. floribunda* Lindl. ex A. Camus)-banj oak, tilonj oak; rianj oak (*Q. lanuginosa* (Lam.) Thuill), rianj oak-kharsu oak (*Q. semecarpifolia* Sm.), silver fir (*Abies pindrow* Royle.); kharsu oak-birch (*Betula utilis* D. Don.), birch; *Rhododendron campanulatum* D. Don. and *R. campanulatum* (scrub land).

Singh and Singh (1992) mentioned that originally an elevational transect up to 2400 m could be divided into two major regimes. The oak regime was present at higher elevations with a colder climate, whereas the sal regime was present at lower elevations with a warmer climate. They also suggested sal and oak as climatic climax communities for the given elevation. The authors mentioned that, due to natural and anthropogenic disturbances, chir pine has now established itself in the regime of sal and oak forests. Chir pine is a pioneer species that is stress tolerant. In fact, they mentioned that the properties of chir pine indicate that it follows the inhibition model of Connell and Slatyer. According to this model, once an early colonist secures the space and/or resources, it resists the invasion of competitor species. The early colonist prevents succession until it dies or gets damaged (Connell and Slatyer 1977). The inner regions of the Himalayas are more arid, as they do not receive much monsoon rainfall. Some of the higher elevation species of the outer range are present in the inner range as well (e.g., birch, rhododendron, and silver fir). However, since the inner range is drier, more drought-tolerant species are present there. For example, in place of *Abies pindrow*, *Abies spectabilis* is found, and instead of *P. roxburghii*, *Pinus wallichiana* (blue pine) is present in the inner range. Some other common species of the inner range are *Cedrus deodara* (deodar) and *Picea smithiana* (Himalayan spruce).

The outer range forests are usually closed canopy (chir pine being an exception), with crown density up to 80%. The importance value of *Rhododendron arboreum*, which first appears at an elevation of about 1200 m, increases with elevation in different kinds of forest communites,especially in oak dominated forest communities. *Rhododendron arboreum* is replaced by *R. barbatum* in the birch forest beyond 2800 m. Finally, at very high elevations, the vegetation consists mainly of scrubs and heaths. *R. campanulatum* and *R. anthopogon* are the only woody species present.

According to Singh et al. (1994) (as mentioned in Zobel and Singh 1997), the annual precipitation range within the forests situated on southern slope of the Central Himalaya is 500-3500 mm, and with the elevation, erratic changes can be noticed in the precipitation. The mean annual temperature range varies from 23°C at the base of the mountains to 7°C near the timberline in the Central Himalayan forests (Muller 1982, Singh et al.1994). The mean annual temperature range is 12-17°C in the oak forests that are dominant in the middle elevations in the Central Himalayas. Generally, the temperature range of 10-19°C can be observed as the difference between the mean temperature of the warmest and the coldest months. The same temperature range (10-19°C) has been associated with broadleaved evergreen forest present in mesic regions of Asia (Wolfe 1979).

Upreti et al. (1985) mentioned that paleoecological evidence suggests the existence of *Quercus leucotrichophora* and *Pinus roxburghii* as dominant species for at least one million years in the Himalayas, yet the distribution of these two species has varied during this time.

More disturbances helped *P. roxburghii* to flourish, whereas stability supported *Quercus leucotrichophora*. The authors suggested that 10,000-4000 years B.P. *Q. leucotrichophora* was dominant at elevations of 1000-2000 m all over Central as well as Western Himalayas. However, in recent centuries, *P. roxburghii* has expanded at the cost of *Q. leucotrichophora,* due to an increase in different types of disturbances.

Some people argue that, since chir pine is also native to the region, it should not have as much adverse impact as exotic species do. However, just maintaining a good amount of forested area will not be much helpful if it is not the natural composition. In addition, it is also important that the forests shouldn't be degraded. Haigh et al. (1988) mentioned that Tiwari et al. (1985) found that only 29% (instead of 67%, as indicated by the official statistics) of the land was under forest in Uttarakhand and only 4.4% of the land had good quality forest with >60% canopy cover.

During my project, I also noticed that the forests located in my study region were heavily exploited by humans. Only a few small patches of forests were less disturbed, and that was because these intact patches were out of human reach, since they were located on steep slopes. However, the decline in oak population is not just due to over exploitation by local people but also by the government. In fact, earlier, the local people used to protect the forests around their villages, and there was better management of forest resources, which is not the case at present.

Due to the heavy dependence of local people on the banj oak forests, the conservation of these forests is not possible without involving the local people.The decline of banj oak forests was triggered by ruthless destruction of these forests in the past, due to biased forest policies that favored commercially important species The improper forest management done in the past is still one of the biggest reasons behind banj oak decline. Therefore, it is important to know how this ecological problem origintated.

History behind the banj oak decline

According to Somanathan (1991), population growth is not the major cause of deforestation in the Himalayan region. According to him, disturbance in traditional management of forests was the primary cause of deforestation in the Himalayan region after the 1920s. Therefore, mismanagement is the main reason behind the deterioration of the forests rather than just population pressure. Increased human population density does make it more difficult to manage shared resources, yet the forest resources can be better managed if the local communities and law-enforcing bodies (forest department or the government) cooperate and together.

Somanathan (1991) mentioned that before the British rule in 1815, forests were used as well as managed by local farmers. Local people could collect forest goods freely. However, with the first British settlement of land revenue, even forests and wasteland were placed within the boundaries of one village or another. These were referred to as ‘assi sal’ (eighty years) boundaries. With time, the populations increased, and this created the situation of overexploitation of the common resources (tragedy of commons). People cut down the nearest timber tree or lopped the nearest fodder tree, as they were afraid that if they did not, then somebody else would do it.

Somanathan (1991) mentioned that the discovery and development of antiseptic treatment for softer pines enabled their use for railway sleepers in about 1911. Along with this, a method of distillation evolved which resulted in increasing the value of Indian resin and turpentine (products of resin extracted from chir pine trees). Due to this, additional restrictions were placed on the villagers in terms of using forest resources, as the forests were more commercially valuable now. The villagers were allotted a specific amount of timber for which they had to send applications to the divisional forest officer. There also were restrictions applied on grazing and lopping as well as the annual practice of burning the floor of pine forests, which was banned within one mile of the reserved forests. The restriction on fire was applied as a measure to promote growth of chir saplings, which are sensitive to fire and also to protect the trees exploited for resin as the resin extraction makes chir trees vulnerable to fire (although when undamaged, chir pine trees are fire tolerant, whereas the banj oak trees are more sensitive). Resin is highly inflammable and thus can cause heavy damage to the exploited trees if the latter are exposed to fire.

Since all these changes adversely affected villagers, it resulted in large scale protests. One of the examples is incendiary fires in 1921 in the Kumaun Himalayas, which affected 830 km^2 of government-owned pine forests, whereas the equivalent large area of broadleaf forests (although owned by government) was left safe, as the broadleaf forests were of greater importance to the village people Guha and Gadgil (1989).

As a result, the government had to make changes in the restrictions being applied. These changes provided more rights to the local people again in civil forests and to some extent in class I forests. Earlier civil forests were categorized by the British government as the forests that were within village boundaries and weren't privately owned. The civil forests used to be under the control of the revenue department, and class I reserves used to include mainly oak forests and some non-exploitable chir pine forests. After massive protests took place, even the class I forests were made available to the people with nominal control by the revenue department. However, the British government did retain some of the commercially important forest areas under its control. Local people were refrained from exploiting these forests (i.e., commercially important forests). Such forests were called class II forests. In 1930, a new category of forests was established that was called the 'Panchayat forest.' Kumaun Panchayat forest rules were issued by the government, under which the villagers could apply for forming forest panchayat, under which they could manage the forest within their 'assi sal' boundaries, which could include civil, class I as well as class II forests. Somanathan (1991) mentioned that in 1964, class I forests were taken back under forest department control as the oak had become valuable for charcoal and firewood and the other species for construction of sports goods. However it was not British government rule anymore (India obtained independence in 1947).

The author (Somanathan 1991) also explained how different categories of forests were managed after independence. Class I forests mainly had oak or broadleaf trees for which there was no exploitation by the state, but the restriction imposed by the previous government had removed the sense of ownership among the local people. Although the restrictions were removed in 1925, the legal sanction dissolved the village boundaries. Due to this fact, the local people could not legally protect the reserved forest which used to lie within their village boundary from outsiders. This resulted in deterioration of reserve forests. Somanathan (1991) quoted the conservator of forests, Kumaun Circle as indicating… this year, 1931,...it is evident that the serious damage reported by the commissioner nearly five years ago has continued practically unchecked (except for small banis) and that the oak is melting away in Kumaun like an iceberg on the equator…Evidence that springs are beginning to dry up here and there is already available…The villagers at Bijepur, who came to see me are very bitter that "all bona fide residents of Kumaun" should come and wipe out their oak forests' and thereby cause their water supply to dry up. As described by the forest department's working plans, by the time forest department took back the control of class I forests, the oak forests closest to the villages were already in a deteriorated condition. They had either turned into scrub, which is vegetation that is comprised of mainly shrubs and stunted trees, or been replaced by chir forests. This adversely affected soil and springs (which act as a major water source).

In the Tehri Forest Division Working Plan (1939-79), Bahuguna mentioned that banj oak was heavily lopped for fodder or frequently cut for rough building timber all over the Tehri forest division, especially in those areas where the population density was higher. It was mentioned that the heavily exploited banj oak forests are clearly distinguishable. The lower banj oak areas exhibited a bushy growth, although the upper forests were still left in a more or less flourishing condition. It was indicated that due to the importance of banj oak as protective soil cover and its value for the local people, its destruction can't be underestimated.

In working plan (Bahuguna 1939-1979), it was mentioned that chir forests acted as the grass reserves for the villagers, and there were no restrictions on grazing and grass cutting in the chir forests. However, it was noted that there was an increasing tendency of setting fire to the chir forests by the villagers, in order to obtain more palatable grass for their cattle. Therefore, the author (Bahuguna) emphasized the need to protect chir pine regeneration areas from fire by taking effective measures.

Somanathan (1991) mentioned that, in class II forests, there was heavy exploitation by the state and also the hill people were restricted as users. This discouraged the villagers from conserving the forests. In addition, the hill people also exploited these forests by not abiding by the law. The forest department estimates about oak regeneration failed, as they were taking into account only the felling and disturbance caused by the state and not that caused by the hill people. Felling of trees and failed regeneration together resulted in deterioration of oak forests. In fact, in some places scrubs replaced the oak trees and in some of the forests which showed regeneration, pine was regenerating rather than oaks, although there are examples of intact forests which are mainly governed by village forest panchayats. However, most of the class II forests were chir pine forests which were not browsed by the livestock. Also, they were not useful as fodder. Due to this, chir pine had successful regeneration and replaced oaks within its lower range.

In addition, chir pine was promoted at the cost of oak forests for several decades as the pine was more commercially valuable. In fact, broadleaf species were even removed from pine-broadleaf mixed forests. However, the commercialization of chir pine also affected the chir pine adversely. Since the villagers were restrained from setting fire in the forests, the fuel load (with dry needles on the floor) accumulated, which resulted in exposing the pine forests to larger destructive fires. Also, due to monodominant forests and the presence of resin due to resin tapping, the risk of fire increased even more. Be it natural fire (due to lightning) or those set by local people, it was hard to control, as there was no cooperation from the local people since they did not receive any benefit from the chir pine forests, and thus they did not have a sense of responsibility towards these forests. Therefore, fires frequently occurred in the chir pine forests. In addition, contractors do not follow the norms, and they often carry out over-felling of trees. Moreover, ruthless damage to trees is done for resin extraction. Fire in such forests weakens chir pine trees further, and this results in the collapse of the heavily exploited trees during storms and heavy rains.

Guha (1983) mentioned that road construction started at rapid pace after 1947 in the U.P. Himalayas (present day Uttarakhand). The hasty construction work not only damaged the fragile mountains but also exposed them for exploitation for raw material and made them accessible for tourism, which also resulted in disturbing the mountain ecosystem. In addition, in order to obtain economic gains, pine was further promoted at the cost of broadleaf species in the Himalayan region.

Somanathan (1991) also mentioned that the exploitation of forest resources increased after independence due to the higher demand for timber, resin, pulpwood and fuelwood. However, it is hard to quantify this increase in exploitation. The civil forests include the land within the village boundary, which is informally managed by villagers but with formal control by the revenue department. Most of the civil forests either never had real forests or lost those due to over-exploitation. During the British era, when restrictions were applied on the use of forest resources by local people, the local people were more or less restricted to the use of civil forests for their needs. This resulted in over-exploitation of limited resources. Also, before British rule, the local people used to believe in community rights. However, under colonial laws, the rights of the community over a village’s common land were derecognized, and only individual rights of user were allowed. This resulted in exacerbating the exploitation of common land. In addition, the civil forest area shrank over time due to the expansion of cultivation by people within it.

Panchayat forests are generally in better condition than all other categories of forests. Oak forests provide manure, fuelwood, and fodder to the local people. Although chir pine needles are less preferred for manure or animal bedding and they cannot be used for fodder either, chir pine still provides timber and resin, but the commercial selling of timber or resin is not permitted to the villagers. Also, there are some restrictions applied to the felling of trees for even personal use. This makes people pay more attention to grass production in chir pine forests by setting fire to the forests, which limits the successful regeneration of chir pine trees, which may or may not be of any use for them in future. Due to this, although oaks have survived better in van panchayat forests, chir pine forests are of poor quality in van panchayat forests as well as in the reserves.

Singh and Singh (1986) reported that the conversion of banj oak forest into chir pine forest has been going on for quite some time. The authors mentioned that according to Dwivedi and Mathur (1978), in the Nainital Forest division seven forest compartments were shifted to the pine working circle, although earlier oaks were the dominant trees in those compartments. Data for 20 compartments in 1978 indicated that in the past 25-50 years the chir pine had increased in density. Out of the 20 compartments, seven compartments showed <5 times an increase in chir pine density, five compartments showed 6-10 times increase, three compartments showed 11-15 times increase, one compartment showed 16-20 times increase and the remaining four compartments showed more than 20 times increase in chir pine density. Improper management and alienation of local people resulted in the deterioration of the banj oak forests.

Other factors contributing in banj oak decline

According to Singh and Singh (1986) and Saxena and Singh (1984), some of the factors that result in poor regeneration of banj oak are as follows:

Poor seed crop followed by heavy infestation by an insect pest, insufficient snowfall resulting in poor water supply (by snow melt) for seed germination during summer, rainfall decline, various animals like rodents, squirrels, monkeys and birds that consume the acorns, frequent lopping for fodder and fuelwood that reduces the vigor as well as seed production, increase in human population that resulted in increase in cattle population, grazing and trampling resulting in soil compaction and therefore inhibiting regeneration.

However, according to Thadani (1999), lopping and litter removal in the banj oak forests are the main reasons behind replacement of banj oak by chir pine in the Central Himalaya (Singh et al. 2014). Singh et al. (2014) mentioned that there are several implications of the removal of litter fall on a large scale, such as a reduction in soil carbon and nutrients, removal of oak acorns and reduction in invertebrates and microorganisms, which could help in decomposition of the litter (Swift et al. 1979). Furthermore, the litter on the ground helps in maintaining moisture and diurnal temperatures, both of which assist in maintaining litter decomposition rates (Stevenson 1982). Singh et al. (2014) suggested that, due to litter removal, the acorns are exposed directly to the sunlight, and even a few days of sun exposure might result in making the light sensitive acorns lose their viability. On the other hand, pine seeds flourish well on bare mineral soils; therefore the soil conditions which hamper banj oak regeneration work in favor of chir pine. Raikwal (2009) suggested that with increase in human influence, the banj oak density declines rapidly (Singh et al. 2014). Also, highly human influenced banj oak forests showed higher presence of chir pine (Singh et al 2014).

Singh and Singh (1986) indicated that natural infestation by larvae on the acorns or consumption by wild animals can regulate banj oak populations. However, the damage done by lopping is so great that the amount of the seed crop produced is insignificant. This results in magnifying the role and impact of seed predators. However, banj oak has a high coppicing capability. Thus, if allowed, it can regenerate in copious amounts. Singh and Singh (1986) also predicted an increase in relative population of tilonj/moru oak (*Q. floribunda*) at the cost of banj oak.

Saxena and Singh (1984) mentioned a possibility of climate change adversely affecting the regeneration. They mentioned that meteorological data from 1912-1977 suggests a decline in total annual rainfall (from 2858 mm to 2527 mm). The authors suggested that a majority of seed production occurs in the months of January, February and March. The total rainfall during these three months was 261 mm in 1937-1952, which decreased to 147 mm in 1967-1977. It is possible that this change in rainfall amount might have contributed in reduction in oak seed germination and seedling establishment.

During my own field work, I noticed various signs of disturbances, e.g. fire, lopping, removal of woody debris, human waste, and garbage including food wrappers, glass bottles and plastic bags. In addition, most of my study sites had livestock inside the forests. Goats, sheep, and cows as well as buffaloes were seen grazing upon the forest vegetation. In their research paper, Nautiyal and Babor (1985) explained how livestock affects the forest in the Central Himalaya adversely. According to the authors, the freely grazing livestock destroy the seedlings of the forests in the vicinity of villages by eating as well as trampling them, which hampers their regeneration. According to Spurr and Barnes (1973), "…around the world grazing by livestock has probably been more important than any other factor in reducing the productive capacity of uncultivated land."

In addition to various forms of exploitations and disturbances that are contributing to banj oak decline, one of the most important factors that is contributing in replacement of banj oak by chir pine forests is the poor competitive abilities of banj oak as compared to the chir pine.

Banj oak vs chir pine competitive abilities

Singh and Bisht (1992) conducted a study in which they grew banj oak and chir pine seedlings at different nutrient (nitrogen, phosphorous and potassium) levels. The authors found that the maximum biomass of chir pine seedlings was significantly greater than the banj oak seedlings. Also, the difference in biomass of the seedlings was evidently larger when these two species were grown together as compared to when they were grown as monoculture. In the experiment done by Singh and Bisht (1992), the nutrient concentrations in the foliage mostly increased with an increase in soil nutrient levels. However, the banj oak foliar nutrient concentration exceeded the chir pine in all cases. This finding was same as that was observed in natural forests by Ralhan and Singh (1987). Both species showed an increase in extraction efficiency for all the nutrients when there was an increase in soil nutrient levels. However, there was no significant relationship between an increase in soil nutrient levels and nutrient extraction efficiency when both species were grown together. For all the nutrients, the nutrient extraction capacity of chir pine was generally twice that of banj oak, and in some cases even greater.

At all soil nutrient levels, the retranslocation of nutrients from the senescing leaves was found to be consistently higher in chir pine than banj oak. However, in both chir pine as well as banj oak, the retranslocation of the nutrients was found to decrease with an increase in soil nutrient levels. The authors found a significant negative correlation between the percent nutrient retranslocation and soil nutrient levels. In addition, there was a significant negative correlation between nutrient retranslocation and foliar nutrient concentration. The maximum production level was greater in chir pine than the banj oak, which suggests that the early successional species grow faster than late successional species. These two species showed the lowest difference in their weights at the lowest nutrient level. This suggests that due to insufficient nutrient availability, the individuals are incapable of displaying strong genetic differences and develop competitive superiority (Parrish and Bazzaz, 1982). Austin and Austin (1980) suggested that interspecific competition has been observed to be more severe at higher levels of nutrients (Singh and Bisht 1992). As nutrient levels increased, the difference between the nutrient extraction capability between chir pine and banj oak becomes more evident. The authors suggested that this might be the cause of replacement of banj oak by chir pine in those nutrient rich banj oak forest sites where canopy gaps resulted in the entry and establishment of chir pine.

The authors (Singh and Bisht 1992) also indicated that the conversion of banj oak forests into chir pine is favored by disturbances such as cutting and thinning which make light available for the successful establishment of chir pine, which is an early successional species and thus a light demander. Bargali and Singh (1996) mentioned that Singh and Singh (1992) indicated that the competition among Central Himalayan forest species is affected by light, nutrients as well as the summer drought. Loshali et al. (1990) suggested that loss of tree cover has resulted in an increase in soil erosion, which has led to the depletion of stored soil moisture in most of the Central Himalayan region. Singh and Singh (1992) also mentioned that the soils of the Himalayas are especially prone to erosion. Therefore, with increasing deforestation, the role of moisture deficiency becomes especially crucial in determining the outcome of the competition among various forest species.

Based on their study, Bargali and Singh (1996) concluded that chir pine seedlings had better moisture availability when they were grown with banj oak seedling as compared to when they were grown with another individual of chir pine. However, they did mention that mycorrhizal associations have been reported for both banj oak as well as chir pine of the Central Himalayan region (Singh and Singh 1992), and mycorrhizal associations could have played some role in nutrient distribution among the seedlings. They mentioned the possibility of chir pine benefiting more than banj oak due to the presence of mycorrhizal associations. They mentioned that at low moisture levels, chir pine was benefited by the presence of banj oak; however, it adversely affected banj oak in its presence. Also, the negative impact of chir pine on the banj oak was lower at low moisture levels but increased with an increase in moisture levels. Moreover, at high moisture levels, not only the banj oak but also the chir pine was adversely affected in mixed culture with both species present.

Bargali and Singh (1996) mentioned that, according to Tilman (1982, 1986), if a species has a lower resource requirement, then it will be able to outcompete the species that has higher resource requirement. However, it will be able to do so only until the resource is a limiting factor. Based on Tilman's predictions, although chir pine will colonize bare sites as it is an early succession species, with development of soil and an increase in soil moisture, then banj oak (a late succession species) should gain a competitive superiority over chir pine. However, in the case of chir pine and banj oak, it was found that if moisture is the resource, then not only does chir pine outcompete banj oak at lower moisture levels but also at the higher moisture levels. It is able to do so because it is benefited by the presence of banj oak at lower moisture levels, and at higher moisture levels, its negative impact on banj oak becomes higher.

Bargali and Singh (1996) further suggested that if the competitive advantage shown at the seedling stage persists, once a bare site is occupied by chir pine, the chir pine will not allow banj oak dominance on that site unless the chir pine population dies due to age or other factors. This conclusion was similar to that noted by Singh et al. (1984) on the basis of feature of nutrient cycling in natural banj oak and chir pine forests of the Central Himalaya. Singh et al. (1984) also mentioned that the successional mechanism shown by chir pine appeared to follow the inhibition model given by Connell and Slatyer (1977).

Singh et al. (1984) recorded that the pine vegetation contained 22% of total nitrogen and 40% of total phosphorous in the system, whereas the corresponding figures for oak vegetation were 37% and 41% of total nitrogen and total phosphorous, respectively. The net production in the oak forest was 4% of the tree layer biomass, whereas in the pine forest, it was 8%. Gross nitrogen uptake was more in the oak forest than the chir pine forest. Chir pine showed significant amounts of nitrogen and phosphorous reabsorption from the old leaves before abscission. In fact, in chir pine 37%

of gross uptake of nitrogen and 33% of the gross uptake of phosphorous were obtained from the reused nutrients of the previous year. However, for oaks these percentages were 10% and 11% for N and P, respectively. For just the foliage, 13.2% of N and 8.5% of P were reused for production of new leaves in oaks, whereas for pine, 51% N and 52% P were reused. The authors indicated that nutrient retranslocation from the senescing plant parts helps in maintaining the nutrients in a relatively mobile pool within the biomass of the ecosystem. According to Singh et al. (1984), this helps the plant to use the same nutrient unit for successive production of new leaves or other plant parts (Bormann et al., 1977, Vitousek, 1982). However, according to Nye (1961) and Gosz (1981), a higher percentage of internal redistribution of nutrients is treated as an adaptive feature of nutrient poor soils. Based on this study by Singh et al (1984), since the nutrient redistribution is higher in chir pine than the oaks, it can be assumed that the chir pine is better adapted for impoverished soils than the oaks.

Singh et al. (1984) also suggested that in the pine forest, a high C: N ratio of the soil and a high dry matter:nitrogen ratio of the litter result in slowing down the decomposition rate and thus increasing the fuel load on the forest floor. Furthermore, if the litter has a high dry matter: nitrogen ratio, the decomposers present in such litter may cause immobilization of the available nitrogen from the soil solution.

Based on these results, Singh et al (1984) concluded that the immobilization of nitrogen was clearly evident in the decomposing pine litter. Generally, a very small proportion of total nitrogen constitutes the dynamic available nitrogen pool in the soil at any given time (Bormann 1977, Robertson 1981), and the deficit of available nitrogen can become intensified due to microbial immobilization in nitrogen poor soils. The authors (Singh et al. 1984) suggested this as the main reason behind the failure of oaks to reinvade in the presence of pine.

Vitousek (1982) argued that the available nitrogen deficiency created by nitrogen immobilization by microbial activity may result in increased nitrogen use efficiency and still higher dry mass:nitrogen ratio litter production (Singh et al. 1984). Frequent fire in pine forests results in significant nitrogen losses through volatilization, which intensifies the nitrogen shortage. Singh et al. (1984) mentioned that oak is a relatively heavy nitrogen demanding tree as compared to pine and therefore cannot flourish in nitrogen deficient soils. With the help of litter rich in nitrogen and rapid mineralization, high soil fertility is maintained in oak forests. However, oak forests are also a source for fodder and fuelwood as a result of which these forests are heavily lopped. Heavy lopping creates large canopy gaps and reduces leaf fall. The absence of nitrogen rich litter reduces the soil fertility. Thus, the conditions become unfavorable for oaks and suitable for pine invasion. Ralhan and Singh (1987) also had findings similar to Singh et al (1984).

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CHAPTER 3. COMPARISON BETWEEN VEGETATIONAL COMPOSITION OF CHIR PINE AND BANJ OAK FORESTS AND ANAYLYSIS OF SIZE CLASS DISTRIBUTIONS TO PREDICT THE FUTURE OF THE BANJ OAK POPULATIONS AT THE STUDY SITES

Introduction

Chir pine (*Pinus roxburghii* Sargent) at 1000-1800 m and banj oak (*Quercus leucotrichophora* A. Camus) at 1500-2100 m are the dominant species in the Central Himalayas (Singh and Singh 1992). Banj oak occurs on sites that are rich in nitrogen and phosphorous, whereas chir pine occurs on sites which are deficient in these nutrients (Singh and Bisht 1992). Bargali and Singh (1996) mentioned that according to Champion and Seth (1968), banj oak, a late successional species, is present on more mesic soils, which are nutrient rich as well. However, chir pine easily colonizes bare sites, and it can occupy even extremely dry and infertile soils that develop on quartzite and sandstones. Singh and Singh (1986) and Singh and Singh (1987) also indicated that chir pine is an early successional species which can form stable communities under forest management techniques like tree felling and frequent burning, whereas banj oak was described as a dominant species of climax communities (Singh and Bisht 1992). Singh and Singh (1992) quoted Champion and Seth (1968a, 1968b), who mentioned that chir pine is likely not the potential climax forest, and the reason behind its extensive presence relates to constant disturbances such as fire, deforestation and landslides. However, chir pine forests have become a permanent feature, as this species has become established over large areas.

Based on the vegetation types given by Champion and Seth (1968a), chir pine forests in the Central Himalayas were listed under the category of low-montane needle-leaf forest with a concentrated summer leaf drop, whereas banj oak was listed under low to mid montane hemi sclerophyllous broadleaf forest with concentrated summer leaf drop (Singh and Singh 1992).

Research Problems

1. Comparison of the vegetation of the two forest types at different strata in terms of species richness.

H0: There is not much difference between species richness of banj oak and chir pine forest.

2. Can we conclude that the banj oak forests are declining in the Central Himalaya?

   H_0: The banj oak forests are not declining in the Central Himalaya.

Methods

General Study Area

All of the sites in the present study are located in the Garhwal division of the Uttarakhand state in India. Uttarakhand (meaning "piece of north") was created on 9 November 2000, has an area of 53,483 km^2 and is located between 28°43' N-31°27' N and 77°34' E-81°02' E. Out of the total geographical area, 86.1% consists of hills, and the remaining 13.9% consists of plains. The forest area is 34,651 km^2, which constitutes 64.8% of the total geographical area of the state (Directorate of Economics and Statistics, Government of India 2013-14). There are six national parks and six wildlife sanctuaries in the state. The state is home for charismatic animals such as tigers, snow leopards, leopards, elephants, black bears, brown bears, sloth bears, and musk deer. The larger animals like elephants and tigers are more common in the plains or foothills of the

Himalayas; however, animals like the snow leopard and musk deer are found at higher elevations.

Uttarakhand is mostly mountainous; with the highest peak (Nanda Devi) reaching 7,817 m. Uttarakhand has several places of great religious importance for Hindus and Sikhs, which results in a large number of pilgrims visiting the state every year. In addition, tourists visit this state due to its scenic beauty and adventure sports like water rafting and mountain climbing. Uttarakhand can be further divided into two main regions—Garhwal and Kumaun. Garhwal is the northwestern region of Uttarakhand and shares a border with Tibet in the north. The glaciers in the Garhwal region are the source of large rivers like the Ganga and Yamuna. The people in this region are known as "Garhwali," as is the dialect spoken by them. Although most of the people also know "Hindi," which is one of the official languages, some of the villagers are fluent only in Garhwali, and thus being a Garhwali myself, knowledge of this dialect was helpful in communicating with local people. According to the 2011 census, the population of Uttarakhand is 10,086,292, out of which 69.8% is considered as rural population and 30.2% as urban. The literacy rate is 78.8%, consisting of male and female literacy percentages 87.4% and 67.1%, respectively. The sex ratio of Uttarakhand, 963 females per 1000 males, is better than the national average, 940 females per 1000 males. Women in the hills play crucial roles in household economy, as they not only cook the meals and do household chores but also collect fodder and fuelwood, take care of the livestock, bring drinking water from natural springs and play important roles in agriculture.

For the comparison of vegetation composition and size class distribution of banj oak forest with chir pine forest, the three kinds of forests (banj oak forest without chir pine trees, chir pine forest without banj oak trees and mixed forests with both chir pine and banj oak trees) were sampled at five different sites. Out of the five study sites sampled for vegetation, four were located in District Tehri Garhwal and one in District Rudraprayag. In terms of forest department classification, the information for all five sites is provided in Table 1. (Note: At the Chamba site, the three plots were under two different forest divisions—Narendranagar and Tehri.)

Magra Study Site

All of the forest sites were named after nearby villages/towns. The first site sampled was located near the Forest Department Guest House of Jaunpur Tehsil, Tehri Garhwal and was named after the nearby subvillage Magra. This site was very different from other four sites. The first plot was in the oak forest, which was located a few kilometers uphill from the guesthouse. This oak forest had a steep slope facing a deep valley, which could have contributed in making this forest the least disturbed among all the 15 different plots sampled. One tree was present with fresh deep cuts around its main trunk, but otherwise there were few signs of lopping or other human disturbances. On the outer edge of the forest, there were few chir pine trees present; however, there were no chir pine trees present inside the plot when it was sampled. The vegetation in this banj forest was also quite different from the other four banj oak forests. The second plot at this site was a mixed forest. This forest had both oak and the pine trees. While sampling, some cultivated species such as kharik [*Celtis australis* Linnaeus and *Toona serrata* (Roxb.) M. Roem] were noticed. Also, just outside the plot, there were several deodar trees *(Cedrus deodara* (*Roxb.*) G. Don) present, although it was a low elevation for the natural occurrence of this species. Upon asking about it, we were informed by the forest department that they had planted these trees inside the forest. A herd of sheep and goats as well as several cattle were grazing and browsing in and around the mixed forest. The chir pine trees inside the forest varied in sizes, in terms of DBH. The largest chir pine tree had a DBH of 66.5 cm and the smallest had a DBH of 15.7 cm.

The third plot at this site was a chir pine forest. This plot was again on a steep slope, although less so than the oak forest, at this locality and was facing the valley. This chir pine plot was also diagonally facing the oak plot, which was sampled at the same site. This chir pine plot was more like woodland with numerous shrubs present. Generally, most of the other chir pine forests had less amounts of shrubs and more grasses. It is possible that if there are less frequent fires, then most of the pine forests will acquire more shrubs; however, frequent fires burn the shrubs and promote growth of the grasses. Villagers prefer grasses, as they serve as a fodder source for livestock. This is the main reason behind intentionally induced fires in the chir pine forests. The chir pine forest at this site was also heavily exploited for timber. The trees were widely spaced, and there were signs of fire and lopping as well as resin extraction. The chir pine trees in this plot were generally large, with the smallest DBH of 28.8 cm and the largest DBH of 65.8 cm.

Jakholi Study Site

This site was located in the Jakholi Block of the Rudraprayag District. This site was very close to human settlements. In fact, the oak and mixed plots were both adjacent to the local market. The oak plot was the first to be sampled at Jakholi. Outside the oak forest, we met a goatherd with his goats and a sheep walking next to the forest, and his animals were feeding on forest plants and tree leaves. Both the oak as well as the mixed

Table 1. Study site locations.

Site Name	Location
Site 1. Magra	Region: Garhwal; Circle: Yamuna; Division: Mussoorie; Subdivision: Mussoorie; Range: Jaunpur.
Site 2. Jakholi	Region: Garhwal; Circle: Garhwal; Division: Upper Ganga (Karnprayag); Subdivision Karnprayag; Range: Jakholi
Site 3. Badshahithaul (B.T.)	Region: Garhwal; Circle: Bhagirathi; Division: Tehri; Subdivision: Ranichauri Range: Tehri
Site 4. Chamba	Region: Garhwal; Circle: Bhagirathi; Division: Narendranagar/Tehri; Subdivision: Narendranagar/Ranichauri; Range Narendranagar (Soyam)/Tehri
Site 5. Ghansali	Region: Garhwal; Circle: Bhagirathi; Division: Tehri; Subdivision: Ghansali; Range: Bhilangana.

forest had human excreta at various places along with other kinds of human waste, like plastic and glass bottles and polythene bags.

Even at present, many households in the villages of the Garhwal region do not have the basic facilities, such as toilets, and thus it is common practice to use the forest for that purpose. Also, being close to the village market makes the forest more prone to receiving all kinds of waste material. The oak and mixed forest at this site were not very polluted but was more polluted on average than the other plots that were sampled. A large number of birds were spotted during the sampling in these two plots at the Jakholi site. Easier access to human food (or human waste) could have been a factor for the higher presence of various bird species. Disturbances were relatively common in these two plots. Some of the trees had been severely lopped, creating large canopy gaps.

During the survey of other areas near the plots, it was noticed that in certain places at this site, the banj oak trees were so heavily lopped that they look like dwarf trees and existed in a woodland form rather than as a dense canopy tree, which is common in oak forests. Another thing that was common with these woodland form oak trees was the presence of chir pine. Blue pine (*Pinus wallichiana* A. B. Jack.) was noticed in a nearby forest, although none of the blue pine trees were present in any of the fifteen plots that were sampled.

There was a nearby community forest, which was actually a banj oak patch that looked like an old growth forest. This forest was protected and managed by a few families in a subvillage called Bhattgaon, which is named after the family name of the people living there ("Bhatt" is the family name and "Gaon" stands for village). A portion of this community forest was quite dense, and the ground was covered with bryophytes and pteridophytes. Trees in this forest also showed various kinds of epiphytes. This community forest showed much less evidence of pollutants like plastic. In addition, this forest had a very dense shrub stratum. Deer droppings were spotted in the forest, indicating the presence of deer. Some portion of this forest under the Bhatt family was free from chir pine trees; however, the other portion of the forest showed interspersed chir pine trees (Figure 3).

One of the volunteers, Usha Nautiyal, whose father was a resident of this village. and who spent her childhood in Bhattgaon, mentioned that "Earlier, residents of the village used to remove chir pine seedlings, saplings and shrubs from the forest, as they used to consider it bad for the banj oak trees, and that is the reason for the absence of chir pine in certain portions of this forest. However, people gradually moved to the cities for better job opportunities, and thus there are not many people left to maintain these forests."

A lot of monkeys were present in this community forest, and the villagers complained that these monkeys were collected from towns and cities and left in these forests, as they cause a nuisance in the towns and cities and cannot be killed due to religious sentiments attached to them. These monkeys cause a lot of trouble to the local villagers, as they eat and destroy their crops, vegetables and fruits.

There are chir pine forests in close vicinity of most of the banj oak forests, which gives easy access to the wind-dispersed seeds of chir pine in case of any kind of canopy disturbance. In order to establish itself successfully inside the oak forests, canopy

Figure 3. Forest near Bhattgaon with chir pine trees inside the oak forest.

Figure 4. Banj oak coppice growth in the chir pine plot at Jakholi.

disturbances are important for chir pine, as it is a light demanding species, and thus cannot survive under the healthy, dense canopy of banj oak.

Even if there is a small amount of human disturbances, like lopping, if the forest is managed better, encroachment and establishment of chir pine can be prevented at least in the community forests or in the forests around the villages. However, there has to be a sense of responsibility towards the forests and overexploitation of forest resources should be avoided.

A resident of Bhattgaon, who is a retired forest ranger, mentioned that the banj oak forests have shrunk a lot, and the chir pine has replaced it in a lot of nearby forests. In fact, according to him, the chir pine plot, which was sampled at this site, used to be an oak forest. The chir pine plot at this site had dense shrub-like banj oak. It was not in the tree form anymore, and there is very little hope that these shrubs can ever become trees again, as the browsing animals do not let them grow taller, which has resulted in this stunted coppicing growth form (Figure 4).

The bark of all trees present in the chir pine plot was scorched due to a forest fire. Most of the trees in the chir pine plot had smaller DBHs, with the smallest tree having a DBH of 3 cm and the largest with a DBH of 39.3 cm.

Badshahithaul (B.T.) Study Site

This site was close to a town called Badshahithaul in Tehri Garhwal. All three forest types, chir pine, mixed and oak occurred along a continuum. At the base of the mountain there was a chir pine forest, as one went uphill, there was chir pine and banj oak mixed forest, and on the top of the mountain was a dense, old, oak forest. The mixed, as well as the oak, forest were close to human settlements. The chir pine forest was next to a road and was mostly on a flat area. The chir pine plot was first to be sampled at this site. The trees at this site also showed scorched tree bark. The chir pine plot was grassy.

While sampling, we noticed that a tree was catching fire, due to short-circuit in an electric wire passing above our plot. Although such an occurrence should not be common, during a dry summer, even a small spark can lead to wild fire on a large scale.

All the trees showed signs of fire damage. Most of the chir pine trees at this site looked relatively young. The largest DBH was 26.2 cm and the smallest 3.2 cm. The surrounding forest area showed some human waste, such as Styrofoam, plastic cups and plates, liquor bottles and human excreta. This possibly could be because this forest was very close to the road, which makes it accessible to people who want to spend time in the forest for recreation and other reasons.

The banj oak forest plot was located on top of the mountain near a village called Lamkot. This oak forest had a dense canopy and looked like an old forest. Being close to the village, there was some human waste in the forest. There were not many houses close to the forest. A few chir pine trees were present at the edge of the oak forest, but none were inside the oak forest plot at the time of sampling.

The mixed forest was located on the same mountain as the oak forest, but at a lower elevation. The largest and smallest chir pine trees present in the plot had DBHs of 26 cm and 4.5 cm, respectively. In the mixed forest plot, many of the trees showed fire damage. The smaller banj oak trees and saplings showed more fire damage, as their leaves had been burned.

Chamba Study Site

Chamba is a small town located in Tehri Garhwal. The unique thing about this site was that for the other four sites, the oak plot was at the top of the mountain; however, at this site, the oak forest was located in the valley. The oak plot sampled at this site was close to one of the forest department range offices. Cow dung inside the forest indicated that cattle did visit this forest. The forest did not show much human waste, which could be due to its close vicinity to the forest range office.

The next plot at this site was the mixed forest. There were various small patches of mixed forest at this site. One of the small patches of mixed forest was chosen for sampling. This forest had a variety of birds based on both audible as well as visible evidence.

The last plot at this site was the chir pine plot. This chir pine plot was different from those in other sites, as it was relatively more humid, shadier and cooler. Moreover, it was located close to the top of the mountain. All other pine plots that were sampled were more exposed to the sun. This chir pine plot was located close to a place called Ranichauri. The pine plot at this site had a thick mat of needle leaves on the forest floor. The bark of the trees was darker with carbon on them due to fire, but the trees appeared not to have been exploited very much, which could be because either most of the trees were too young for resin extraction, or they did not have much resin. The smallest DBH was 19.2 cm and the largest 41.5 cm.

Ghansali Study Site

This site was also located in Tehri Garhwal and was the last one to be sampled. Ghansali is the closest town, so the site was named after it. However, all the plots were a bit farther from Ghansali. The Moolgarh village was chosen for chir pine plot, and it was the first plot to be sampled at the Ghansali site. Moolgarh had large pine trees. In fact, the largest pine tree spotted during the three field seasons was located there. Unfortunately, it was dead yet still standing with an impressive DBH of 112 cm (Figure 5). Attempts to extract its cores were futile, as there was a lot of resistance inside the tree.

The trees at this site were heavily exploited for resin, and the fire damage was rather evident as well. The “French cup and lip technique” was the older method of resin extraction, which was followed until 1993. From 1994 onwards, the “Rill technique” was adopted. There were deep scars on these trees which were made due to older method of resin extraction, which was much more destructive than the newer method (Figure 6). The older method of resin extraction left deep scars, and frequent fires contributed to further damage to these already wounded trees. The chir pine plot in Moolgarh was grassy and on a slope.

The next plot at this site was the oak forest plot, which was located on the mountain top close to a village called Hulanakhal. The oak forest was close to a little pond called Bhansar taal (“taal” in local language stands for pond/lake). This forest also had some cattle roaming around, but it was very dense and rich in faunal diversity. In addition, numerous fungal fruiting bodies were noticed during vegetational sampling in 2011.

Most of the mixed forest patches at this site were of very small sizes, so they could not be used for sampling purpose. Therefore, a plot with a woodland kind of growth form was used. The soil in this plot seemed much more compact and less moist than in the oak forest.

Vegetational sampling

In order to conduct vegetation sampling at different vegetation strata, three plot sizes were used. The largest plot was 0.1 ha (50×20 m^2). The plot was demarcated with the help of four tapes. The baseline tape (50 m) was placed first and then three other tapes (20 m) were placed perpendicular to the baseline tape at the two corners and at the center of the base line tape. The tapes were held in place with the help of iron pins. Figure 7 shows one of the chir pine plots with tapes on it. Since there were five sites with three different types of forests, a total of 15 plots of 0.1 ha size were sampled.

The 0.1 ha plot was used to record the DBH and species names of all the trees >2.5 cm in DBH. In addition, the saplings which were >1 m in height were recorded, along with their

Figure 5. A dead chir pine tree at Moolgarh (Ghansali pine site) with a DBH of 112 cm. (Photograph by Akshay Uniyal.Used with permission).

Figure 6. The deep scar is due to “French cup and lip technique” for resin collection method and on the left is resin being collected with the less damaging "Rill Technique."

species name. Inside these 0.1 ha plots, four (5 × 5) m^2 sub plots were sampled for woody stems including smaller saplings, shrubs and woody vines. An effort was made to identify all the plants from the 60 total 25 m^2 sub plots (belonging to all five sites) to genus level at the least.

Also, inside each 0.1 ha plot ten (1 × 1) m^2 nested plots were sampled for the ground cover estimation using a 1 m^2 plastic frame (Figure 8). Daubenmire cover classes (Daubenmire 1959) were used for ground cover estimation in these plots (Table 2). The percent ground cover by different categories such as bryophytes, rocks, bare soil, woody debris and various herbaceous plants was recorded. An effort was made to identify all the herbaceous plants that were sampled inside the 1 m^2 plot. Most of the plants were identified at least up to the genus level. A majority of the unidentified plants were different grass species. The 1 m^2 as well as the 25 m^2 plots were sampled along the base line tape. Along with sampling, the geographical features including coordinates, slope aspect and slope percent were measured using a GPS unit, compass and clinometers respectively (Table 3).

Absolute density, relative density, absolute basal area and relative basal area were calculated for all the trees >2.5cm DBH, as well as for two sub-categories of trees (smaller trees 2.5 < DBH < 10 cm and larger trees with a DBH >10 cm). The importance value was calculated by adding the relative density and relative basal area and then dividing the total by 2. Trees were divided into different size categories, and their frequencies in different categories were plotted in bar graphs. For shrub data, there were a total of 20 oak forest plots (five oak forests, and each had four 25 m^2 plots), similarly there were 20 pine forest plots. The number of stems in each 25 m^2 plot was added, and then the data was analyzed by using Wilcoxon-Mann-Whitney Rank Sum Test.

Figure 7. The 0.1 ha chir pine plot at B.T.

Figure 8. 1×1 m^2 plot in a chir pine forest.

Table 2. Daubenmire cover classes.

Cover Class	Range of Coverage (%)	Mid Point Values (%)
1	T-5	2.5
2	25-50	15.0
3	25-50	37.5
4	50-75	62.5
5	75-90	85.0
6	95-100	97.5

The species richness for shrub stratum was calculated for all five oak plots as well as pine plots (Figure 15). In addition, the stem count per ha and relative density were also calculated for each plant species for all 15 forest plot.The herbaceous ground cover percent for each quadrant was calculated by multiplying the midpoint % value of each category with the number of times it appeared, all the values were then added and the total was divided by 10 in order to get average percent herbaceous ground cover per quadrant. Similarly, in order to calculate the percent ground cover occupied by each individual plant species, the midpoint % value of each category was multiplied with the number of times it appeared, then all the values for different categories were added and the total was divided with 10, which provided the average value for 1 m^2.

Total number of herbaceous species (species richness) was calculated for different vegetation strata in all 15 forest plots that were sampled. Also, the average number of herbaceous species was calculated for each forest type.

Results and Data Analysis

The banj oak forest had higher tree density compared to the chir pine. The lowest tree density in the oak forest was at Chamba, with a total of 86 trees in 0.1 ha, and the highest was at Jakholi site with 336 trees in 0.1 ha (Table 4-Table 8). The chir pine forest had a monodominant stand with a 100% importance value at four sites out of five, and it was only at the Magra site where the importance value of chir pine was less than 100%, although it was still very high at 96.84%. The banj oak forest had a greater variety of tree species, and it never made a monodominant stand in any of the five sites that were sampled (Figure 9).

Out of the five total sites, at two sites (BT and Magra) the number of herbaceous species was higher in oak forest (Figure 16). At BT, the banj oak forest had 20 species, whereas the chir pine forest had 10 species. At Magra, there were 21 species in the oak forest and 15 in the pine forest. At Chamba, the chir pine and oak forest had a marginal difference in terms of herbaceous species of 25 and 23, respectively. At Ghansali, the chir pine forest had 18 species, whereas the banj oak forest had 14. However, at Jakholi, the chir pine forest had almost thrice as many species as present in banj oak forest, 38 and 13, respectively. At Jakholi, the chir pine plot was a bit farther away from a human settlement, whereas the oak forest was next to the village market and showed a lot of disturbance as mentioned in the site description.

The average herbaceous ground cover for chir pine, mixed forest and banj oak forest at all five sites was 60.65%, 55.75%, and 48.1 % , respectively. Only Chamba and Magra showed higher ground cover as compared to the chir pine (Figure 16a). Average number of species (based on data from all five sites) for ground cover was 21, 23 and 18 for chir pine, mixed and banj oak forest, respectively.

The average number of woody stems per 25 m^2 plot was higher for the oak forests than the chir pine forest at 93 and 78, respectively. Although based on Wilcoxon-Mann-Whitney Rank Sum Test ($df = 19$, $p = 0.2558$), the banj oak and chir pine forests were not significantly different from each other in terms of total number of stems.

The banj oak forest had higher species richness in four out of the five sites for the shrub stratum (Figure 15), and for the fifth site (Jakholi), the species richness was higher in chir pine plot by just one number at 17 and 16. Saxena and Singh (1984) reported that in chir pine forests, *Lantana camara* was the dominant shrub and *Myrsine africana* was the dominant shrub in banj oak forests whereas in the current study, *Randia tetrasperma* was the dominant shrub in two of the pine forests (B.T. and Jakholi) as well as two of the oak forests (Chamba and Jakholi) and one mixed forest (B.T.). On the other hand *Myrsine africana* was dominant shrub in one pine

(Chamba) as well as one mixed (Chamba) and one oak (B.T.) forest. *Indigofera heterantha* had highest density in two.of the plots (Ghansali pine and Magra mixed). The shrubs which dominated the remaining five plots were *Cotoneaster bacillaris* (Ghansali mixed), *Lindera pulchrrima* (Ghansali oak), *Strobilanthus atropurpureus* (Jakholi mixed), *Rubus ellipticus* (Magra pine) and *Wikstroemia canescens* (Magra oak).

(Note: The tables and figures are arranged according to the vegetation strata category.)

Discussion and Conclusions

The chir pine forests are generally monodominant. Oak forests, on the other hand, have a higher species richness for the tree stratum. For shrubs, four out of five sites had a higher species richness in banj oak forest, and for the fifth site (Jakholi), chir pine exceeds the banj oak forest by just one at 17 and 16, respectively. The average number of stems was higher for banj oak forests (93) than the chir pine forests. The chir pine forests had large shrub growths in some of the sites, yet at other sites, the forest floor was mostly covered by grasses. Some of the grassy plots had a larger number of stems for shrub stratum; however those stems were present in the form of patches. Some of the chir pine forests in the study region are very grassy because the local people set fire to the forests to enhance grass growth. Fire results in burning down the shrub-like growth forms; however, the production of grass is enhanced (Figure 18).

For the herbaceous stratum, the banj oak forest had a greater species richness in two out of five sites (BT and Magra), and Chamba had a marginal difference between the two (chir pine had 25, and banj oak had 23 species). The average herbaceous ground cover percentage per quadrant, as well as species richness for the herbaceous strata, was higher in the chir pine forest (60.65%, 21) as compared to the banj oak forest (48.1%, 18).

At the Jakholi site, the ground in the oak forest was mostly covered by leaves (Figure 17). It is possible that many herbs and little seedlings could have died due to frequent visits by people and livestock. Livestock not only graze and browse the forest vegetation but also trample the vegetation, which makes the environment inhospitable for seed germination.

All the oak forests that were sampled had at least a few chir pine trees at the edge of the forest, and sometimes even inside the forest (Figure 19). There was only one oak seedling that was present in ground cover data from all fifteen sites, which indicates a low seedling establishment or survival.

If the current level of human disturbances persists, chances are very low that shrubs like banj oak plants will ever grow into tree forms, since they will continue to be browsed upon by livestock. The conditions at the Jakholi site are perfect examples of how human disturbances are facilitating the banj oak displacement by chir pine. Canopy gaps facilitate the establishment of light demanding species like chir pine, which make conditions unsuitable for the establishment of banj oak and other broadleaved tree species. In addition, due to the continuous human disturbances in the form of livestock grazing and browsing, the further stages of succession are being inhibited, which may lead to the further expansion of the chir pine forest.

Since the species richness of the banj oak and chir pine forests was different at different strata, we can reject the first hypothesis (H_0: There is not much difference between species richness of banj oak and chir pine forest.).

Singh and Singh (1986) indicated that based on the work carried out by a number of different researchers (Saxena 1979, Tewari and Singh 1981, Upreti 1982, Tewari 1982, Saxena and Singh 1982a, Ralhan et al. 1982, Saxena et al. 1984, Singh and Singh 1984, Saxena and

Singh 1984, Tewari and Singh 1985, Upreti et al. 1985) between 1976-1985, populations of banj oak were declining.

During the current study, a number of disturbances were noticed in the banj oak forests which included grazing, browsing, fire damage, lopping, canopy gaps and garbage. Only one seedling was present in all 15 plots (total area1.5 ha) that were sampled, which indicates negligible seedling establishment rate. The forests, which showed higher number of banj oak stem density (in shrub stratum) had shrub like growth form of banj oak which was an outcome of coppicing. Therefore, it cannot be considered as an indication of good regeneration but rather of disturbances

In their study, Saxena and Singh (1984) had noticed that in chir pine forest, a greater proportion of individuals were in lower DBH classes than larger classes. The authors further mentioned that as per Knight (1975), this kind of pattern indicates frequent reproduction. On the other hand, the authors recorded more banj oak trees in intermediate diameter classes, whereas the number of banj oak trees declined in the upper, as well as lower, diameter classes in both the mixed forests and the banj oak forests. The authors mentioned that according to Knight (1975), such a structure indicates infrequent reproduction. Also, according to Benton and Werner (1976), if such a trend continues, it indicates that the population is heading towards its extinction (Saxena and Singh 1984). Saxena and Singh (1984) also reported that in the banj oak forest, the seedlings of this species were completely absent.

Out of the five banj oak plots, three (B.T., Chamba and Jakholi) showed less frequency towards the lower and higher DBH classes, which indicates a decline in population (Saxena and Singh 1984) (Figure 10-Figure 14). As mentioned in the site description section, Magra and Ghansali banj oak plots were relatively less disturbed, and that could be the reason behind the different result for these two sites. However, more information will be needed to predict the future of banj oak populations at these two sites although at present these populations do not seem to be declining.

Based on the observations and results we can conclude that the banj oak populations are declining. And therefore, we can reject the second null hypothesis as well (H_0: The banj oak forests are not declining in the Central Himalaya.). Saxena and Singh (1984) mentioned that since the banj oak makes luxuriance forests, various authors (Kenoyer 1921, Puri 1960, Champion and Seth 1968) considered it as the climax species of the region. Therefore, the possible disappearance of this species in future, due to poor regeneration in all the forests, will be a noteworthy feature.

Table 3. Summary data on plots sampled within the general study area of northwestern India.

Plot	Collection Date	Elevation (m)	Aspect		Slope (%)	Latitude/Longitude
Magra pine	17 June 2010	1870	244°	SW	77	30.46° N, 78.16° E
Magra oak	15 June 2010	1964	62°	NE	90	30.45° N, 78.16° E
Magra mixed	16 June 2010	1844	260°	SW	58	30.46° N, 78.16° E
Badshahithaul pine	28 Jun 2010	1895	280°	NW	34	30.35° N, 78.42° E
Badshahithaul oak	28 June 2010	1954	39°	NE	55	30.34° N, 78.42° E
Badshahithaul mixed	30 June 2010	1853	62°	NE	55	30.35° N, 78.42° E
Jakholi pine	10 July 2010	1716	29°	NE	65	30.39° N, 78.91° E
Jakholi oak	9 July 2010	1808	56°	NE	35	30.39° N, 78.90° E
Jakholi mixed	11 July 2010	1800	48°	NE	39	30.39° N, 78.90° E
Chamba (Ranichauri) pine	5 June 2011	1831	40°	NE	46	30.32° N, 78.41° E
Chamba oak	3 June 2011	1512	350°	NW	50	30.35° N, 78.39° E
Chamba mixed	4 June 2011	1718	N		39	30.34° N, 78.40° E
Ghansali (Moolgarh) pine	11 July 2011	1396	250°	SW	45	30.39° N, 78.75° E
Ghansali (Bhansar-taal) oak	12 July 2011	2215	45°	NE	50	30.40° N, 78.78° E

Table 4. Composition of the tree stratum (≥ 2.5 cm DBH) in the Badshahithaul study site.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Pine	*Pinus roxburghii*	175.0	100.0	26.6	100.0	100.0
	Total	175.0	100.0	26.6	100.0	100.0
Oak	*Quercus leucotrichophora*	103.0	47.7	19.9	72.3	60.0
	Rhododendron arboreum	102.0	47.2	6.6	23.9	35.6
	Myrica esculenta	11.0	5.1	1.0	3.8	4.5
	Total	216.0	100.0	27.5	100.0	100.0
Mixed	*Pinus roxburghii*	76.0	66.7	19.3	70.0	68.3
	Quercus leucotrichophora	38.0	33.3	8.3	30.0	31.7
	Total	114.0	100.0	27.5	100.0	100.0

Table 5. Composition of the tree stratum (≥ 2.5 cm DBH) in the Chamba study site.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Pine	*Pinus roxburghii*	41.0	100.0	35.1	100.0	100.0
	Total	41.0	100.0	35.1	100.0	100.0
Oak	*Quercus leucotrichophora*	79.0	91.9	21.2	86.4	89.1
	Pyrus pashia	1.0	1.2	0.0	0.1	0.6
	Myrica esculenta	6.0	7.0	3.3	13.6	10.3
	Total	86.0	100.0	24.6	100.0	100.0
Mixed	*Quercus leucotrichophora*	248.0	91.5	29.3	81.5	86.5
	Pinus roxburghii	18.0	6.6	6.3	17.5	12.1
	Rhododendron sp.	5.0	1.9	0.4	1.1	1.5
	Total	271.0	100.0	35.9	100.0	100.0

Table 6. Composition of the tree stratum (≥ 2.5 cm DBH) in the Ghansali study site.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Pine	*Pinus roxburghii*	94.0	100.0	20.9	100.0	100.0
	Total	94.0	100.0	20.9	100.0	100.0
Oak	*Quercus leucotrichophora*	209.0	91.7	38.7	80.4	86.0
	Pyrus pashia	2.0	0.9	0.7	1.4	1.1
	Rhododendron sp.	6.0	2.6	3.8	8.0	5.3
	Symplocos chinensis	1.0	0.4	0.3	0.6	0.5
	Lyonia ovalifolia	9.0	4.0	4.4	9.2	6.6
	Ilex dipyrena	1.0	0.4	0.2	0.5	0.5
	Total	228.0	100.0	48.1	100.0	100.0

Table 6. Cont.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Mixed	*Pinus roxburghii*	17.0	60.7	24.2	86.9	73.8
	Quercus leucotrichophora	5.0	17.9	0.4	1.4	9.7
	Rhododendron sp.	3.0	10.7	0.7	2.5	6.6
	Lyonia sp.	3.0	10.7	2.6	9.2	10.0
	Total	28.0	100.0	27.8	100.0	100.0

Table 7. Composition of the tree stratum (≥ 2.5 cm DBH) in the Jakholi study site.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Pine	*Pinus roxburghii*	60.0	100.0	25.5	100.0	100.0
	Total	60.0	100.0	25.5	100.0	100.0
Oak	*Quercus leucotrichophora*	203.0	60.4	21.7	71.8	66.1
	Rhododendron arboreum	14.0	4.2	1.2	3.9	4.0
	Ficus nemoralis	3.0	0.9	0.1	0.2	0.6
	Myrica esculenta	63.0	18.8	5.7	18.8	18.8
	Lyonia ovalifolia	32.0	9.5	1.2	4.0	6.8
	Pyrus pashia	1.0	0.3	0.1	0.2	0.3
	Symplocos chinensis	20.0	6.0	0.3	1.1	3.5
	Total	336.0	100.0	30.2	100.0	100.0

Table 7. Cont.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Mixed	*Pinus roxburghii*	13.0	2.5	4.5	12.5	7.5
	Rhododendron arboreum	98.0	19.2	5.5	15.2	17.2
	Quercus leucotrichophora	263.0	51.5	20.4	56.5	54.0
	Myrica esculenta	82.0	16.1	4.2	11.5	13.8
	Lyonia ovalifolia	41.0	8.0	1.4	3.9	6.0
	Symplocos chinensis	12.0	2.4	0.1	0.3	1.3
	Pyrus pashia	1.0	0.2	0.0	0.1	0.1
	Chyuda *(local name)*	1.0	0.2	0.0	0.1	0.1
	Total	511.0	100.0	36.2	100.0	100.0

Table 8. Composition of the tree stratum (≥ 2.5 cm DBH) in the Magra study site.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Pine	*Pinus roxburghii*	15.0	93.8	24.3	99.9	96.8
	Coriaria nepalensis	1.0	6.3	0.0	0.1	3.2
	Total	16.0	100.0	24.3	100.0	100.0
Oak	*Quercus leucotrichophora*	149.0	67.1	17.8	61.8	64.4
	Rhamnus virgatus	1.0	0.5	0.0	0.1	0.3
	Quercus floribunda	22.0	9.9	2.5	8.7	9.3
	Abelia triflora	1.0	0.5	0.1	0.2	0.3
	Coriaria nepalensis	16.0	7.2	3.9	13.6	10.4
	Pyrus pashia	8.0	3.6	1.0	3.4	3.5
	Lyonia ovalifolia	2.0	0.9	0.4	1.2	1.1
	Cornus macrophylla	11.0	5.0	1.0	3.4	4.2
	Cornus capitata	10.0	4.5	2.0	6.9	5.7

Table 8. Cont.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Oak	*Viburnum coriaceum*	2.0	0.9	0.3	0.9	0.9
	Total	222.0	100.0	28.9	100.0	100.0
Mixed	*Quercus leucotrichophora*	85.0	69.7	34.2	56.7	63.2
	Pinus roxburghii	14.0	11.5	24.7	40.9	26.2
	Morus alba	1.0	0.8	0.3	0.6	0.7
	Cornus capitata	1.0	0.8	0.1	0.1	0.5
	Celtis australis	1.0	0.8	0.0	0.0	0.4
	Toona serrata	15.0	12.3	0.4	0.7	6.5
	Coriaria nepalensis	1.0	0.8	0.1	0.2	0.5
	Cornus macrophylla	1.0	0.8	0.0	0.0	0.4
	Pyrus pashia	3.0	2.5	0.4	0.6	1.6
	Total	122.0	100.0	60.4	100.0	100.0

Table 8. Cont.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Mixed	*Toona serrata*	15.0	12.3	0.4	0.7	6.5
	Coriaria nepalensis	1.0	0.8	0.1	0.2	0.5
	Cornus macrophylla	1.0	0.8	0.0	0.0	0.4
	Pyrus pashia	3.0	2.5	0.4	0.6	1.6
	Total	122.0	100.0	60.4	100.0	100.0

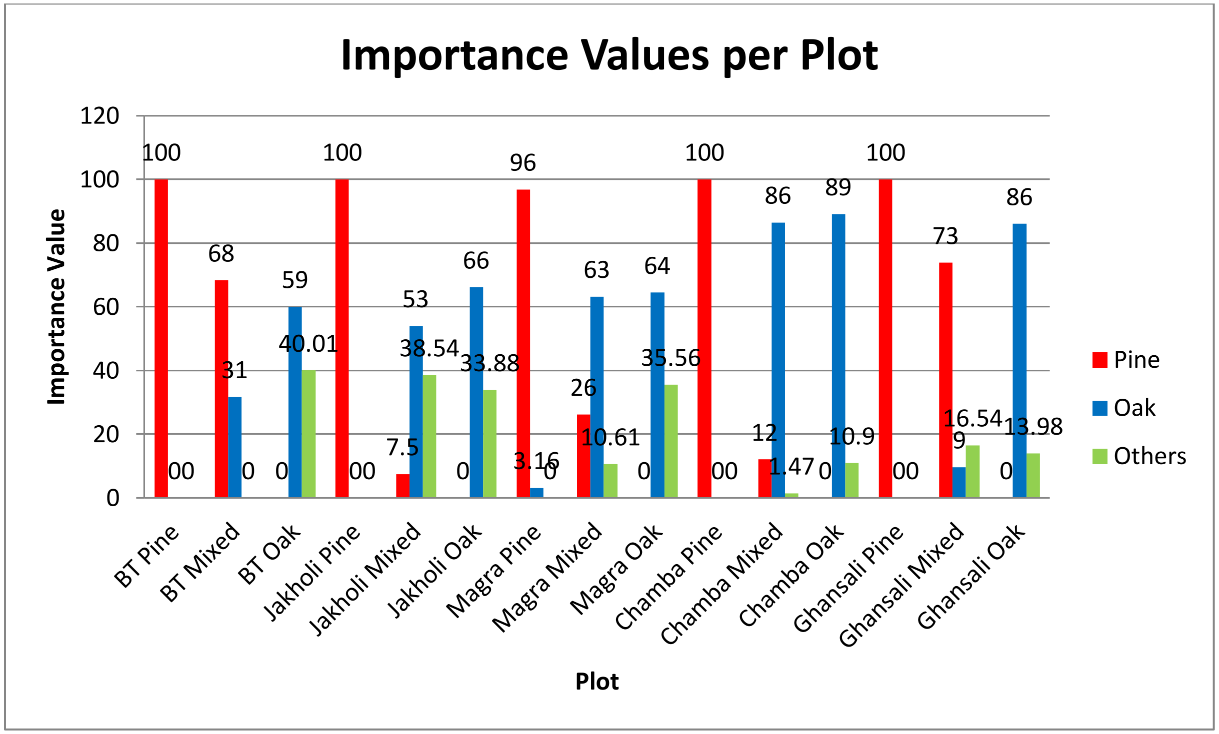


Figure 9. Importance Values for chir pine, banj oak and other species for all 15 plots.

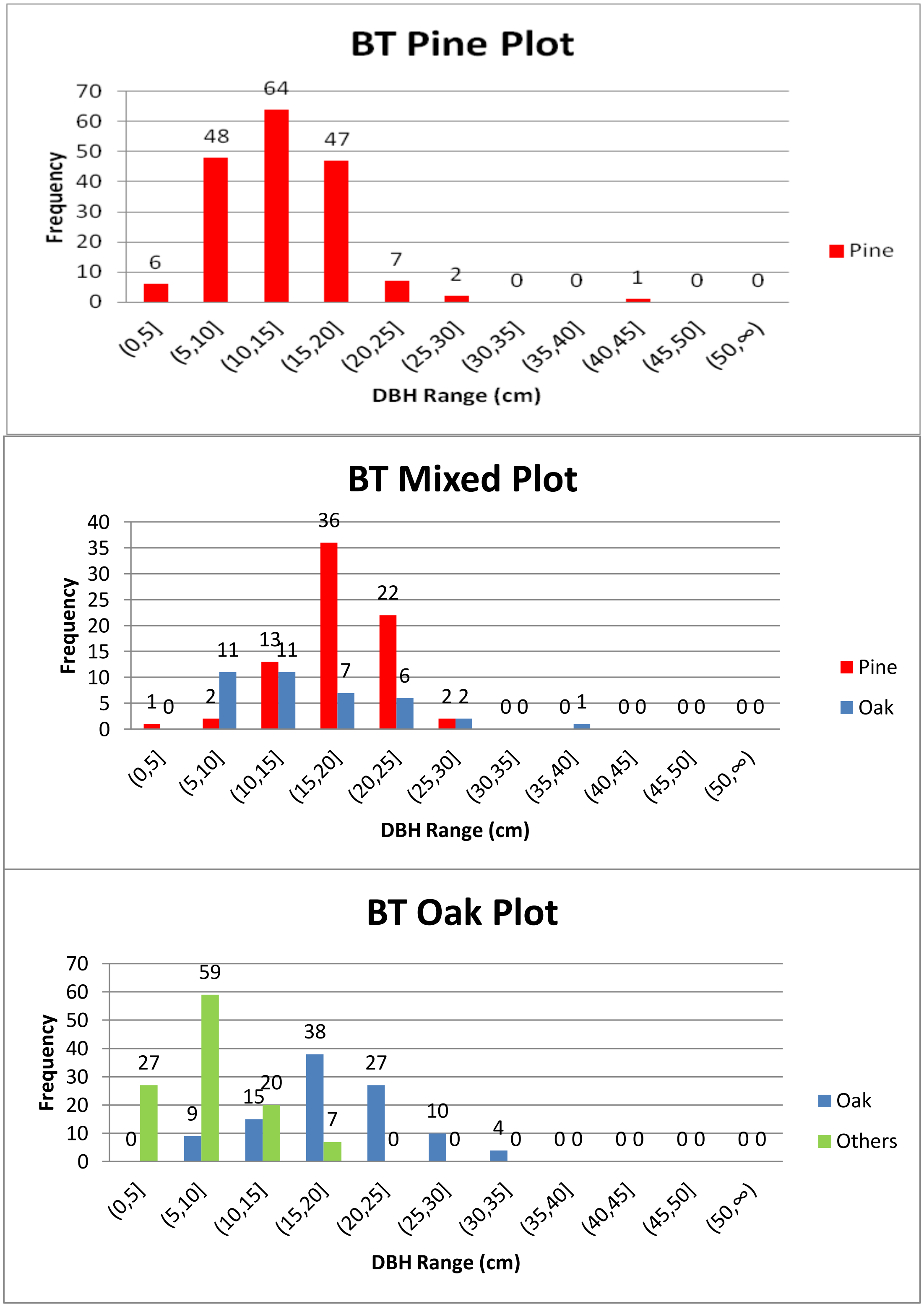


Figure 10. DBH categories and tree frequencies for the Badshahithaul site.

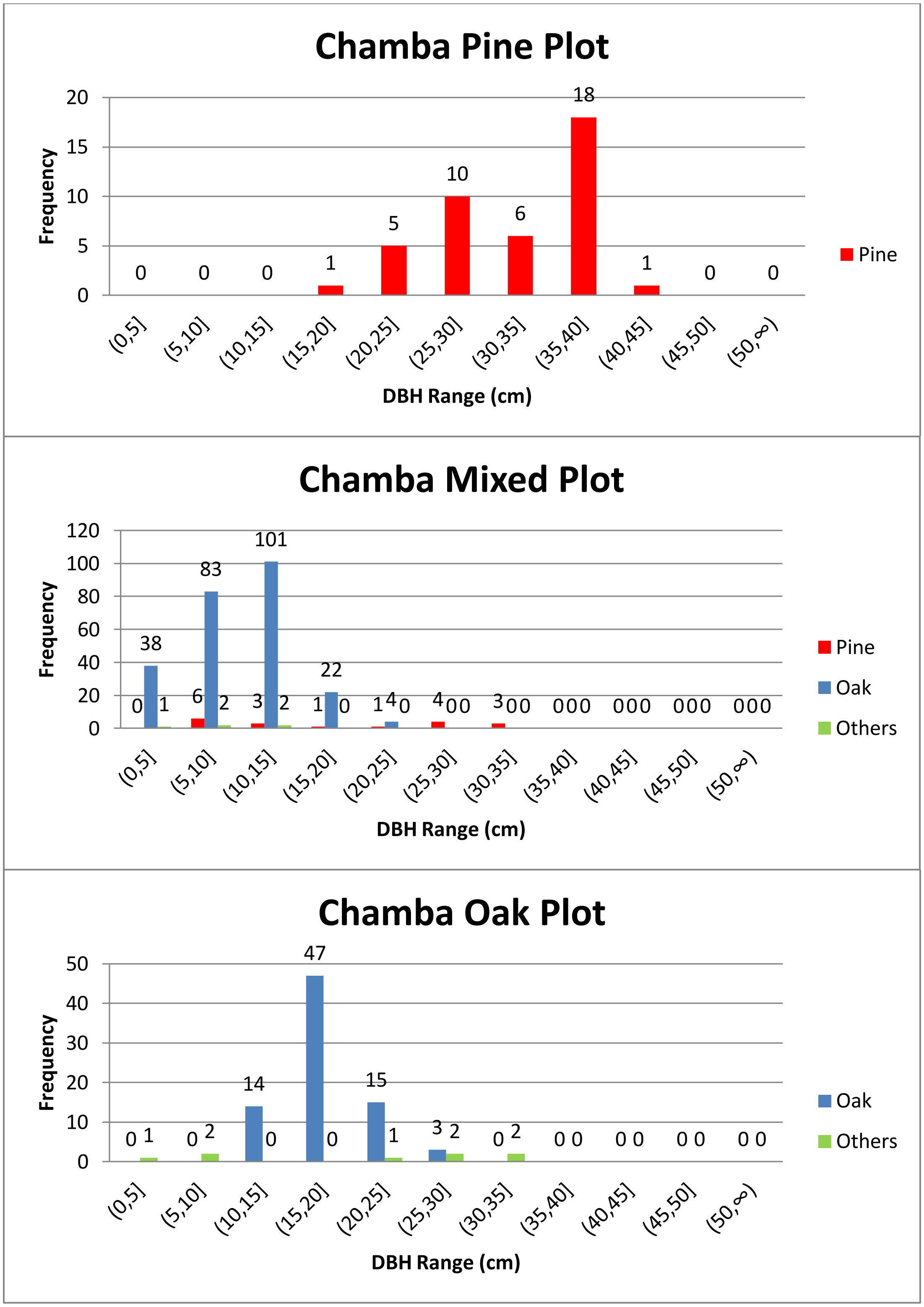


Figure 11. DBH categories and tree frequencies for the Chamba site.

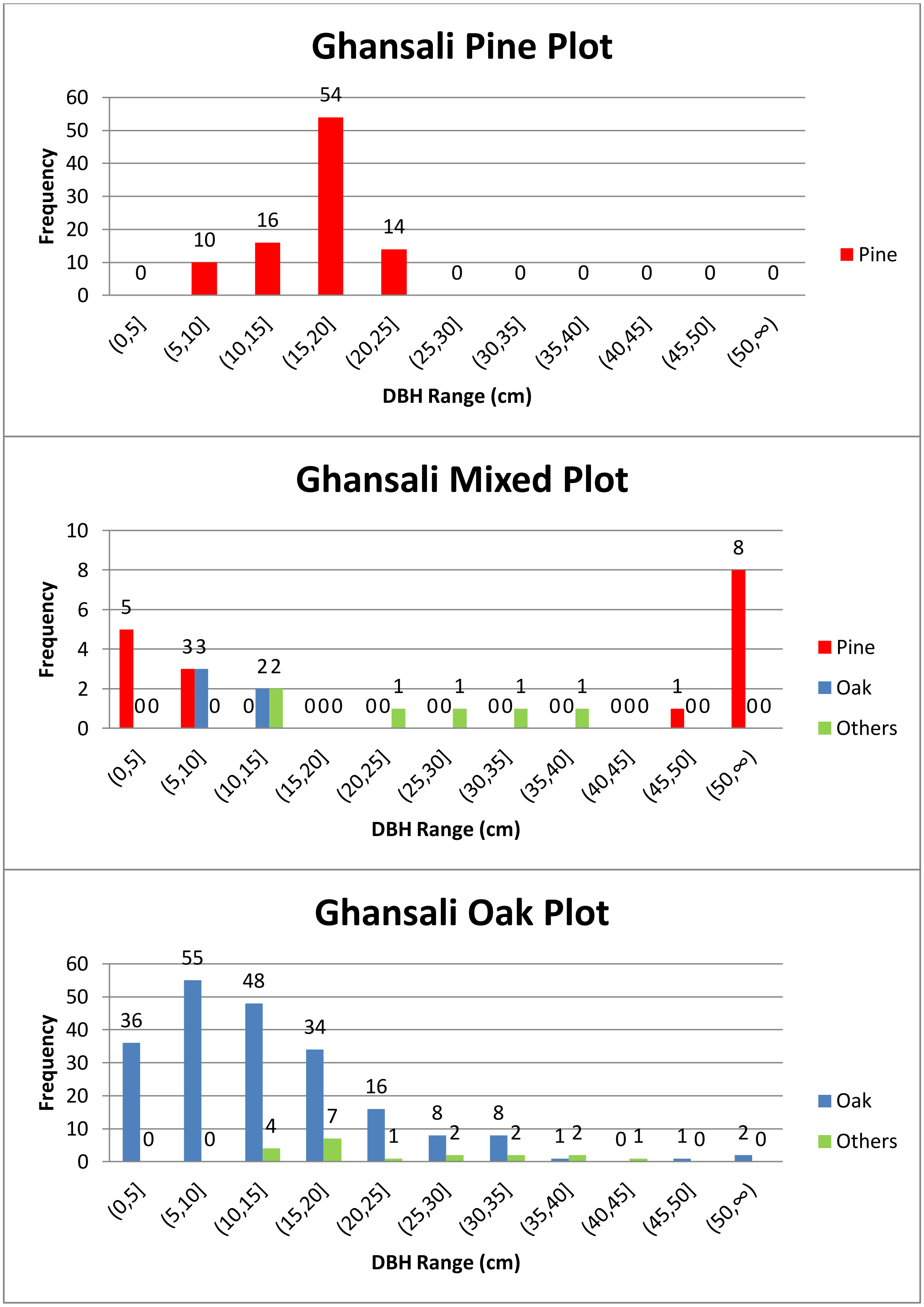


Figure 12. DBH categories and tree frequencies for the Ghansali site.

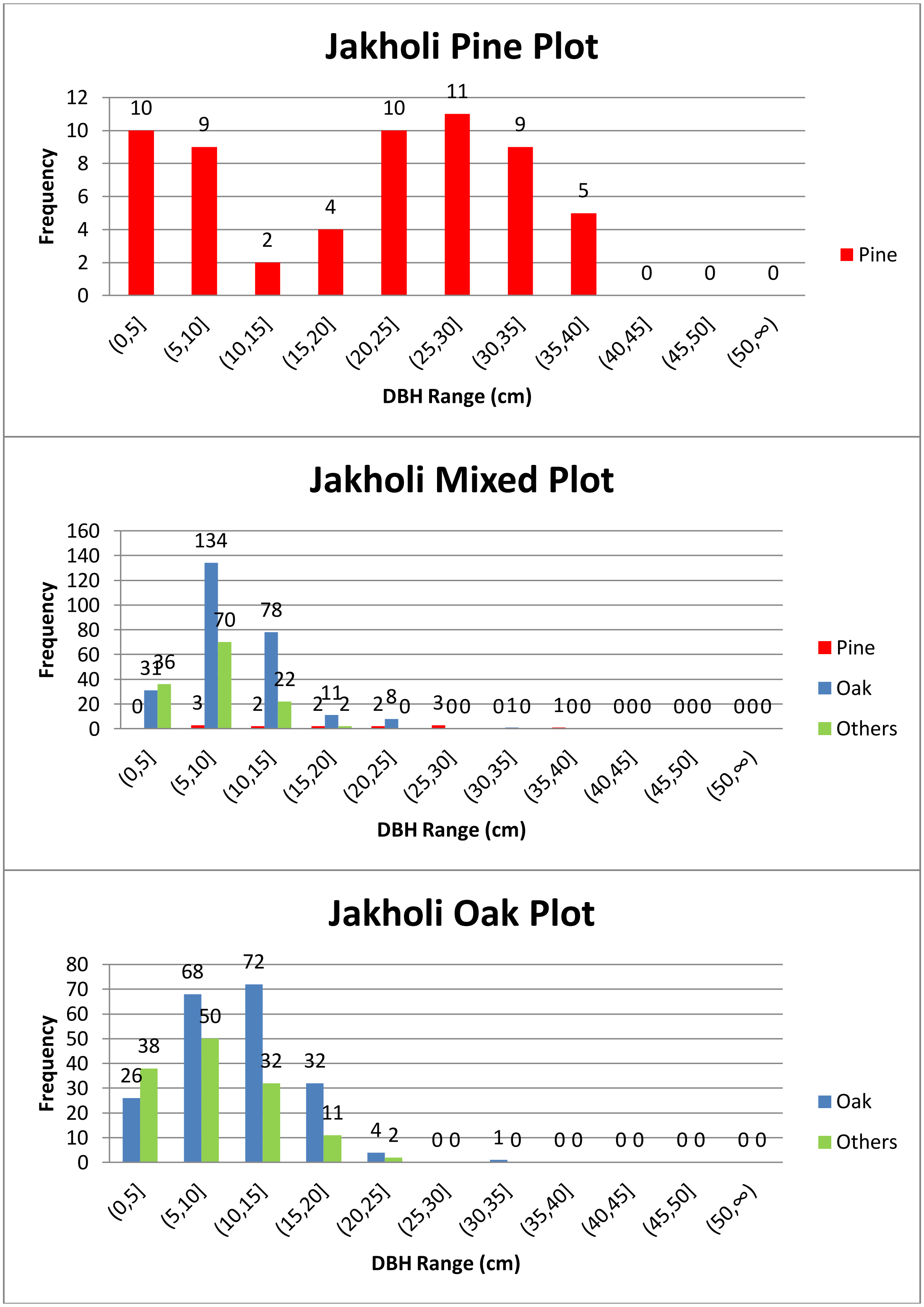


Figure 13. DBH categories and tree frequencies for the Jakholi site.

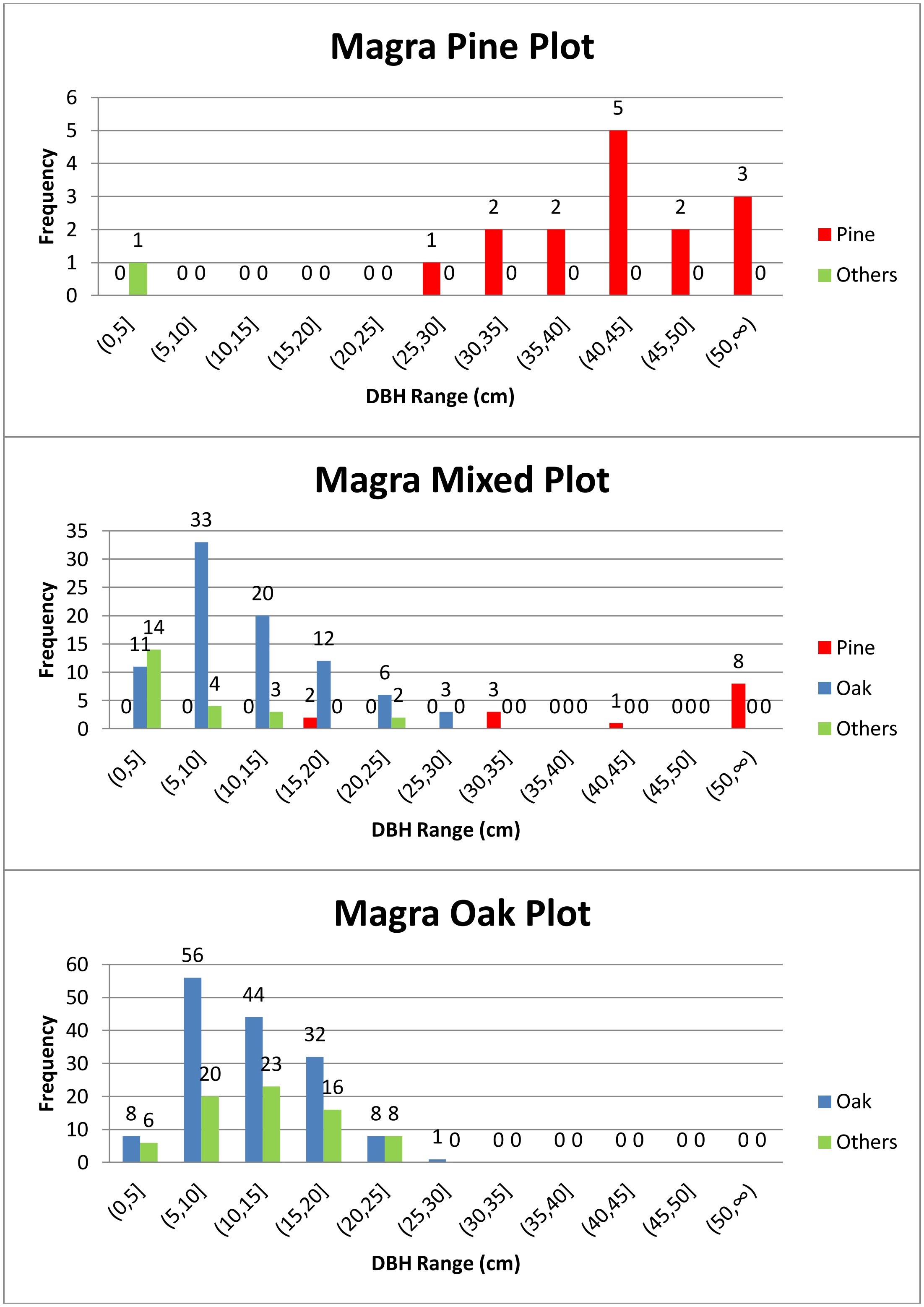


Figure 14. DBH categories and tree frequencies for the Magra site.

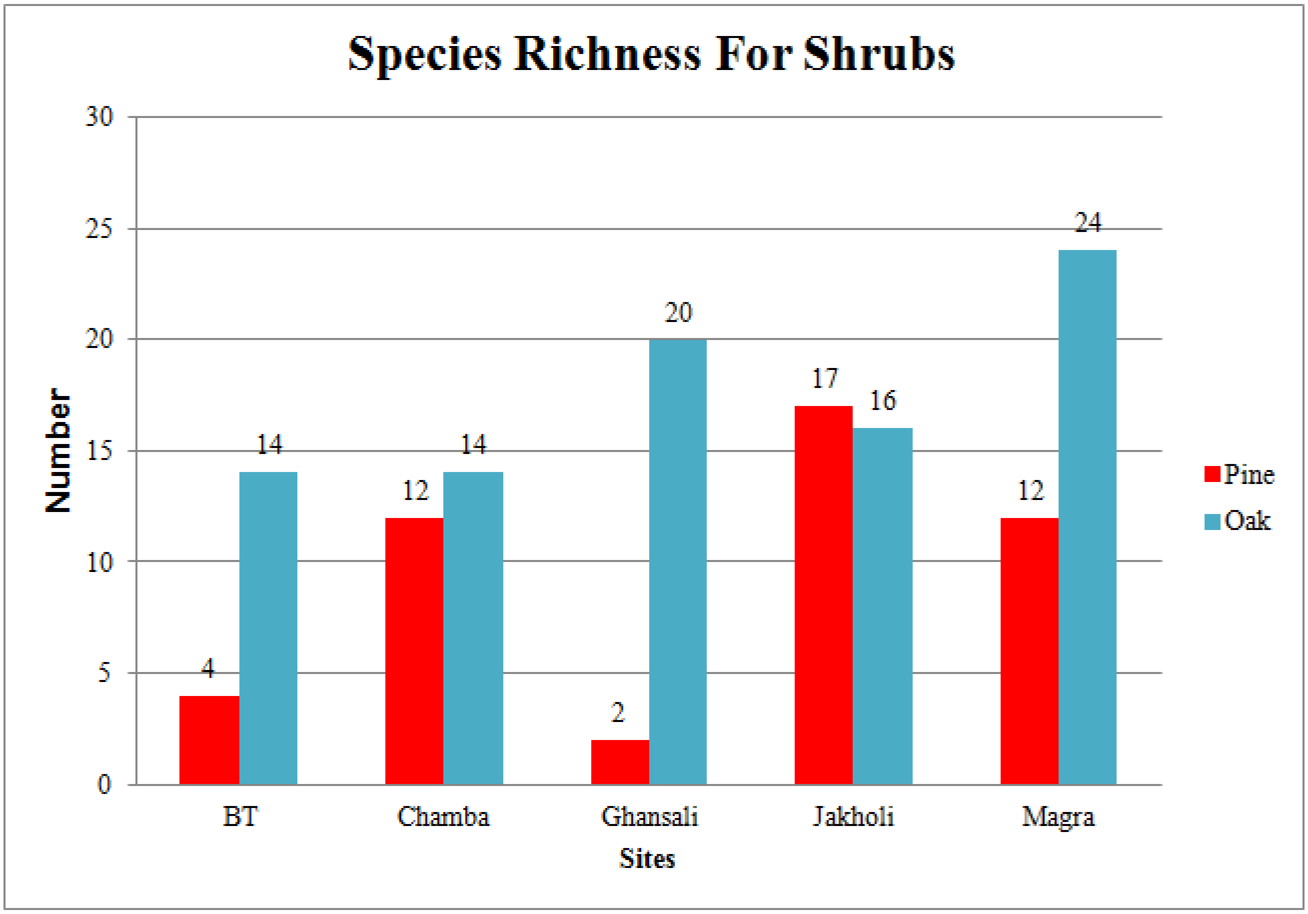


Figure 15. . Species richness for shrubs for all five study sites.

Table 9. The average stem count per species per ha in the sampled oak forests.

Shrub Specimen	Stem Count
Abelia triflora	40
Artemisia vulgaris	180
Berberis spp.	980
Caryopteris grata	900
Caryopteris odorata	1040
Colebrookea oppositifolia	420
Cornus capitata	180
Cornus macrophylla	160
Cotoneaster bacillaris	120
Cotoneaster microphyllus	20
Daphne papyracea	140
Desmodium elegans	200
Desmodium multiflorum	100
Dioscorea deltoidea	20
Eupatorium adenophorum	1140
Ficus nemoralis	160
Ficus racemosa	20
Ficus scandens	320
Hedera nepalensis	340
Hypericum oblongifolium	260
Ilex dipyrena	100

Table 9. Cont.

Shrub Specimen	Stem Count
Indigofera heterantha	220
Jasminum humile	100
Leptodermis lanceolata	140
Lindera pulcherrima	220
Litsea umbrosa	100
Lonicera quinquelocularis	20
Lyonia ovalifolia	80
Myrica esculenta	500
Myrsine africana	6020
Myrsine semiserrata	60
Pinus roxburghii	20
Prunus cerasoides	460
Pyrus pashia	1580
Quercus floribunda	40
Quercus leucotrichophora	2060
Randia tetrasperma	5820
Rhamnus sp.	20
Rhododendron sp.	340
Rhus wallichii	180
Rosa moschata	120
Rubus ellipticus	280

Table 9. Cont.

Shrub Specimen	Stem Count
Rubus niveus	40
Sarcococca saligna	80
Smilax spp.	1260
Solanum torvum	20
Spiraea canescens	2740
Strobilanthes atropurpureus	540
Symplocos chinensis	260
Symplocos sp. 2 (5964)	120
Viburnum coriaceum	80
Viburnum mullaha	20
Vitis himalayana	3520
Wikstroemia canescens	1040

Table 10. The average stem count per species per ha in the sampled mixed forests.

Shrub Specimen	Stem Count
Abelia triflora	20
Berberis spp.	2000
Caryopteris odorata	120
Cornus capitata	40
Cornus macrophylla	20
Cotoneaster bacillaris	1140
Cotoneaster microphylla	40
Daphne papyracea	20
Dicliptera sp.	680
Elaeagnus sp.	40
Ficus nemoralis	160
Flemingia bracteata	220
Indigofera heterantha	1880
Jasminum humile	80
Leptodermis lanceolata	80
Lespedeza stenocarpa	200
Lyonia ovalifolia	560
Myrica esculenta	100
Phyllanthus sp.	380
Pinus roxburghii	740
Pyracantha crenulata	240

Table 10. Cont.

Shrub Specimen	Stem Count
Pyrus pashia	1780
Quercus leucotrichophora	1820
Randia tetrasperma	7120
Rhododendron sp.	300
Rhus parviflora	80
Rhus wallichii	220
Rubus spp.	200
Sterculia villosa	40
Smilax spp.	720
Spiraea canescens	220
Strobilanthes atropurpureus	1000
Symplocos chinensis	1520
Toona serrata	20
Viburnum cotinifolium	80
Viburnum cylindricum	20
Vitis himalayana	340
Wikstroemia canescens	700

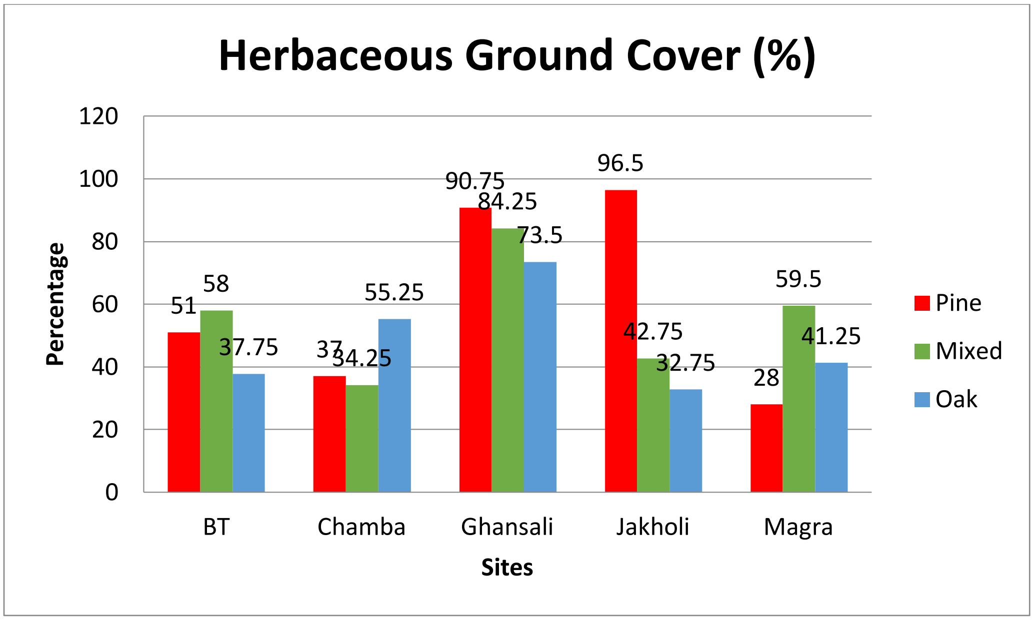
Table 11. The average stem count per species per ha in the sampled pine forests.

Shrub Specimen	Stem Count
Asparagus sp.	20
Berberis spp.	2140
Caryopteris grata	340
Citrus sp.	140
Coriaria nepalensis	60
Daphne papyracea	40
Flemingia bracteata	1560
Indigofera heterantha	3940
Myrica esculenta	1260
Myrsine africana	6100
Pinus roxburghii	200
Pyracantha crenulata	540
Prunus cerasoides	60
Pyrus pashia	1720
Quercus leucotrichophora	2880
Randia tertasperma	4660
Rhododendron sp.	400
Rhus wallichii	40
Rubus ellipticus	1280
Rubus niveus	20

Table 11. Cont.

Shrub Specimen	Stem Count
Smilax spp.	240
Symplocos chinensis	1280
Toona serrata	20
Viburnum cotinifolium	40
Vitis himalayana	40

a.



b.

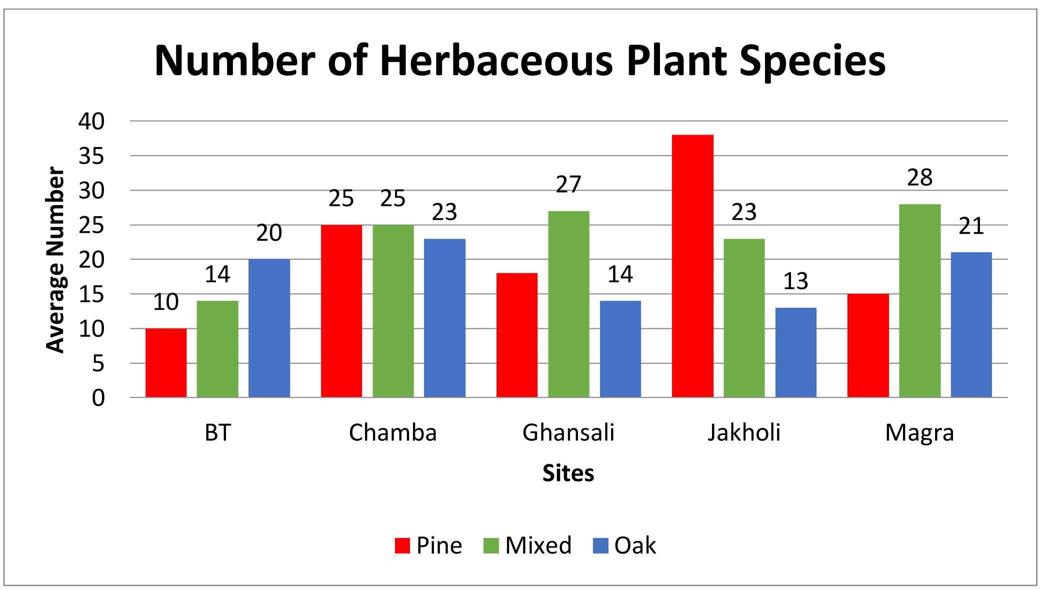


Figure 16. (a) Herbaceous ground cover per ha for all 15forest plots (b) Species richness of herbaceous stratum for per (0.1 ha) plot.

Table 12. Average ground cover in the sampled oak forests.

Specimen	% ground cover/ha
Agrimonia spp.	0.2
Apluda mutica	0.1
Arundinella nepalensis	0.05
Arundinella sp.	0.4
Bergenia ciliata	0.05
Blumea sp.	0.05
Boenninghausenia biflora	0.45
Bryophyte	10.55
Calathea sp.	0.35
Caryopteris grata	0.4
Commelina benghalensis	0.8
Cornus macrophylla	0.05
Cyperus sp.	0.95
Desmodium elegans	0.05
Desmodium triflorum	0.05
Dicliptera sp.	0.5
Dioscorea deltoidea	1.05
Elsholtzia frutescens	2.5
Erigeron karvinskianus	1.45
Eriophorum comosum	1.5

Table 12. Cont.

Specimen	% ground cover/ha
Eupatorium adenophorum	3
Fern	3.4
Fimbristylis dichotoma	0.3
Fragaria indica	0.1
Galium aparine	0.8
Gerbera gossypina	0.15
Justicia sp.	0.05
Lespedeza juncea	0.15
Leucas lanata	0.05
Micromeria biflora	0.1
Myrsine africana	0.6
Oplismenus spp.	1.35
Origanum vulgaris	0.4
Oxalis corniculata	0.05
Pilea sp.	0.75
Pimpinella diversifolia	0.05
Quercus leucotrichophora	0.05
Randia tetrasperma	0.05
Reinwardtia indica	0.4
Rosa moschata	0.05

Table 12. Cont.

Specimen	% ground cover/ha
Roscoea purpurea	0.3
Rubia cordifolia	0.05
Salvia lanata	0.15
Scutellaria scandens	0.05
Senecio nudicaulis	0.05
Smilax spinosa	0.15
Solanum nigrum	0.35
Solanum torvum	0.05
Spiraea canescens	0.05
Strobilanthes atropurpureus	0.9
Symplocos chinensis	0.05
Thalictrum foliolosum	0.75
Themeda anathera	0.75
Verbascum sp.	0.05
Viola serpens	1.8
Vitis himalayana	0.15

Table 13. Average ground cover in the sampled mixed forests.

Specimen	% ground cover/ha
Ageratum conyzoides	0.4
Agrimonia sp.	0.25
Ainsliaea aptera	0.05
Ajuga bracteosa	0.35
Anaphalis royleana	0.7
Anaphalis triplinervis	0.05
Apluda sp.	0.55
Artemisia annua	0.15
Artemisia roxburghiana	0.1
Artemisia vulgaris	0.1
Arundinella bengalensis	1.65
Arundinella nepalensis	0.35
Berberis spp.	0.1
Bergenia ciliata	0.05
Bidens pilosa	0.1
Blumea sp.	0.15
Bryophyte	5.65
Calathea sp.	0.45
Carex sp.	0.25
Coccinia grandis	0.3

Table 13. Cont.

Specimen	% ground cover/ha
Commelina benghalensis	0.25
Cynodon dactylon	0.35
Cynoglossum sp.	0.4
Debregeasia hypoleuca	0.2
Desmodium gangeticum	0.05
Dicliptera sp.	0.8
Dryopteris sp.	0.05
Erigeron karvanskianus	1.95
Eriophorum comosum	3.8
Eupatorium adenophorum	3.45
Fern	1.25
Ficus nemoralis	0.3
Ficus racemosa	0.15
Flemingia bracteata	0.9
Fragaria indica	0.05
Galium aparine	0.25
Galium rotundifolium	0.05
Galium triflorum	0.35
Geranium wallichianum	0.8
Gerbera gossypina	0.05

Table 13. Cont.

Specimen	% ground cover/ha
Gnaphalium sp.	0.45
Heteropogon contortus	3.05
Indigofera heterantha	1.05
Jasminum humile	0.1
Lantana camara	0.25
Leptodermis lanceolata	0.35
Lespedeza juncea	1.65
Lyonia ovalifolia	0.35
Micromeria biflora	0.1
Myrica esculenta	0.05
Myrsine africana	0.05
Oplismenus spp.	0.9
Origanum vulgare	1.75
Oxalis corniculata	0.3
Phyllanthus sp.	0.05
Pimpinella diversifolia	0.75
Pinus roxburghii	0.05
Polygala sp.	0.3
Pouzolzia sp.	1
Pteridophyte	0.05
Reinwardtia indica	0.55

Table 13. Cont.

Specimen	% ground cover/ha
Rhus wallichii	0.3
Roscoea purpurea	1.6
Rubia cordifolia	0.8
Salvia lanata	0.05
Silene sp.	0.1
Smilax spp.	0.25
Spiraea sp.	0.05
Stellaria media	0.15
Sterculia villosa	0.45
Strobilanthes atropurpureus	1.4
Taraxacum officinale	1.1
Thalictrum sp.	0.05
Uraria picta	0.15
Valeriana wallichii	0.1
Veronica cineraria	0.1
Viola canescens	0.05
Vitis himalayana	0.45

Table 14. Average ground cover in the sampled pine forests.

Specimen	% ground cover/ha
Acacia mollissima	0.3
Agrimonia spp.	0.65
Ajuga bracteosa	0.45
Anaphalis triplinervis	0.3
Apluda mutica	0.05
Arisaema tortuosum	0.15
Artemisia vulgaris	0.15
Barleria cristata	0.35
Bergenia spp.	0.15
Bryophyte	3.2
Bupleurum sp.	0.1
Carex sp.	0.2
Caryopteris odorata	0.15
Commelina benghalensis	0.35
Cynodon dactylon	1.2
Desmodium elegans	0.05
Desmodium triflorum	0.7
Desmostachya bipinnata	2.3
Dicliptera sp.	0.1
Dioscorea deltoidea	0.05

Table 14. Cont.

Specimen	% ground cover/ha
Eleusine indica	0.5
Erigeron sp.	0.5
Eriophorum comosum	1.15
Eupatorium spp.	5.35
Evolvulus alsinoides	1.7
Fern	0.35
Flemingia macrophylla	0.1
Flemingia bracteata	1.05
Fragaria indica	0.1
Galium aparine	0.45
Galium rotundifolium	0.05
Geranium wallichianum	0.1
Gerbera sp.	0.05
Indigofera heterantha	1.45
Indigofera sp.	0.35
Leptodermis lanceolata	0.05
Lespedeza gerardiana	0.05

Table 14. Cont.

Specimen	% ground cover/ha
Lespedeza juncea	1.25
Lespedeza stenocarpa	0.15
Leucas lanata	0.3
Medicago sp.	0.25
Micromeria biflora	0.05
Myrsine africana	0.05
Oplismenus spp.	1.05
Origanum vulgare	0.7
Oxalis corniculata	0.3
Pilea spp.	0.5
Pinus roxburghii	0.05
Potentilla microphylla	0.05
Pyrus pashia	0.25
Reinwardtia indica	0.05
Rubus ellipticus	0.05
Sagittaria sp.	0.05
Salvia lanata	0.65
Scutellaria scandens	0.35
Senecio nudicaulis	0.05
Stachys sp.	0.05

Table 14. Cont.

Specimen	% ground cover/ha
Stellaria sp.	0.75
Taraxacum officinale	0.7
Uraria picta	0.35
Valeriana jatamansi	0.05
Verbascum thapsus	0.05
Veronica sp.	0.9

Figure 17. Banj oak forest floor at Jakholi.

Figure 18. Chir pine plot at Ghansali site

Figure 19. The banj oak forest next to a village at BT site showing chir pine trees on its edge.

Figure 20. Shrub like growth form of banj oak at Jakholi chir pine plot

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CHAPTER 4. SOIL ANALYSIS.

Research Problem

The research problem for this component was to compare the soil fertility of banj oak forests with chir pine forests present at the study sites.

H0: The soil of chir pine and banj oak forests are equivalent in terms of major nutrients (N, P, K) and soil organic carbon.

Methods

This was done to understand the impact of banj oak replacement by chir pine on the soil fertility levels at the study sites. A small amount of top soil was collected from all 15 (0.1 ha) plots. These samples were sent to the soil testing lab at CSK HP Agriculture University (Palampur, Himanchal Pradesh) for the analysis of nutrients, organic carbon and pH.

Result and Data Analysis

As can be seen from (Figure 22-Figure 27), except for the Chamba site, at all other sites, the oak forest was richer in terms of soil carbon, nitrogen, potassium and magnesium. Oak was richer than pine at all five sites in terms of phosphorous. Out of the five, at three sites pine was richer in terms of calcium as compared to the oak. There was no significant difference between chir pine and banj oak based on ANOVA in terms of major nutrients (N, P, K) and soil organic carbon. However, since Chamba oak was very different in terms of geographical location as well as soil nutrients, it was treated as an outlier. ANOVA was conducted again after the removal of the Chamba site. The result indicated that the two types of forests were significantly different in terms of nitrogen ($df = 7$, $Error = 6$, $F = 8.16$, $p = 0.03$). However the two types of forests were not found to be significantly different in terms of soil organic carbon ($df = 7$, $Error = 6$, $F = 2.90$,

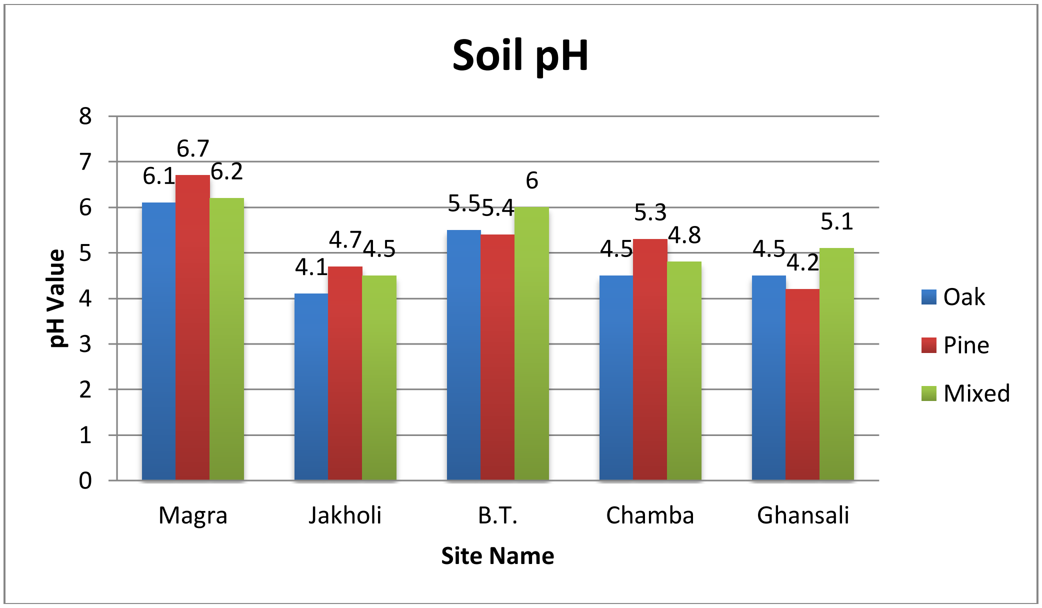

Figure 21: Soil pH values for all 15 (0.1 ha) plots.

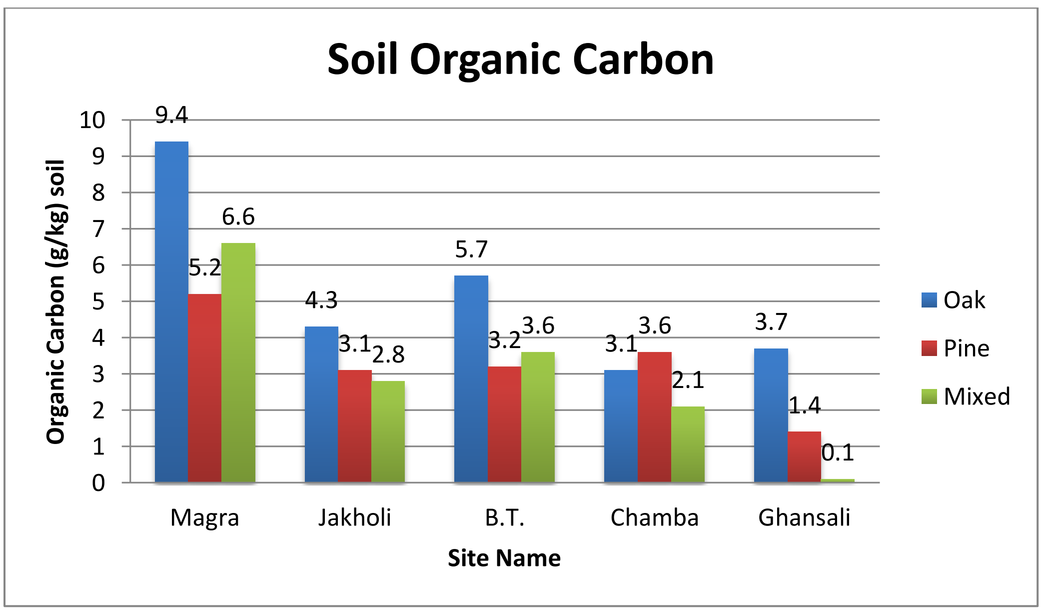

Figure 22: Soil Organic Carbon for all 15 (0.1 ha) plots.

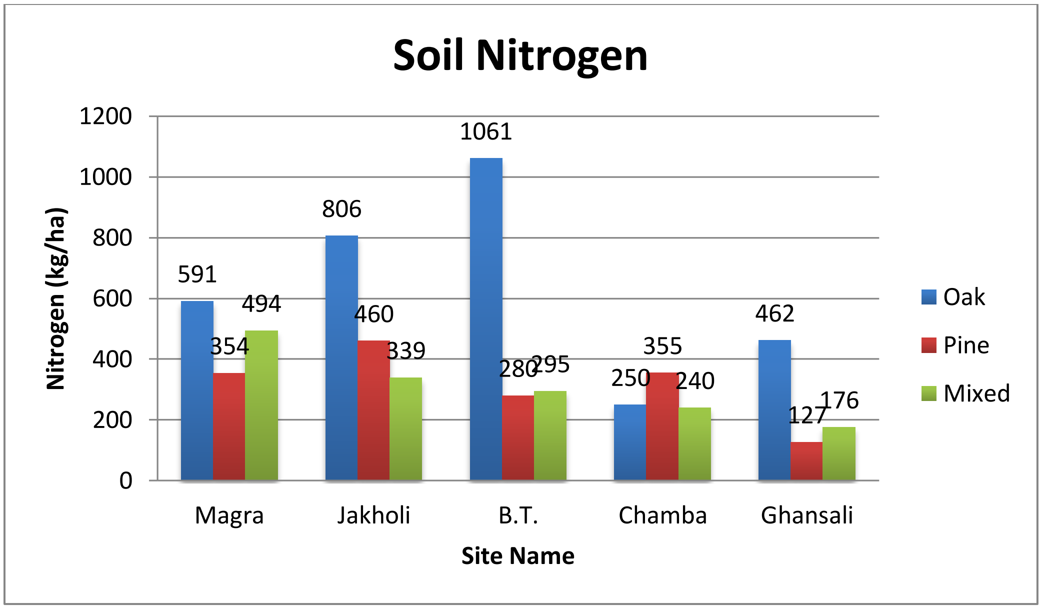

Figure 23. Soil Nitrogen for all 15 (0.1 ha) plots.

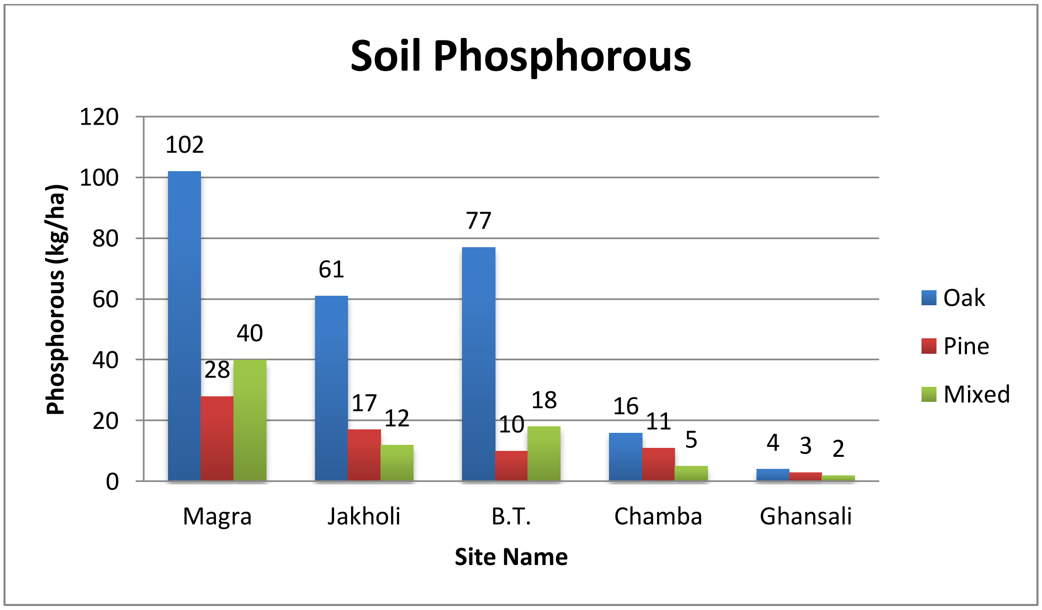

Figure 24. Soil Phosphorous for all 15 (0.1 ha) plots.

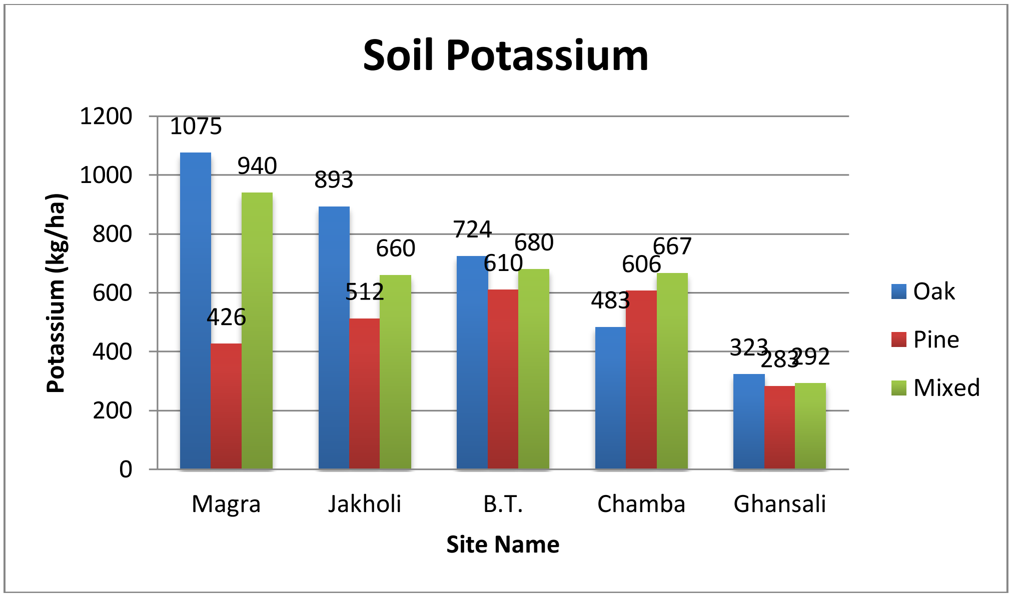

Figure 25. Soil Potassium for all 15 (0.1 ha) plots.

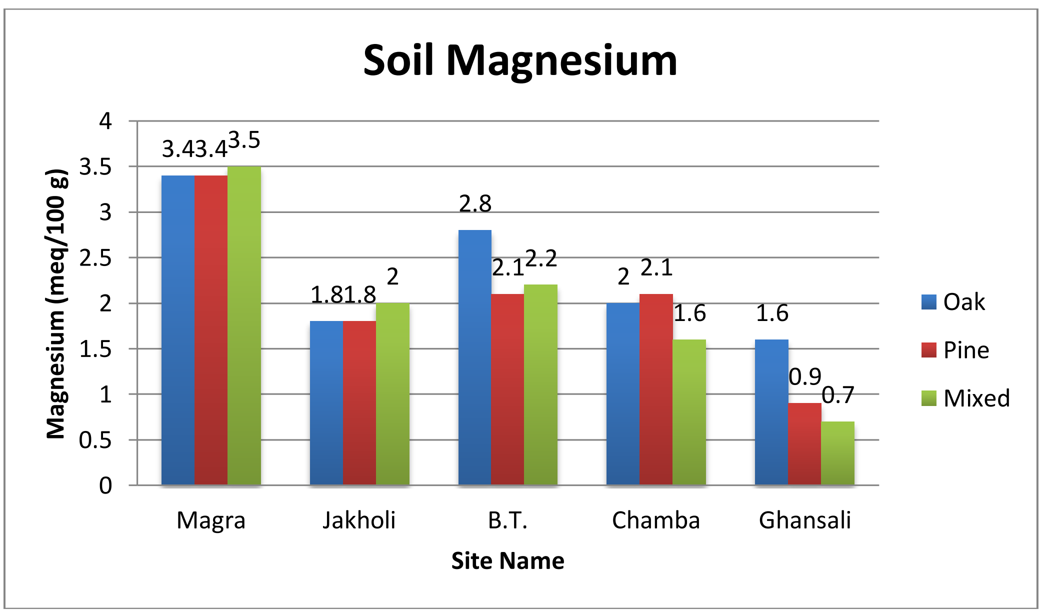

Figure 26. Soil Magnesium for all 15 plots.

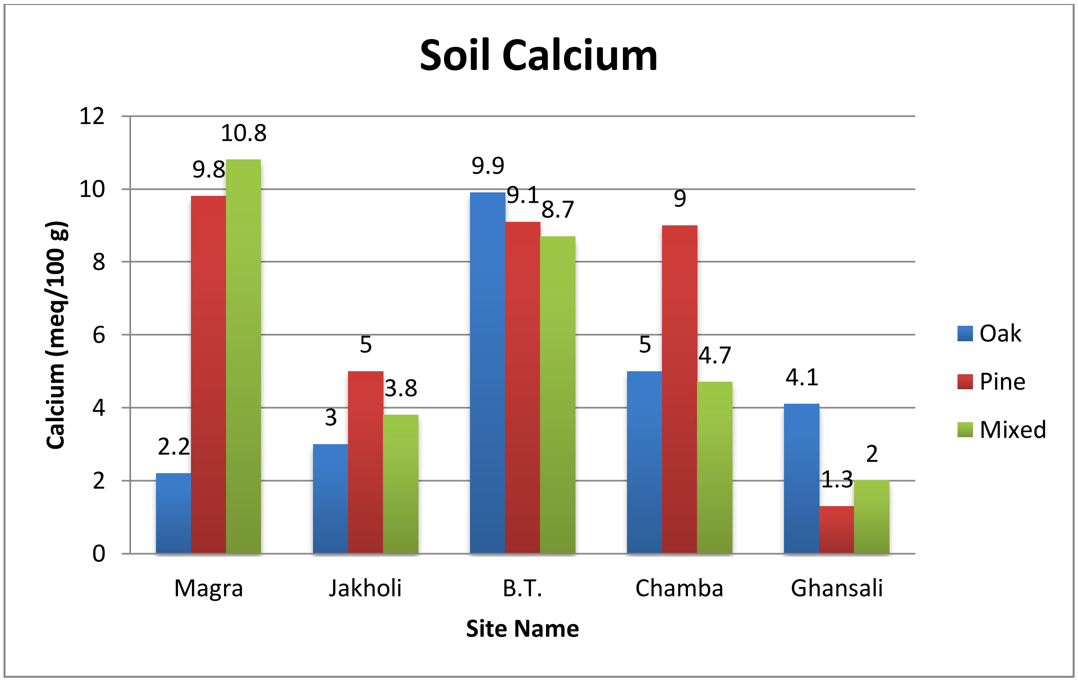

Figure 27. Soil Calcium for all 15 plots.

p = 0.14), phosphorous (df = 7, Error = 6, F = 4.7, p = 0.07) and potassium (df = 7, Error = 6, F = 2.87, p = 0.14).

Conclusions

All the 15 plots had a soil pH in the acidic range, with a pH range of 4.1-6.7. Joshi and Bargali (1992) also indicated that the soil of banj oak and chir pin forests in their study was acidic in nature with a pH range of 5.6-6.3. Banj oak was richer in terms of phosphorous at all five sites and except for Chamba oak. At the remaining four sites, the banj oak forests had higher values of soil organic carbon, nitrogen and potassium. For magnesium, banj oak and chir pine had equal values at Magra and Jakholi sute, whereas banj oak had higher values at Ghansali and B.T. site. And the value was slightly higher at Chamba pine as compared to the oak (2.1 and 2 meq/100 g). The banj oak forest had a higher value for calcium at only two sites, B.T. and Ghaansali. For the remaining three sites, chir pine had higher values as compared to the banj oak. However, based on ANOVA, when compared in terms of major nutrients (N, P and K) and soil organic carbon, the difference between banj oak and chir pine was significant only for nitrogen content (soil organic carbon, nitrogen, phosphorous and potassium). Yet since nitrogen content is significantly different in the banj oak forests as compared to the chir pine, we can reject the second hypothesis (H_0: The soil of chir pine and banj oak forests are equivalent in terms of major nutrients (N,P,K) and soil organic carbon.).

Except for phosphorous, Chamba oak had lower values for all other nutrients as compared to the Chamba pine forests. The reason behind the lower nutrients at Chamba site could be its geographical location. In all other four sites, banj oak was located at a higher elevation than the chir pine forest; however at the Chamba site, the oak forest was in a valley, and the chir pine forest was on the top of a mountain. Also, the chir pine forest at this site was relatively colder and moister than the oak forest, although usually oak forests are at higher elevations than the chir pine and have colder and moister conditions than the pine forest.

The result obtained in this study are similar to the study done by Sheikh and Kumar (2009), who concluded that oak forests had higher soil organic carbon, nitrogen, phosphorous and potassium. In the study done by Joshi and Bargali (1992), the banj oak forest soil was found to be better than chir pine forest in terms of other parameters as well. Joshi and Bargali (1992) mentioned that based on their study, chir pine forest soil had higher bulk density than banj oak. However, for porosity, total nitrogen, organic carbon, water holding capacity and soil moisture, these forests showed reverse trend (i.e., banj oak > chir pine). Joshi and Bargali (1992) quoted Schreven (1967) and Bargali (1990), who indicated that soil moisture affects the microbial activity and thus plays a role in enhancing the rate of decomposition of organic matter. According to Lundegardh (1927) (as mentioned in Joshi and Bargali 1992), lower bulk density and higher porosity are indicators of good soil aeration. Soil aeration includes the downward diffusion of oxygen and upward diffusion of carbon dioxide. Pore space availability also plays role in affecting microbial trophic structure and thus it influences the rates of decomposition and mineralization (Elliott 1980, as mentioned in Joshi and Bargali 1992). Singh and Singh (1986) mentioned that the rate of leaf litter decomposition for the oak forests in the Central Himalaya is higher when compared to the values reported for most of the temperate oak forests, based on work done by Jenny et al. (1949), Shanks and Olson (1961), Witkamp and Olson (1963), Witkamp (1966). Therefore, based on the results obtained in the current study as well as the studies done by various researchers, we can conclude that overall, banj oak forest soil are better than chir pine forest soil in terms of various soil parameters.

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CHAPTER 5. APPLICATION OF DENDROCHRONOLOGY TO DIFFERENTIATE BETWEEN NATURAL VS DISTURBED FORESTS

The research problem of this component was to determine whether the presence of chir pine trees at the study sites is a natural stage of succession or outcome of chir pine encroachment in a banj oak forest.

H0: All the chir pine and mixed stands are natural stages of succession.

Methods

Fifteen cores were collected from chir pine trees located at six plots (chir pine and mixed forests located at BT, Jakholi and Magra). The cores were sanded, and the annual rings were counted for age estimation of the trees at these plots (The detailed procedure for sample preparation has been described in Chapter 6). It was very difficult to count the annual rings on some of the cores, so those samples were not used for age estimation.

Results and Data

The chir pine trees located at the Magra site were older compared to those present at BT and Jakholi. The oldest tree at the Magra mixed plot was 89 years old, and the youngest was 17 years old (Table 16). The oldest tree at Magra chir pine plot was 95 years old, and the youngest was 40 years old. (Table 15) indicates that a majority of the trees present in the plots are towards the larger DBH range, and the trees of smaller DBH range are absent. Therefore, the age of the trees and Figure 14, suggest that this population is probably close to extirpation.

The oldest and youngest trees for the BT mixed plot were 36 and 23, respectively, and that for BT chir pine plot were 27 and 14. For the Jakholi mixed plot, the oldest and youngest trees were 27 and 14, respectively, and for the Jakholi chir pine plot, the oldest and youngest trees were 40 and 16.

Table 15. Tree ring Data Magra Chir Pine Plot, 17th June 2010.

Specimen Name	DBH	Direction	Age
MCPr01	42.2	N	40
MCPr02	37.5	N	68
MCPr03	36.3	N	76
MCPr04	29.5	S	83
MCPr05	36.1	N	84
MCPr06	21	N	70
MCPr07	27	N	61
MCPr08	25	N	58
MCPr09	52	N	77
MCPr10	29.3	N	79
MCPr11	34.6	N	90
MCPr12	50	N	95
MCPr13	27.5	E	82
MCPr14	21.6	E	80
MCPr15	33.3	E	78
Mean = 74.73, Std Error = 3.56			

Table 16. Tree Ring Data Magra Mixed Plot, 17th June 2010.

Specimen Name	DBH	Direction	Age
MMPr01	42	E	56
MMPr02	60.2	E	---
MMPr03	30.5	E	---
MMPr04	28.5	NE	65
MMPr05	27.8	N	48
MMPr06	51.5	N	68
MMPr07	36	NE	61
MMPr08	42	E	89
MMPr09	35.8	E	74
MMPr10	46.2	N	75
MMPr11	44.4	NE	---
MMPr12	42	NE	76
MMPr13	22	E	17
MMPr14	57.2	NE	58
MMPr15	---	---	82
Mean = 51.27, Std Error = 8.09			

Table 17. Tree ring data Badshahithaul Chir Pine Plot, 28th June 2010.

Specimen Name	DBH	Direction	Age
BCPr01	14.8	N	22
BCPr02	20.3	N	18
BCPr03	24	N	20
BCPr04	17.8	E	21
BCPr05	20.3	E	14
BCPr06	19.2	N	14
BCPr07	19.8	NE	24
BCPr08	17.2	N	18
BCPr09	18.7	N	19
BCPr10	21.1	N	23
BCPr11	15.8	N	22
BCPr12	17.4	N	17
BCPr13	18.3	S	22
BCPr14	17.5	N	26
BCPr15	26	N	27
Mean = 20.47, Std Error = 1			

Table 18. Tree ring data Badshahithaul Mixed Plot, 30th June 2010.

Specimen Name	DBH	Direction	Age
BMPr01	21.7	N	35
BMPr02	21.7	N	33
BMPr03	24	N	31
BMPr04	19	N	33
BMPr05	21.9	S	34
BMPr06	16.6	S	34
BMPr07	15.6	S	29
BMPr08	24.6	S	36
BMPr09	19.8	S	33
BMPr10	15	S	28
BMPr11	16.9	N	27
BMPr12	15.1	N	34
BMPr13	16.4	N	23
BMPr14	20	N	35
BMPr15	13.9	S	26
	Mean = 31.4, Std Error = 1		

Table 19. Tree ring Data Jakholi Chir Pine, 10th July 2010.

Specimen Name	DBH	Direction	Age
JCPr01	20.8	SE	21
JCPr02	28.7	S	25
JCPr03	26.5	N	24
JCPr04	30	N	27
JCPr05	38.5	N	40
JCPr06	26.5	NW	26
JCPr07	34	SE	27
JCPr08	24.7	SW	24
JCPr09	26	SW	16
JCPr10	28.7	SE	27
JCPr11	23.3	NW	19
JCPr12	23	NW	25
JCPr13	21	SW	19
JCPr14	38	SW	35
JCPr15	19	S	24
Mean = 25.27, Std Error = 1.56			

Table 20. Tree ring Data Jakholi Mixed Plot, 11th July 2010.

Specimen Name	DBH	Direction	Age
JMPr01	16.9	N	16
JMPr02	21.4	N	24
JMPr03	36.4	N	25
JMPr04	22.9	N	21
JMPr05	21.4	N	24
JMPr06	28.5	N	26
JMPr07	26.2	N	21
JMPr08	29.2	S	27
JMPr09	16.2	S	21
JMPr10	29	---	26
JMPr11	21.4	N	20
JMPr12	25	N	20
JMPr13	---	---	--
JMPr14	11	N	14
JMPr15	24	N	14
Mean = 19.93, Std Error = 1.79			

Conclusions

Since a mixed forest with both chir pine and banj oak is also a stage of succession, and chir pine is a native species, some people deny that the chir pine is replacing the banj oak. All fourteen trees from Jakholi mixed plot were less than 30 years old, with the average age being just about 20 (Table 20). The mixed plot at Jakholi was located at the edge of an old oak forest. Since this oak forest was definitely more than 30 years old, it cannot be a stage of succession at all, because in order to be a normal stage of succession, the oak trees should be younger than the pine trees.

Also, according to the local people, the plot which was sampled for chir pine at the Jakholi site used to be an oak forest. Out of the 15 trees that were used for age estimation, only one was > 30 years at 40 years old and the average age was about 25 (Table 19). This site had many oak plants with coppice growth, which made them look like shrubs (Figure 20). Since the trees at this site were so young, it is not possible that it was getting transformed into a mixed forest. Also, since the forest had a very open canopy, as the trees were very young, this forest does not seem to be suitable for oak establishment (although banj oak seedlings do require some amount of light availability, this site had too much exposure to light). The shrub like growth form of banj oak could be remnant of an earlier existing banj oak forest at this site. The only other possibility which justifies the presence of banj oak plants in this young chir pine forest is if the oak plants were planted in this forest. The Ghansali mixed plot also had the coppicing growth form of oak. Therefore, a higher number of banj oak stems in the 25 m^2 plots in some of the forest plots cannot be considered as indicative of good growth of this species.

All of the trees at BT chir site were <30 cm in DBH and the average age was just 20.47, so what was there before these trees? Remote sensing data could be useful to answer such questions, but unfortunately such data is not freely accessible, and how much remote sensing data from the past exist for this region is also questionable. Based on visual observations as well as dendrochronology data, some of the mixed forests were evidently an outcome of human disturbances, and therefore they were not a natural stage of succession. Therefore, we can reject the null hypothesis (H_0: The mixed forest is a natural stage of succession).

The banj oak forests are already in very small patches in a majority of this region. If the current trend continues, these forests will keep shrinking. There is need of serious efforts in conservation of banj oak forests, which cannot be done without the help and cooperation of the local people.

There are limited studies done in the field of dendrochronology in India. Dendrochronology can be very helpful in differentiating natural mixed forests from the oak forests which have been encroached by the chir pine trees. This can further help in developing remedial strategy for restoration of natural forests.

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CHAPTER 6.GROWTH RESPONSE OF EARLYWOOD AND LATEWOOD RING WIDTH TO PRECIPITATION IN THE HIMALAYAS IN *PINUS ROXBURGHII*

Introduction

Dendrochronology, or tree-ring dating, is the most accurate and precise dating method in geochronology (e.g., Fritts 1976, Stahle et al 2015). Dendroclimatology, or the use of dated tree-ring chronologies to study the effect of climate on tree growth, is an important and reliable tool that can also help us to understand the climate of the past (Fritts 1966). Tree-ring analysis can also help identify the tree growth response to climatic factors. Based on his research, Fritts (1966) concluded that the correlation between ring width and climate can be explained by valid biological processes, as the initial food manufacturing processes are controlled mainly by climate. However, dendroclimatology also has some limitations. For example, it is only feasible in those species that produce annual growth rings. Also, tree-ring widths should be sensitive (i.e., high interannual variability), since complacent rings of similar width are difficult to accurately date and may not be useful for dendroclimatology. Douglas (1941) indicated that in the absence of sensitivity, there are no ring width patterns and thus the crossdating involved in dendrochronology based on pattern recognition may not be feasible. Moreover, if there is no crossdating, then the specimens are not useful for a climatic study. According to Douglas (1941), "Crossdating is the recognition of the same ring pattern in different trees, so that the actual growth date of any one ring of the pattern is the same in the different trees and one may carry chronology across from tree to tree."

Borgaonkar (1999) mentioned that Chowdhury (1939, 1940a, b) was the pioneer for tree-ring research in India. However, there was no further work in this field in India until the late

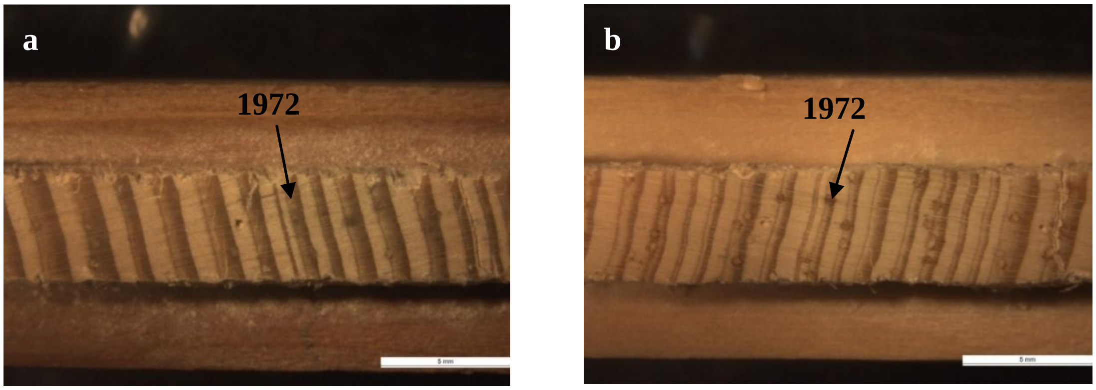


Figure 28. These photographs display cores extracted from two different trees at the Hulanakhal site in India. Both cores exhibit a narrow ring in 1972, suggesting a common climate control on tree growth at this location. Note the prominent latewood bands and the sharp transition from earlywood to latwood in both cores.

1970s. He further added that Pant (1979, 1983) was the first to carry out successful studies in the field of dendroclimatology for the Indian region.

Climate change is one of the biggest concerns of present era. Climate change may not be unidirectional when it comes to precipitation. It is projected to alter not only the drought frequency as well as magnitude but also the frequency and magnitude of the floods. Based on the few studies done so far, it has been suggested that flood hazards will affect more than half of the world. India is one of those countries that will especially be affected by flood hazards (IPCC 2014).

The floods witnessed in the Himalayan region during the monsoon season of 2013 and 2014 may provide some preliminary support to this prediction. Since this Ph.D. research project was concerned mainly with the expansion of chir pine at the cost of banj oak, it is important to understand the degree to which chir pine growth might be affected by climate variability and possibly by climate change. It would have been ideal if we could also study the impact of climate variability and change on banj oak, but banj oak does not appear to produce reliable annual growth rings and therefore could not be used in a tree-ring analysis of climate response.

Annual growth rings in many species of temperate latitude trees, especially conifers, contain two subannual ring components, the earlywood (EW) and latewood (LW) bands (Figure 28). The latewood cells are often more lignified and thus appear darker than the earlywood. Extensive phenological analyses of chir pine growth have not been widely published, but the EW band in chir pine probably develops during the spring and early summer season whereas the latewood band likely forms during the summer-monsoon season. In order to understand the impact of cool and warm season precipitation on earlywood and latewood growth, this project developed separate chronologies of earlywood and latewood width using the methods to separate the two subannual growth bands in the manner described by Schulman (1942) and Stahle et al. (2009).

Few tree-ring chronologies of chir pine have been developed or made publically available, and apparently none exist for earlywood and latewood in chir pine. Although Bhattacharyya et al. (1992) recommended the use of earlywood and latewood ring widths in chir pine as potential tools for deriving climatic information, no research on these subannual ring components has been published for this species.

All available chir pine chronologies represent total ring width. In fact, thus far, there are no records of earlywood and latewood data for any tree-ring collections from India [based on 23 different datasets submitted on NOAA (National Oceanic and Atmospheric Administration)]. Only seven collections of chir pine chronologies have been submitted to NOAA, NCDC (National Climatic Data Center) thus far. Out of these seven, two are from India, three from Nepal and two from Bhutan.

During this research project, dendrochronology was used for two purposes. First, age estimation of trees present at the vegetation sampling sites was carried out in order to find out whether the presence of chir pine trees in the mixed forest is a natural stage of succession or may be a consequence of human disturbances. The data and conclusions regarding age estimations of chir pine trees present at the study sites were discussed in the Chapter 2. Second, dendrochronology was used to understand the growth response of chir pine to cool and warm season precipitation and the potential impact of climate variability and change on chir pine growth.

The following research questions were investigated during this tree-ring analysis.

1. Is there any difference between climate response of earlywood and latewood in chir pine at three study sites in the Himalaya of India, Nepal, and Bhutan?

   H_0: There is no difference between climate response of earlywood and latewood at any of the study sites.

2. Does the climate response of earlywood and latewood width in chir pine vary from one site to another?

   H_0: The climate response of earlywood and latewood width in chir pine is site specific.

3. On average, do earlywood and latewood width constitute equal proportions of total annual ring width in chir pine at the three study sites? In other words, do earlywood and latewood have same importance in terms of total annual radial growth?

   H_0: There is no significant difference between the proportion of earlywood and latewood width.

4. Once the climate response of earlywood and latewood width have been defined for chir pine, will predicted climate change tend to favor or retard chir pine growth?

H_0: Chir pine EW or LW growth will likely not be strongly affected by predicted climate change.

In order to answer these research questions, earlywood and latewood components of chir pine cores from three different sites, located in India, Nepal and Bhutan, were measured and analyzed. KNMI, an online analytical tool made available by the Royal Netherlands Meteorological Institute was extensively used for the statistical analysis of the precipitation signal in EW and LW width of chir pine at the three study sites (http://climexp.knmi.nl/).

Study Area

As part of my Ph.D. project, this study was conducted in the Central Himalayan region of India, and cores were collected from Hulanakhal, Uttarakhand, India (HKP, 34.41° N and 78.77° E, 2050 m). The nearest large town was Ghansali. Uttarakhand is one of the Himalayan states, and a majority of its area is in hills or mountains. The glaciers in Uttarakhand state are very important, as they are source of major rivers like the Ganga and the Yamuna. Uttarakhand is also politically important since it shares its border with Tibet and Nepal.

In order to enhance the reliability of the result and to obtain a better representation of the chir pine species, cores from Bhaktapur, Nepal (BAT) and Kalipang, Bhutan (KLP) were obtained on loan from Dr. Edward R. Cook (Lamont-Doherty Earth Observatory, Columbia University, New York). The aerial distance between Hulanakhal and Bhaktapur is 677 km and that between Bhaktapur and Kalipang is 561 km. Therefore, the sites are separated by 1238 km (Figure 29). Based on the coordinates provided by the original contributors (P. J. Krusic and R. Zuber for Nepal and E.R. Cook.; P. J. Krusic.and D. Dukpa for Bhutan) on the NOAA website, Kalipang (27.18° N, 91.2° E) is located towards the eastern part of Bhutan with Phrumsengla

National Park to its west, and Bhaktapur (27.45° N, 85.15° E) is located southwest of Nepal's capital, Kathmandu, and east of Chitwan National Park.

The most difficult problem in using chir pine from the Central Himalayan region for dendrochronology is the heavy exploitation of trees for commercial resin extraction. Frequent fires further worsen the situation (Figure 30). The fires in the forests of this region are usually not natural but instead are human induced. Local people often set fire to the chir pine forests because it tends to result in more grass production after the monsoon rains. The trees used for resin extraction have deep wounds and cavities, and thus they are more prone to damage by fire as compared to unexploited trees, as chir pine is a fire tolerant species. Although the modern Rill method of resin extraction is less damaging as compared to the traditional Cup and Lip technique, many trees have huge cavities in their boles due to previous extractions, some as deep as their pith. These damaged and heavily exploited trees are unsuitable for accurate dendroclimatology purposes, as there tends to be too much noise in the ring width data collected from such trees.

Trees growing in colder areas produce less resin than the warmer areas (Tewari 1994). Therefore, chir pine forests present in colder areas are less valuable for commercial resin extraction. Thus the colder, less exploited forests were the only areas that could be utilized for core extraction. The Hulanakhal site, being at an elevation of 2050 m, was relatively cold even during the summer, and chir pine was present along with other species such as *Quercus leucotrichophora* (banj oak). The monodominant stands of chir pine are more prone to fire. Therefore, although there were signs of fire, the chir pine trees were relatively less disturbed at the Hulanakhal site.

Figure 29. The location of all three tree core sites on the map. (Source: Google Earth, Landsat Imageries, 4/9/2013. Accessed on 3/31/2015).

Figure 30. Trees at Moolgarh (Ghansali chir vegetation sampling plot) were heavily damaged due to resin extraction and fire.

Methods and Data

A total of 263 tree cores were collected during the summers of 2010, 2011 and 2012. Of these, 90 tree cores were extracted in the summer of 2010 with the use of Swedish increment borers. Fifteen cores were collected from chir pine plots, as well as from mixed plots at three (B.T., Jakholi and Magra) of the five sites that were sampled for vegetation. These cores were used to obtain an age estimate of the trees present inside the plots for dendroecological purposes and, therefore, these data have been included in the chapter on vegetation sampling (Chapter 2). The remaining cores were collected mostly from three different sites during 2011 (81 cores) and 2012 (92 cores). However, only the cores from Hulanakhal, Uttarakhand, were used for dendroclimatology purposes, since this was the only site which was relatively less disturbed and had trees >45 cm in diameter. Also, the tree-ring series from this site were usually sensitive (Figure 31).

The cores collected in the field were stored in plastic straws, with the open ends of the plastic straws sealed with masking tape. On each straw, the date of sample collection, the DBH of the sampled tree, the direction from which the core was collected and a unique core identification number were recorded based on the site, species and sample number. For example, HKPr01 stands for sample number one from the Hulanakhal site, and the species is *Pinus roxburghii.* Usually, two cores were collected from the same tree from opposite directions. The collection of two cores is helpful for dendrochronological dating because occasionally there can be a locally absent ring which might not be visible in one core but can be seen in the other core from the same tree. Two cores are therefore helpful in confirming the dating and/or identifying problematic rings or false rings. It was noticed that in some cases, one core sample had a better climate signal than the other from the same tree. Therefore, it is suggested that two cores be

Figure 31. The Hulanakhal (2012) collection site was relatively less disturbed and had chir pine trees along with broadleaved trees.

collected from each tree whenever possible. An attempt was made to avoid core sampling from the uphill and downhill sides of the tree to avoid reaction wood.

The cores were glued on wooden mounts, and all the information related to the core was labeled on the wooden mount. After this, the cores were sanded. After sanding, the tree-rings were counted using a stereomicroscope, and the chronologies were developed on skeleton plots. A master chronology was developed and, with the help of the master chronology, other tree cores from the Hulanakhal (2012) collection were cross-dated. Most of the procedures used followed those described by Stokes and Smiley (1996). There were 62 tree cores in the Hulanakhal (2012) collection. Out of these, 46 could be cross-dated. Following this, the earlywood, latewood and total ring widths were measured to a precision of 0.001 mm with the use of a stereomicroscope, a stage micrometer measuring machine and the software program pjk10v10e (Paul Krusic, personal communication). The ring width series for earlywood, latewood and total ring width of chir pine cores from Nepal and Bhutan were also measured.

The thin-walled cells of earlywood and the thick-walled cells of latewood are clearly distinguishable (Schulman 1942). However, this species often produces false rings which also have thick-walled cells like the latewood and thus makes crossdating and measuring challenging (Figure 32). Since there is a sharp termination of the latewood of an annual ring before the earlywood growth of the next year’s annual ring (which is not usually the case with false rings), the false rings can be differentiated from the actual annual rings by close observation and/or with the help of crossdating.

To avoid discrepancies in measurements, the three criteria mentioned by Stahle et al. (2009) were followed. These are listed below.

1. When an abrupt boundary defines the transition from earlywood to latewood, the measurement is made at that boundary.
2. If the transition between earlywood and latewood is gradual, pure earlywood and latewood zones are identified and the transition zone is distributed equally between earlywood and latewood by making measurement at the midpoint of the transition zone.
3. When false rings are present, the measurement is made at the first lignified latewood-like cell. This means that the false ring as well as the remaining portion of the annual

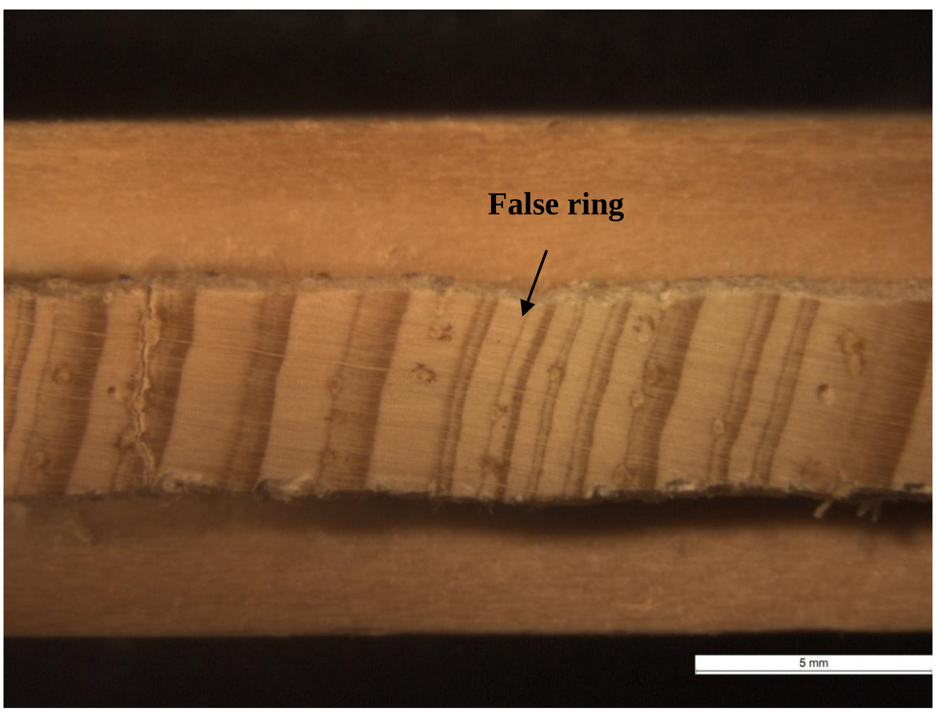


Figure 32. This Hulanakhal 2012 sample shows various false rings.

growth ring after the false ring is measured as latewood.

Chowdhury (1939) indicated that the presence of these layers (false rings) is possibly due to some irregularities in normal growth conditions. He supported this opinion by giving examples of three tree specimens he studied from 1931-1933, mentioning that the trees showed the presence of false rings in 1932 and 1933 but not in 1931. He noticed that the difference between the temperature and humidity was not enough to account for the presence of this phenomenon in 1932 and 1933 but not in 1931. However, the rainfall data showed some interesting results.

In 1931, rainfall from May to August was 44.98 inches (1143 mm), and the cells formed from May onwards to the end of the growth season were uniformly thick-walled. On the other hand, rainfall from May to August in 1932 and 1933 was 70.93 and 87.38 inches (1802 and 2219 mm), respectively, and in these two years, thick-walled cells were produced from the middle of May to the end of June, followed by thin-walled cells during July and August, and again thick-walled cells from September to the end of the growth season. The author suggested that there might be a relation between the formation of thin-walled cells during July and August and the higher rainfall during these two months of 1932 and 1933.

Brauning (1999) investigated the dendroclimatological potential of drought sensitive trees growing in the Yarlung Tsangpo River catchment area located in Southern Tibet. He indicated the presence of intra-annual bands (false rings) in *Pinus densata* in the westernmost stand. He also mentioned that the discontinuous distribution and the synchronous occurrence of intra-annual growth bands (false rings) in multiple trees suggest that unfavorable conditions could be the reason behind their formation. He further mentioned that the false rings occurrence is lower during the period of suppressed growth and therefore, the false rings can be useful in getting information about climatic events, especially when the climatic conditions are not extremely harsh. When the false ring was present in the transition zone of earlywood and latewood, the author noticed a negative precipitation anomaly in May and especially June.The author mentioned that higher temperature in June indicates reduced cloudiness and increased insolation, which could have resulted in drought conditions. This drought stress would have resulted in false ring formation. Climate data indicates an above average amount of rainfall in July, which resulted in earlywood type cell formation following the false ring and before the latewood formation. He suggested that the presence of false rings indicates the delayed arrival of monsoon in southern Tibet during corresponding years. Brauning's (1999) research is very interesting, but the conclusions drawn for *Pinus densata* in Tibet are very different from the conclusions I drawn from *P. roxburghii* in the Himalaya (see below), and may arise from differences in the precipitation climatology of the arid site in Tibet and the relatively moist sites in the Himalya.

Brauning (1999) found strong correlation between his tree-ring data and August to October precipitation. He indicated that in his study he could not calibrate tree-ring growth and climate data in the usual manner because the metereological data was available for only a short period of time. In addition, there is low spatial representativeness in terms of moisture conditions. Therefore, Brauning (1999) used only simple correlation and other tests for his study. He used climate data from six different meteorological stations. The longest time span among the data series he used was 1941-1990, and the shortest was 12 years (1980-1992). The limitation of climate data was one of the challenges faced during my own research project as well.

After the measurement of ring widths, COFECHA (Holmes 1983) and ARSTAN (Cook and Krusic 2005) were used to analyze the tree-ring width data. COFECHA provided information about the dating and measurement of the individual ring width series and was helpful in fixing the dating errors and the removal of problematic segments. Table 21 provides some of the important information obtained from COFECHA for all three sites.

With the help of ARSTAN, de-trending and standardization of the tree-ring series was conducted in order to remove “non-climatic” growth trends and fluctuations (Cook 1985). The correlation between earlywood and latewood standard chronologies produced by ARSTAN was calculated. The results showed there was a very low correlation between the earlywood and latewood ($R = 0.19$, Figure 33) in Hulanakhal. Therefore, in this case the latewood was considered largely independent of the earlywood.

The correlation between earlywood and latewood standard chronologies (produced by ARSTAN) was also calculated for both Bhaktapur as well as Kalipang, and they were found to be 0.57 and 0.67, respectively (Figure 34, Figure 35).

In order to observe the impact of summer precipitation on latewood formation, the correlation between earlywood and latewood needed to be removed. Following Meko and Baisan (2001), a bivariate regression of latewood on earlywood was computed. The residual LW values from this bivariate regression were considered as adjusted latewood and used in order to find the discrete LW growth response to summer precipitation after the removing the correlation with EW, which primarily reflects winter/spring precipitation.

It was possible that the trees at Hulanakhal site lacked correlation between earlywood and latewood, since they were much younger as compared to those at the Kalipang site. In order to check whether the age factor was responsible for this low correlation, the correlation was calculated for the first 120 years (the same length as the Hulanakhal site) of the Kalipang series

Table 21. Information about the tree-ring series obtained from COFECHA.

Site Name/ Parameter	HKP Earlywood	HKP Latewood	BAT Earlywood	BAT Latewood	KLP Earlywood	KLP Latewood
Number of dated series	42	42	13	13	47	47
Master series	(1892-2011) 120	(1892-2011) 120	(1882-1996) 115	(1882-1996) 115	(1650-2003) 354	(1650-2003) 354
Total rings in all series	3276	3276	1190	1190	10259	10120

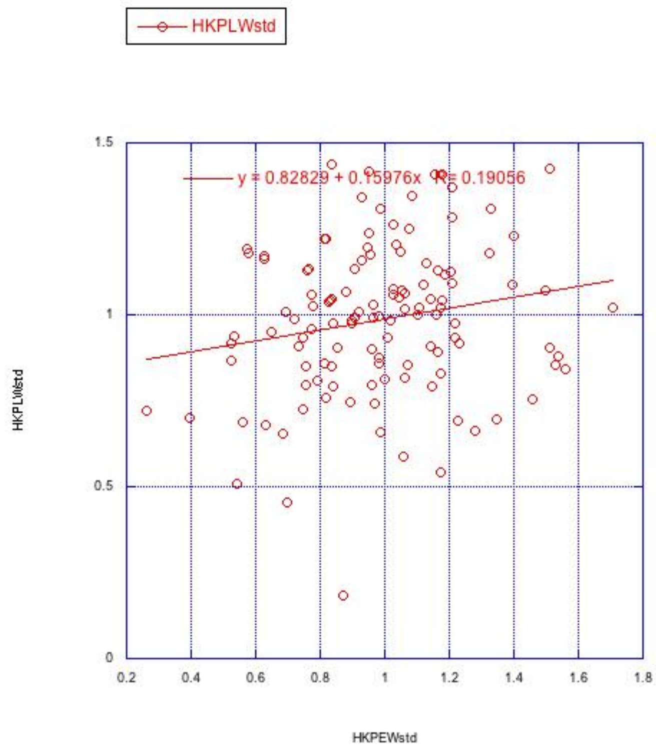


Figure 33. Correlation between earlywood and latewood in Hulanakhal *Pinus roxburghii*.

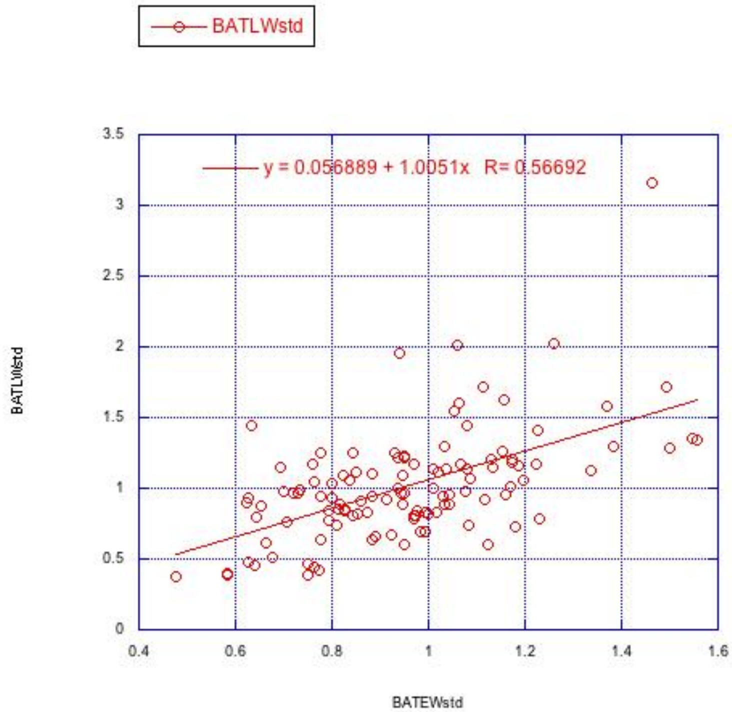


Figure 34. Correlation between earlywood and latewood of Bhaktapur *Pinus roxburghii*.

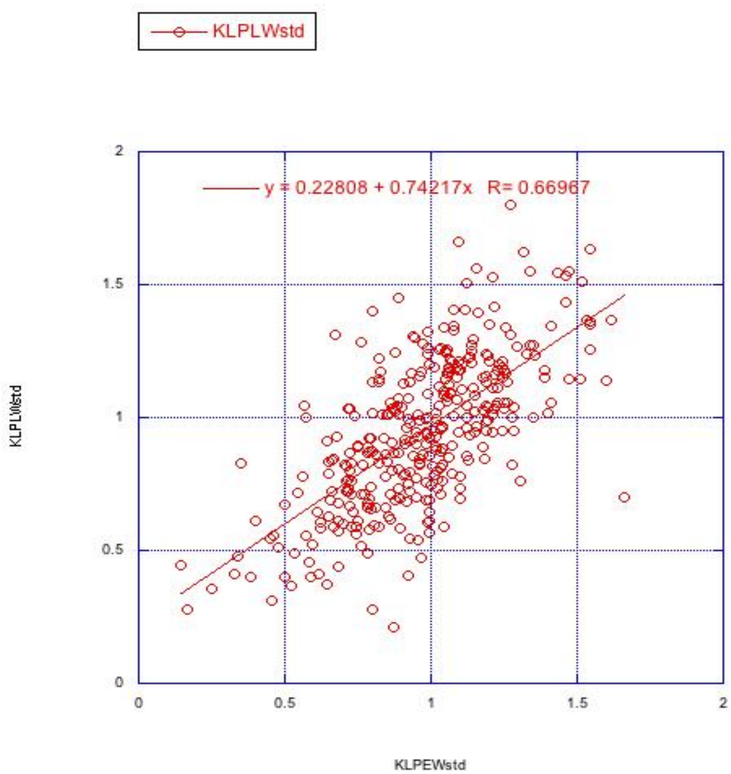


Figure 35. Correlation between earlywood and latewood of Kalipang *Pinus roxburghii*.

(1650 to 1770). The correlation was 0.56, which was still much higher as compared to the Hulanakhal site (R = 0.15). For Kalipang, the 1700 to 1820 time period was also chosen, since there was a larger number of series in this time range. This further increased the correlation to 0.66. Therefore, we can reject the assumption that the younger age could be the reason behind the low correlation between earlywood and latewood at the Hulanakhal site, since neither the young trees at Bhaktapur nor the younger age of trees at Kalipang site showed a similar pattern.

ARSTAN did not produce a residual chronology for the Hulanakhal site, which indicates a low autocorrelation within the series, and, as already mentioned, the earlywood and latewood had a very low correlation. Therefore, for this site, the standard earlywood and standard latewood chronologies were uploaded to KNMI to analyze the correlation between precipitation and tree-ring series.

For the Bhaktapur (Nepal) and Kalipang (Bhutan) samples, residual chronologies were produced by ARSTAN. In order to avoid the impact of autocorrelation, residual ARSTAN chronologies were used on KNMI for the earlywood of Nepal and Bhutan sites, and the adjusted latewood chronologies as explained before were used for both Nepal and Bhutan in order to calculate the correlation between the tree-ring series and precipitation for these two sites .

The CRU TS3.22 (land) precipitation dataset was chosen at 0.5° grid points for analysis on the KNMI Climate Explorer. The CRU TS3.22 precipitation dataset was available from 1901 to 2013. Although the chronologies from all three sites began before 1900, that portion of the chronologies could not be correlated with precipitation due to the lack of precipitation data before 1900. The earlywood correlation with winter and spring months was tested, and the latewood correlation with pre-monsoon and monsoon months (summer months) was tested using the KNMI Climate Explorer, where the sign and magnitude of correlation between the precipitation and tree-ring data were isoplethed and mapped.

The correlation between tree-ring series and precipitation declined if the period after 1970 was included. This decline in correlation appears to be due to the loss of nearby weather recording stations available for the CRU TS3.22 precipitation dataset. In order to find the reason behind the decline in correlation after 1970, the monthly stations (with at least 10 years of data) within a few degree latitude and longitude around the sites were searched on KNMI (GHCN-M (all) option was chosen). For Hulanakhal (30.41°, 78.77° 2050 m), monthly weather stations between 30°-31°, 78°-79° were searched. Out of 11 stations found, none of the stations contributed to any data after 1970.

For Bhaktapur, Nepal (27.45° N, 85.15° E, 1320 m, P. J. Krusic and R. Zuber), 16 stations were found within 27°-28° and 85°-86°. All these stations were located in Nepal. Out of the 16 stations, only one (Kathmandu) had data before 1970 (1951-2014) and the remaining had data from 1971 to 1990. Therefore, a larger range was chosen to find stations with data prior to 1970. Coordinates 26°-28° N and 84°-86° E resulted in 62 stations. 22 were located in Nepal, and of these, only Kathmandu had data before 1970 while the remaining had data from 1971-1990. All the remaining 40 stations were in India, none of them had data beyond 1970 except Darbhanga (1875-1996). Therefore, the majority of data contributing stations between 26°-28° N and 84°-86° E had data only until 1970. While1900-1990 could be chosen for Nepal, since there was data available beyond 1970, 1900-1970 was chosen for measuring the correlations between tree data and precipitation data in order to maintain consistency between all three sites. Also, as mentioned before, majority of the stations did not contribute the data beyond 1970.

For Kalipang, Bhutan (27.18° N, 91.2° E, E. R. Cook.; P. J. Krusic.and D. Dukpa), only one station was found within 27°-28° N and 91°-92° E, and that station's precipitation data was not displayed on the KNMI website. Therefore 26°-28° N and 90°-92° E were chosen for the search. Out of 19 stations that were found within these coordinates, only one (Gauhati, Assam-1848-2015) had data beyond 1970. All of these stations were located in India. Therefore, for the analyses of the seasonal precipitation response of EW and LW at the three sites locations in India, Nepal, and Bhutan, only the period 1900 to 1970 was used.

The correlation between the earlywood (EW) and latewood (LW) chronologies among all three sites was also calculated to see whether these sites are intercorrelated and whether they can be used to compute regional average for EW or LW growth, but none of the sub-annual ring width chronologies correlated between the three sites.The summary of calculated correlations is provided in (Table 22).

Table 22. Correlation between tree-ring series of all three sites.

Series used and time period	Correlation
EW (HKP) vs EW (BAT)-1892-1996	0.04
EW (HKP) vs EW (KLP)—1892-2003	0.07
EW (BAT) vs EW (KLP)-1882-1996	0.07
LW (HKP) vs LW (BAT)-1892-1996	0.02
LW (HKP) vs LW (KLP)-1892-2003	0.14
LW (BAT) vs LW (KLP)-1882-1996	0.04

Finally, regional precipitation data for the latitudes and longitudes encompassing the sites were extracted from the CRU TS3.22 precipitation dataset using the KNMI Climate Explorer. These extracted precipitation data were used to make monthly and seasonal total precipitation time series for each tree-ring sampling region. These regional precipitation series were used to compute the correlation value between precipitation and EW and LW growth.

Results

The monthly precipitation data (CRU TS3.22 {land} dataset at 0.5° grid points) were significantly correlated with the earlywood and latewood chronologies at all three sites during the period of 1900-1970. However, it was interesting to notice that the correlation was positive between earlywood and winter/spring precipitation, whereas latewood was negatively correlated with summer precipitation for all three sites. Figure 36-Figure 38 were generated by the KNMI Climate Explorer show the correlation between tree-ring data and precipitation.

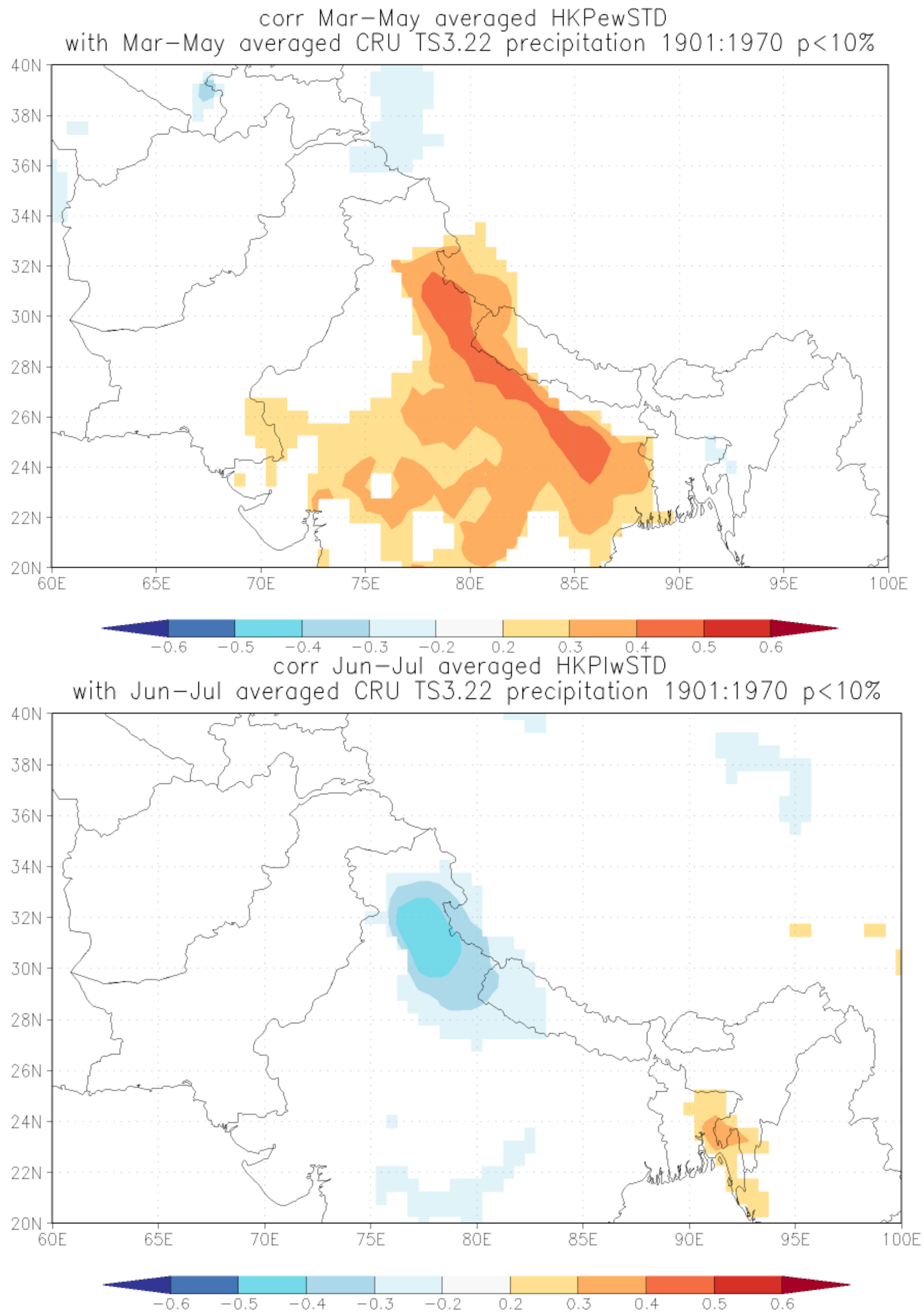
Numerous studies that include earlywood and latewood measurements have been carried out on a variety of tree species in different countries. However, an antagonistic precipitation signal between EW and LW from the same trees has apparently not been documented prior to this research (e.g., Schulman 1942; Hughes et al. 1994; Wimmer and Grabner 2000; Meko and Baisan 2001; LiuYu et al. 2004; Campelo et al. 2006; Vieira et al. 2009; Stahle et al. 2009; Griffin et al. 2011; Michelot et al. 2012). Several studies have been carried on different species of *Pinus,* and in these, earlywood as well as latewood were in agreement in terms of their correlation (usually positive) with precipitation. Examples include the study by Campelo et al. (2006) on *Pinus pinea* in Portugal, Schulman (1942) on *Pinus echinata* Mill. in Arkansas in the United States, Hughes et al. (1994) on *Pinus armandii* in China, LiuYu (2004) on *Pinus tabulaeformis* in Inner Mongolia, Vieira et al. (2009) on *Pinus pinaster* in Portugal), United

States, and Michelot (2012) on *Pinus sylvestris* in France, and Griffin et al. (2013) which includes *Pinus ponderosae* from Arizona and New Mexico, United States.

The pre-monsoon and initial monsoon months with a sudden increase in precipitation amount showed a more negative influence on chir pine than the later monsoon months (Figure 39). Since chir pine is a light-demanding species, we hypothesize that the negative correlation of latewood with summer precipitation could be due to light limitation during the pre-monsoon and monsoon rains in this region.

This is opposite to the conditions prevalent in the study done by Brauning (1999), where the decreased cloudiness resulting in increased insolation was considered to be negatively affecting the species of pine (*Pinus densata*) examined. In this study, the cloudy conditions resulting in reduced insolation could be the reason behind the negative correlation between the latewood and precipitation during pre-monsoon and early monsoon months.

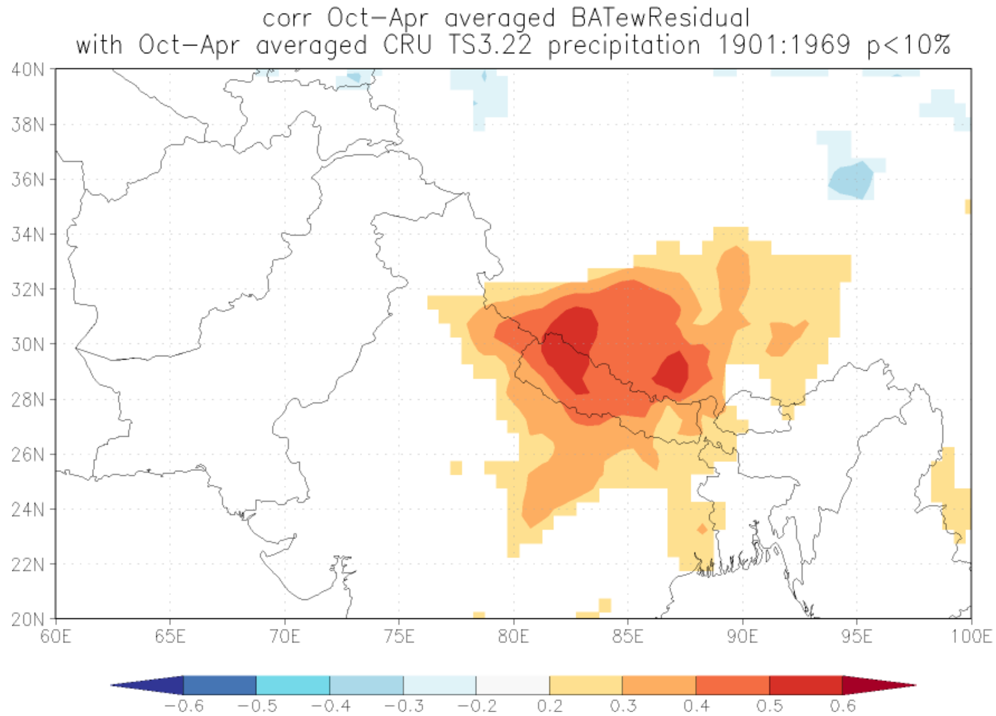
The highest correlation values between the precipitation data from the latitude and longitude encompassing the site and tree-ring series are summarized in (Table 23) and can be observed in the form of graphs (Figure 40-Figure 45) as well.



a.

b.

Figure 36. (a) Hulanakhal earlywood correlation with precipitation.(b) Hulanakhal latewood correlation with precipitation. The scale below the figures indicates the ranges of correlations in terms of colors. The colors on the map display those correlation ranges.



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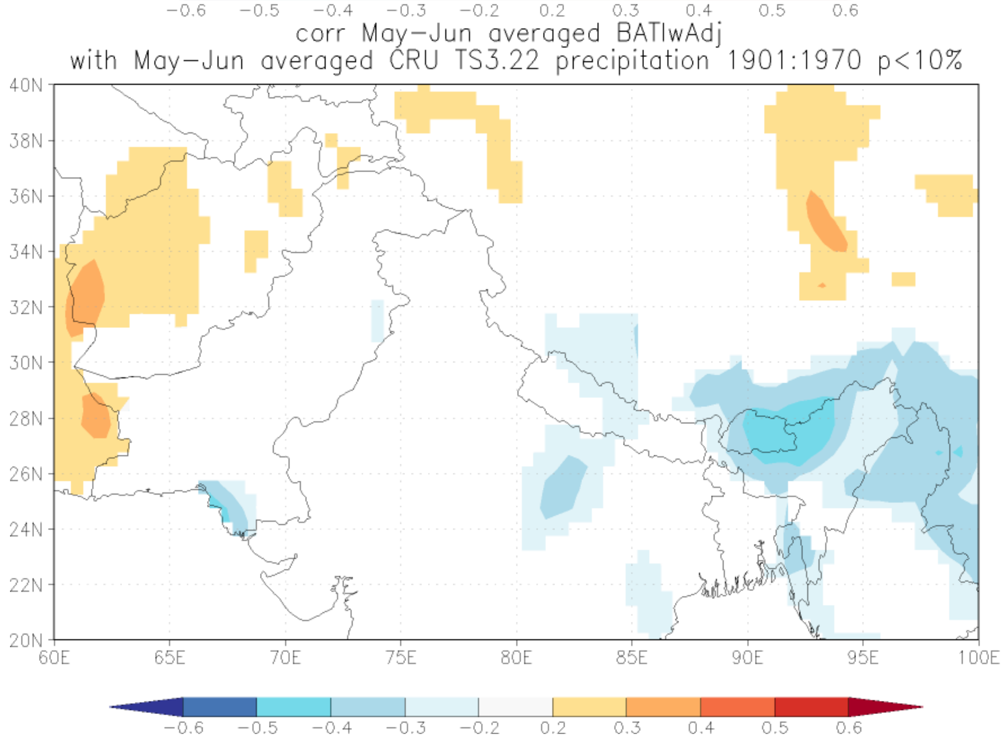
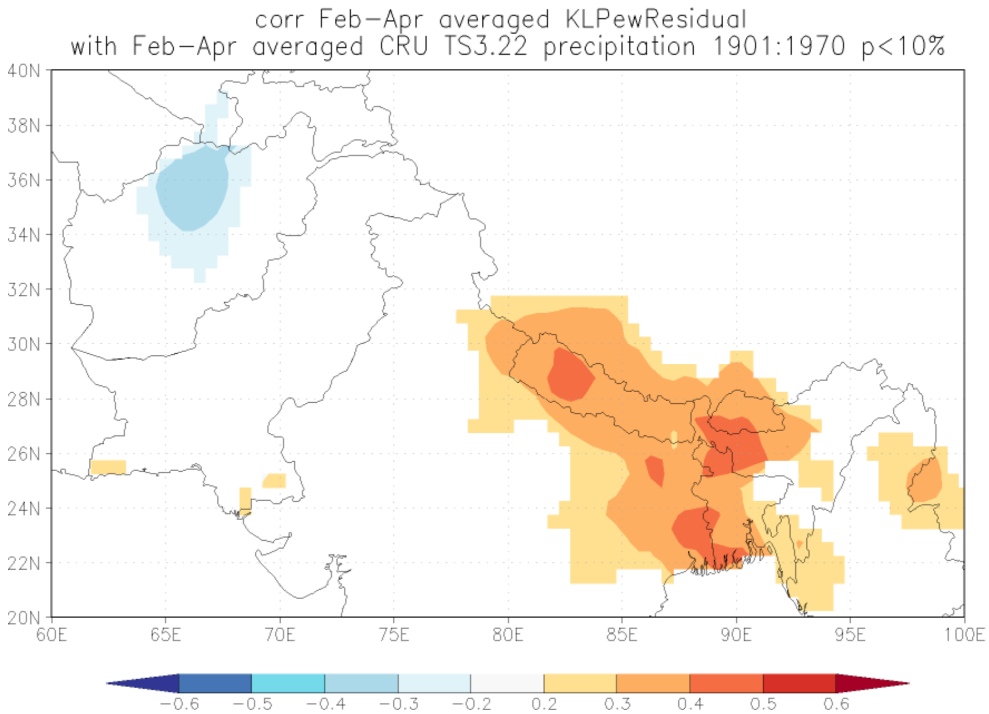


b.

Figure 37. (a) Bhaktapur earlywood correlation with precipitation. (b) Bhaktapur latewood correlation with precipitation. The scale below the figures indicates the ranges of correlations in terms of colors. The colors on the map display those correlation ranges.



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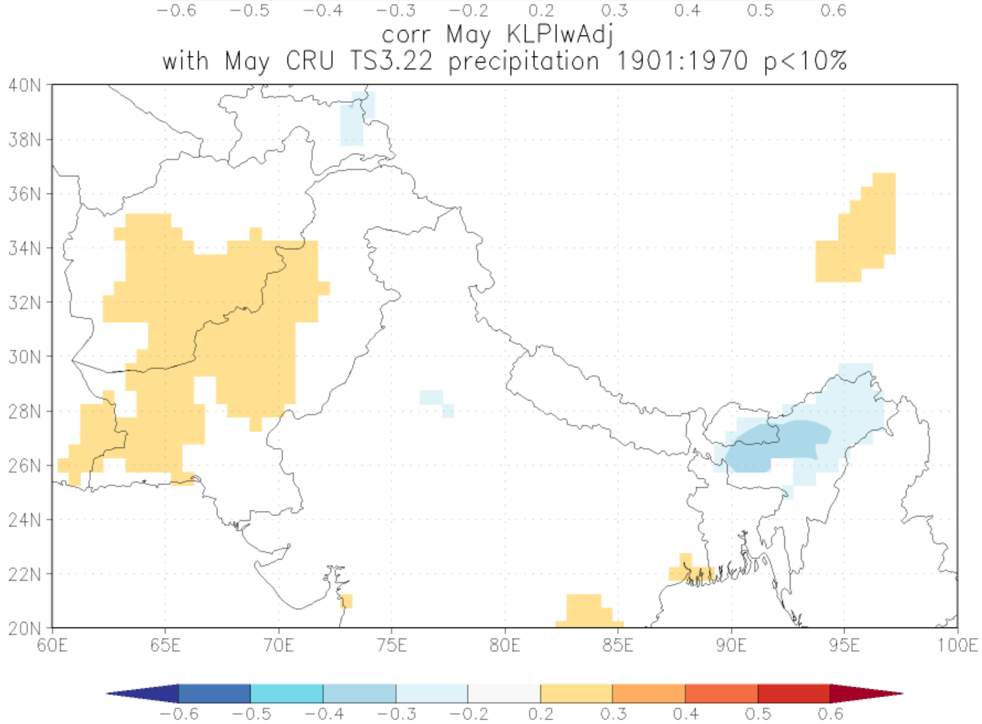
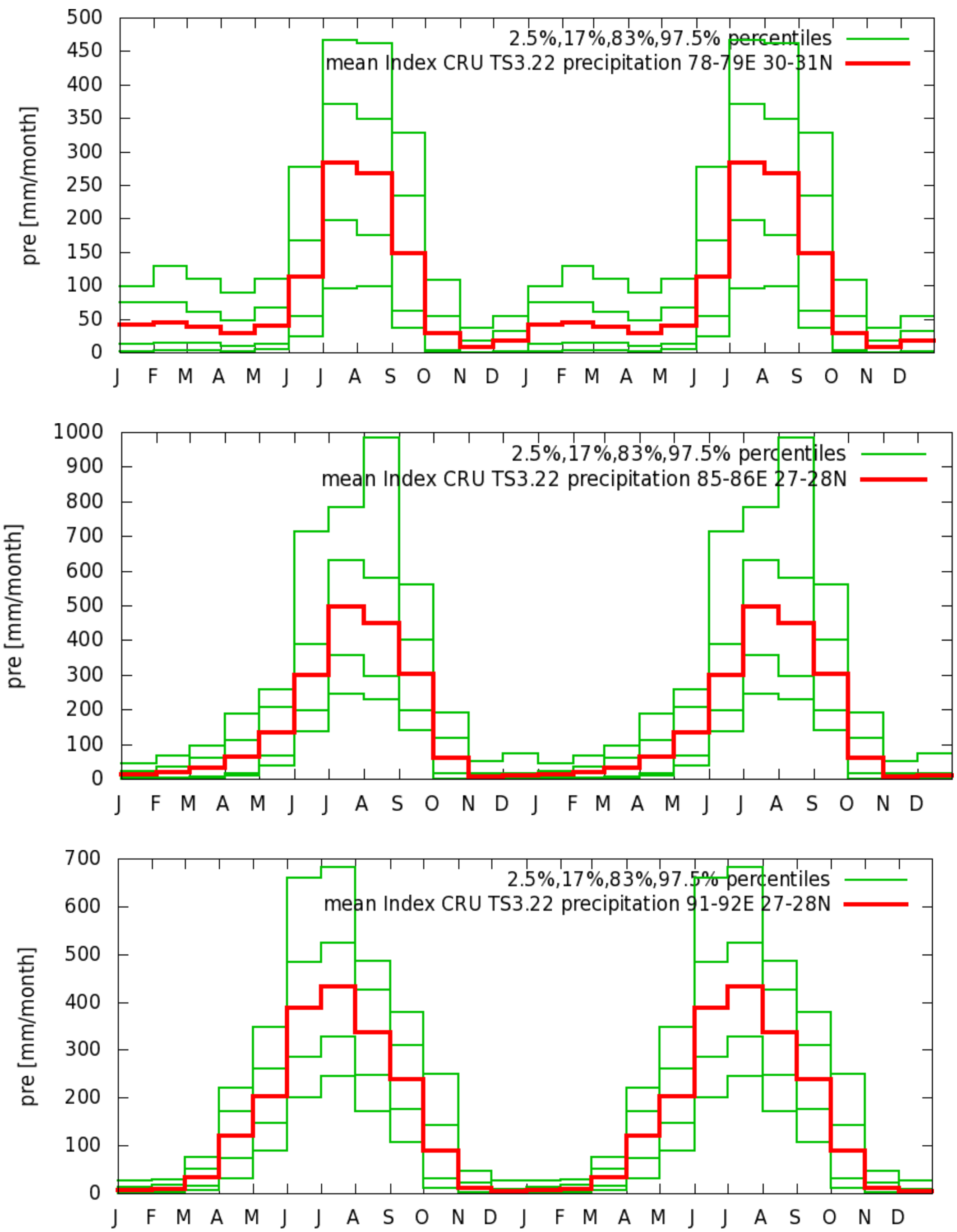


b.

c.

Figure 38. (a) Kalipang earlywood correlation with precipitation. (b) Kalipang latewood correlation with precipitation. The scale below the figures indicates the ranges of correlations in terms of colors. The colors on the map display those correlation ranges.



a.

b.

c.

Figure 39. Two annual precipitation cycles for (a) Hulanakhal, India; (b) Bhaktapur, Nepal; and (c) Kalipang, Bhutan. The summer month with sudden increase in precipitation was found to have a negative correlation with latewood (Table 23)

Table 23. Correlation between the monthly climate data for the sites and earlywood/latewood.

Tree-ring Series	Coordinates for ppt data (1901-1970)	Month/months	Correlation Value
HKPEWstd	30-31 N, 79-79 E	April-May	+0.496
HKPLWstd	30-31 N, 79-79 E	June-July	-0.435
BATEWstd	27-28 N, 85-86 E	October-April	+0.432
BATEWres			+0.434
BATLWadj	27-28 N, 85-86 E	May	-0.239
KLPEWstd	27-28 N, 91-92 E	Jan-April	+0.317
KLPEWres			+0.356
KLPLWadj	27-28 N, 91-92 E	May	-0.318

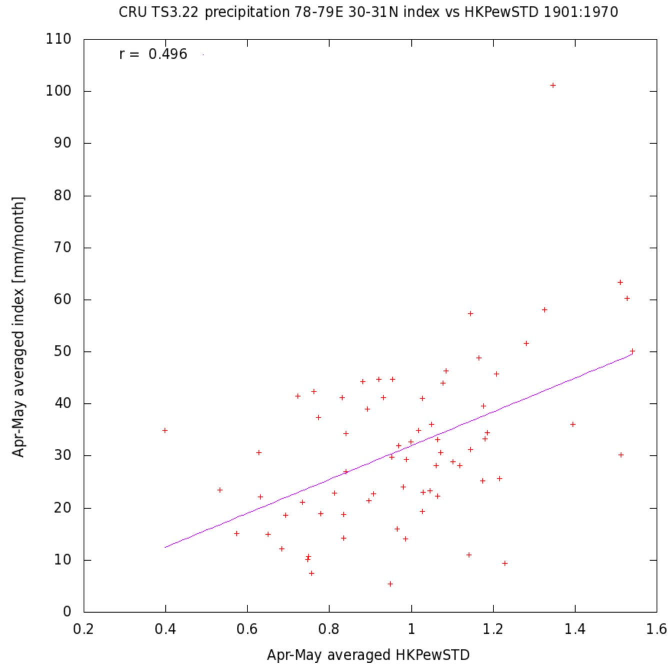


Figure 40. Hulanakhal earlywood vs. March-May precipitation.

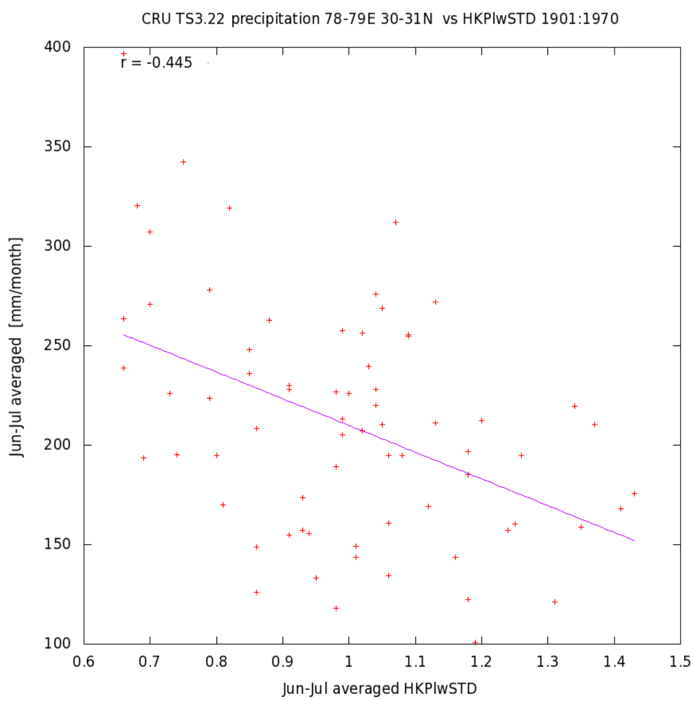


Figure 41. Hulanakhal latewood vs. June-July precipitation.

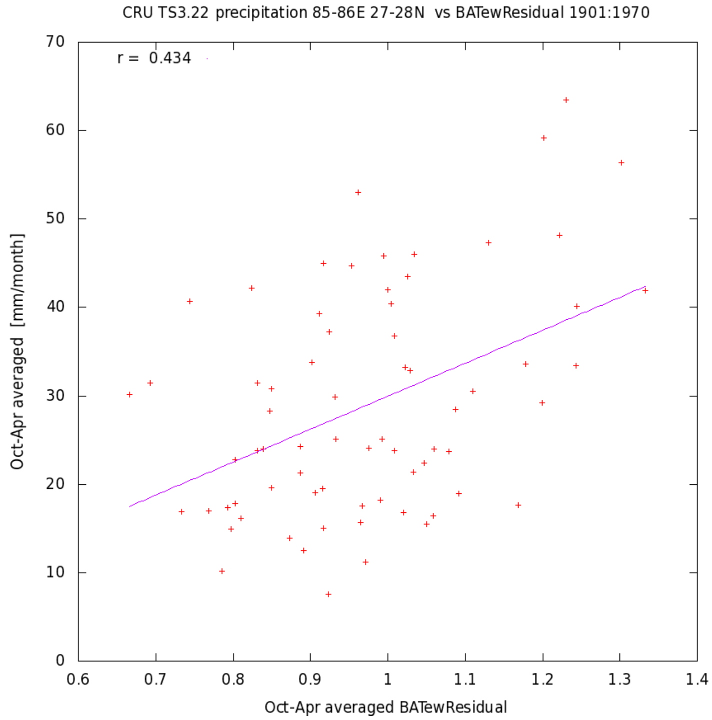


Figure 42. Bhaktapur earlywood vs. Oct-April precipitation.

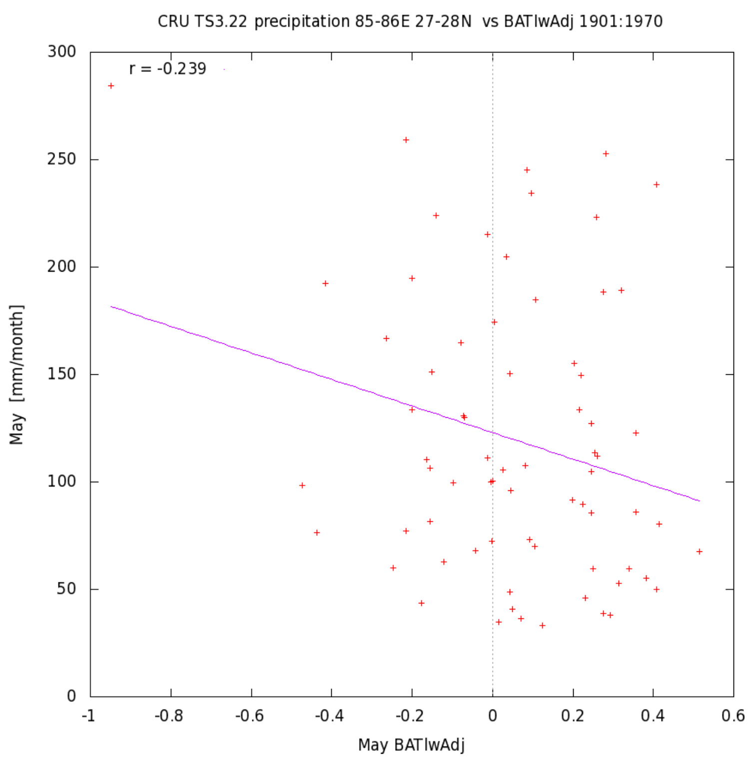


Figure 43. Bhaktapur latewood vs. May precipitation.

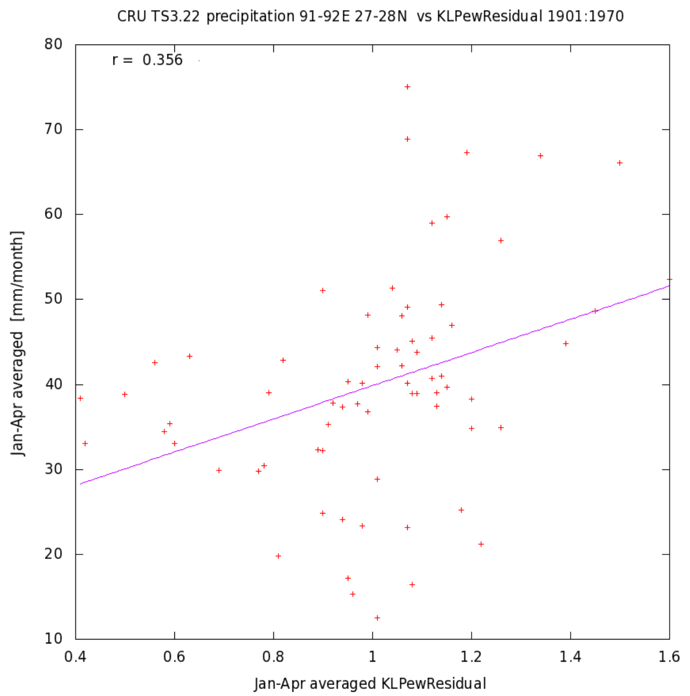


Figure 44. Kalipang earlywood vs. Jan-April precipitation.

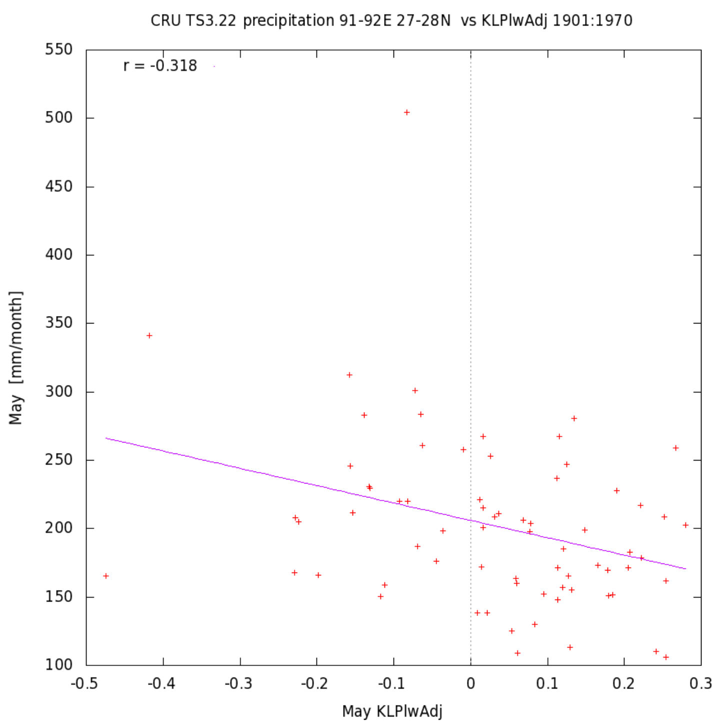


Figure 45. Kalipang latewood vs. May precipitation.

Table 24. COFECHA Mean Ring Measurements.

Tree-ring Series	Mean Ring Measurement (mm)	Contribution in Total Ring Width (TRW)
HKPEW	1.21	51% KLPTRW
HKPLW	1.16	49% KLPTRW
BATEW	0.88	34.78% BATTRW
BATLW	1.65	65.22% BATTRW
KLPEW	0.59	50.86% KLPTRW
KLPLW	0.57	49.14% KLPTRW

Conclusions

The chir pine samples from all three sites were datable. Vivid earlywood and latewood could be differentiated with visual observation in this species from all three sites. All three sites showed the presence of very frequent false rings, and that was the biggest hurdle in accurately cross-dating this species. The Hulanakhal site was most different in terms of the absence of ARSTAN residual chronologies (lack of autocorrelation within the individual tree-ring chronologies) and the presence of a very low correlation between earlywood and latewood (due to which latewood was considered largely independent of earlywood).

For all three sites, the total number of stations contributing precipitation data drastically declined beyond 1970, particularly for Hulanakhal and Bhutan. Therefore, the weaker correlation between tree-ring series and precipitation after 1970 could be due to the lack of climate data.

The tree-ring chronologies from the three different sites were not correlated to each other. Therefore, they were not used to compute regional chronology averages for EW and LW width for the analysis of possible regional precipitation signals.

The negative correlation between latewood and summer precipitation and the positive correlation between earlywood and winter/spring precipitation was consistent for all three sites for *Pinus roxburghii*. The Hulanakhal site had a higher correlation with precipitation relative to Bhaktapur and Kalipang. As mentioned before, the majority of the monthly stations around the Nepal (Bhaktapur) and Bhutan (Kalipang) study sites were located in India for the time period of 1900-1970. On the other hand, for the Indian Hulanakhal site, the stations were located much closer to the study site. The closer proximity of the precipitation stations is likely the most important factor in the higher correlations for Indian site as compared to the other two sites.

Since the climate response of earlywood and latewood is opposite, the first null hypothesis (H_0: There is no difference between climate response of earlywood and latewood) can be rejected. The opposite climate response between earlywood and latewood is consistent for all three sites. Therefore, the second null hypothesis (H_0: The climate response of earlywood and latewood is site specific) can be rejected for these three study sites.

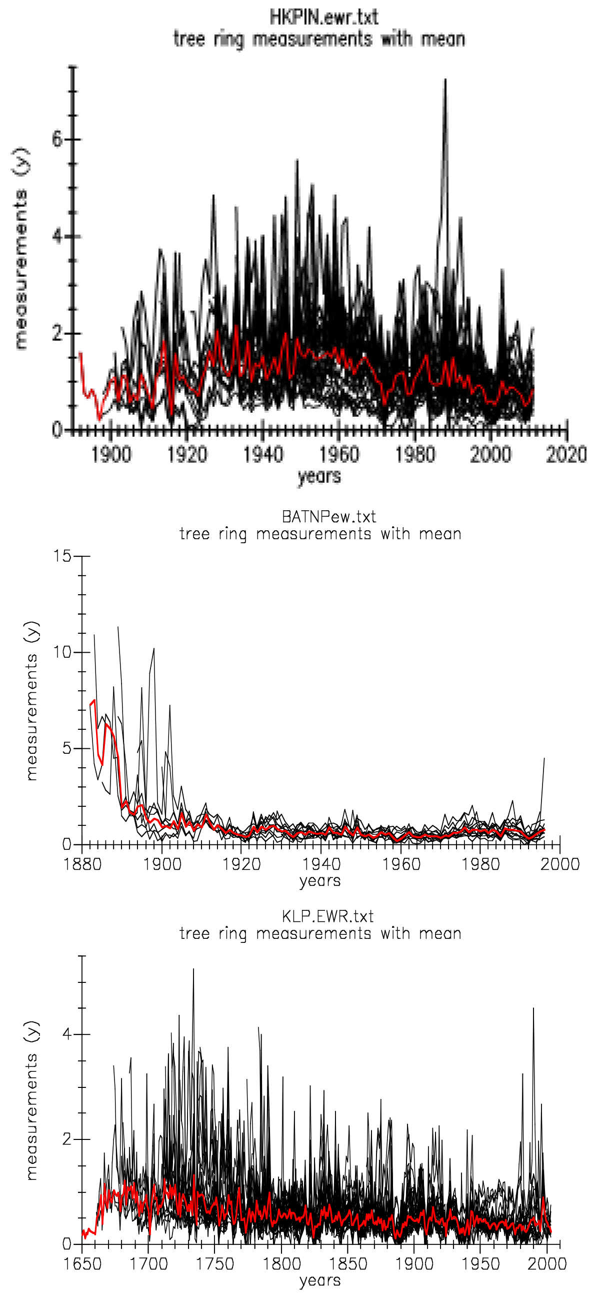
As can be noticed in Table 24, the earlywood and latewood make up an almost equal contribution in the tree growth in the Hulanakhal and Kalipang sites. Therefore, for these two sites, the third null hypothesis (H_o: There is no significant difference between proportion of earlywood and latewood) cannot be rejected. However, in case of Nepal, based on chi square analysis at a 0.005 P value, there is a significant difference between the proportion of earlywood and latewood. For the Nepal site, latewood contribution to the total ring width is significantly higher than that of earlywood. Therefore, the null hypothesis can be rejected for this site. Generally, earlywood constitutes a larger proportion than the latewood in an annual ring, but this was not the case for the tree-ring chronologies studied in this research project. The results indicate that for chir pine, latewood can make an equal contribution to the annual ring, and it can also become a major contributor in some cases, as in the case of the Nepal chronologies.

The negative correlation between the LW chronologies and summer precipitation at all three sites might suggest that a persistent increase in summer precipitation due perhaps to anthropogenic climate change could adversely affect chir pine. Therefore, we can tentatively reject the fourth null hypothesis (H_0: Chir pine EW or LW growth will likely not be strongly affected by predicted climate change).

Although it is too early to conclude that this signal is completely reliable, this study does indicate and emphasize on the need of measuring earlywood as well as latewood when developing tree-ring chronologies of *P. roxburghii* in the Himalaya. The opposing seasonal precipitation signals in EW and LW width may in fact weaken the precipitation signal in total ring width at these particular study sites, and perhaps for other *P. roxburghii* sites in the region. The fact that this opposing EW and LW precipitation signal was detected at all three sites, which were located at a considerable distance from one another, suggests that it might be real feature of *P. roxburghii* growth. Further studies should be conducted to test this hypotehsis.

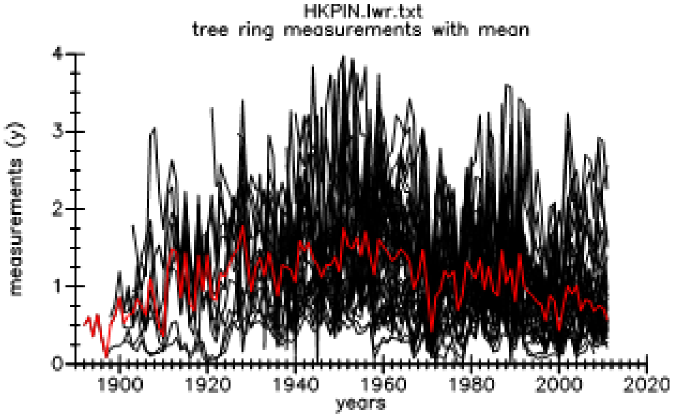
Based on this study, the predicted increase in warm weather precipitation may adversely affect the growth of chir pine, because latewood constitutes about half of the annual ring width at the Indian study site. This indicates that the expected increase in summer precipitation might actually be beneficial in reducing the encroachment of chir pine into broadleaved forests like banj oak. However, banj oak could also be adversely affected by heavy rains due to the leaching of nutrients and the removal of top fertile soil, and in that case, climate change might facilitate the expansion of chir pine.

One of the unexpected observations of this study was the disappearance of available monthly precipitation data after 1970 for a majority of Indian stations located close to the three study sites. It was expected that the number of monthly stations contributing the climate data would actually increase with time. However, for the past four and half decades the data from most of the stations around the sites has disappeared. Some of these stations may still be collecting data but have stopped contributing them to the open databases. Yet, it will be very helpful for dendroclimatology based studies if the good quality climate data from the study regions becomes freely available.



a.
b.
c.

Figure 46. Mean tree-ring measurement series for earlywood in (a) Hulankhal, (b) Bhaktapur and (c) Kalipang.



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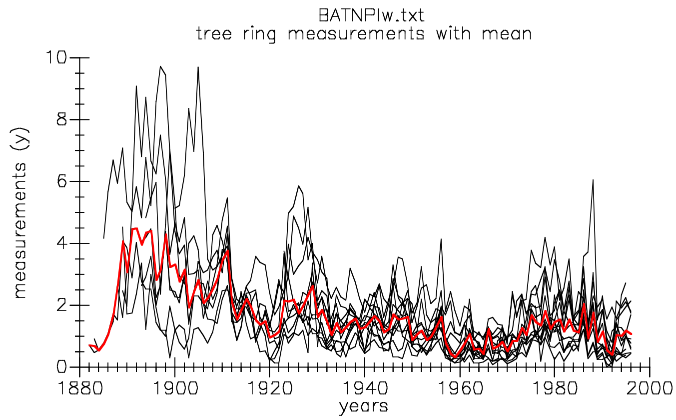

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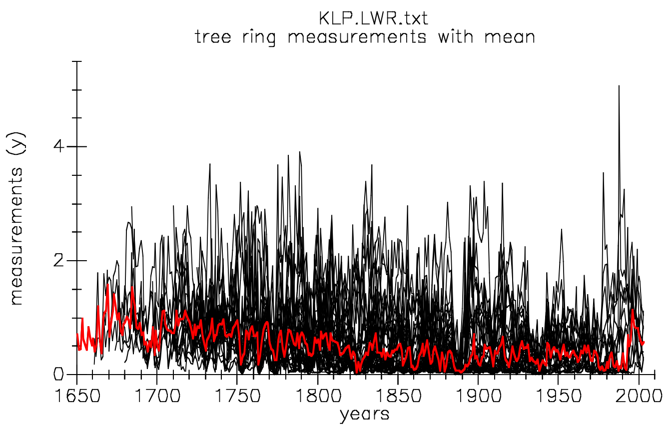

c.

Figure 47. Mean tree-ring measurement series for latewood in (a) Hulankhal, (b) Bhaktapur and (c) Kalipang.

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CHAPTER 7. MORPHOLOGICAL AND MOLECULAR ANALYSIS OF ECTOMYCORRHIZAL FUNGI ASSOCIATED WITH BANJ OAK AND CHIR PINE FORESTS AND GENERAL FUNGAL DIVERSITY OF THE TWO FOREST TYPES

Introduction

Fungi play various crucial roles in all types of ecosystems; however, they rarely receive the amount of attention and appreciation that they deserve. Even if we do not notice their presence, we are always surrounded by some forms of fungi. Fungi can be deadly parasites or catastrophic pathogens, such as the case of the American chestnut blight, where *Chryphonectria parasitica* (a fungal species) was the main cause behind the decline of this major dominant tree species in the hardwood forests of eastern North America. However, besides being parasites or pathogens, fungi also play many other vital roles which are beneficial for other organisms. Fungi act as a food resource for various animals. They play a very important role as decomposers and help in improving the soil texture and composition. Also, fungi live in symbiotic associations with algae in order to create lichens. Lichens act as pioneer species in succession and inhabit those places unfavorable for most other organisms. Ultimately, lichens create favorable conditions for other species. Furthermore, fungi have mycorrhizal associations with plants. In mycorrhizal associations, fungi assist the host plant to absorb various nutrients and water, and they also provide some level of protection to the host roots.

Fungi also have immense commercial importance for humans. Fungi are used as in medicines (e.g., the antibiotic derived *Penicillum*), food (mushrooms, morels, puffballs, chanterelle, truffles, etc.), manufacturing food products (yeast is used for fermentation and making products like bread and beer) and biocontrol agents (e.g., *Beauveria bassiana* is used for controlling various agricultural insect pests). Various species of the genus *Cordyceps* are used in traditional Chinese medicines and are believed to have a number of health benefits. *Ophiocordiceps sinensis* is a highly priced fungus, as it is believed to have numerous health benefits as well as aphrodisiac properties.

According to Hawkworth and Rossman (1997), we know only 5% of the total number of fungal species in the world. These authors gave a conservative estimate of about 1.5 million fungal species, out of which 1.43 million were indicated as not described. In one of his research paper, Hawksworth (2012) mentioned that, due to lack of confidence in estimating the exact number of global fungal species, the current situation, it will be most appropriate to consider the existence of at least 1.5 million species; however, there are probably as many as 3 million species. However, Blackwell (2011) mentioned that the data acquired by using several molecular methods predicts the existence of as many as 5.1 million fungal species (O'Brien et al. 2005, Taylor et al. 2010).

Heijden et al. (1998) mentioned that the functioning as well as stability of terrestrial ecosystems depends upon the biodiversity of vegetation and the species composition of the other organisms present (Schulze and Mooney 1993, Tilman and Downing 1994, Naeem et al. 1994, Tilman et al. 1996, Hooper and Vitousek 1997). Heijden et al. (1998) conducted two different experiments where they simulated European calcareous grasslands and North American old fields. The authors concluded that the below-ground diversity of arbuscular mycorrhizal fungi was the determining factor for the maintenance of plant biodiversity, ecosystem variability, as well as productivity and functioning. Therefore, they emphasized the need of proper management and conservation of arbuscular mycorrhizal fungi in order to maintain the biodiversity of ecosystems. In addition, the authors mentioned that the loss of arbuscular mycorrhizal fungi in agricultural systems could result in decline of vegetational biodiversity and ecosystem productivity. Furthermore it could also increase ecosystem instability (Helgason et al. 1998, Johnson 1993).

According to Tedersoo et al. (2010), “Based on taxonomic and ecological extrapolation, an estimated 86% of terrestrial plant species acquire mineral nutrients via mycorrhizal root symbionts (Brundrett 2009).” They mentioned that the estimated numbers of fungus and plant species involved in ectomycorrhizal associations are 20,000-25,000 and ca. 6000, respectively (Rinaldi et al. 2008, Brundrett 2009). The authors also mentioned that the “Pinaceae” is the oldest extant plant family that has ectomycorrhizal associations (Hibbett and Matheny 2009). The authors indicated that the oldest known fossil assigned to the Pinaceae is 156 million years old, whereas, the oldest ectomycorrhizal (EcM) root fossil dates back 50 Ma (LePage et al. 1997, LePage 2003).

Tedersoo et al. (2010) suggested that many EcM fungi clades had never been isolated in pure culture, but in the 1990s, a revolution in molecular technology significantly improved the identification of EcM fungi *in situ*, since these techniques reduced the “culturability problems” (Gardes et al. 1991, Egger 1995, Horton and Bruns 2001). Furthermore, molecular techniques helped in taxonomical assignment of those EcM fungi, which were commonly present on the roots yet remained unidentified (Egger 1996; Koljalg et al. 2000, 2002; Vralstad et al. 2000). The advancement in the application of molecular techniques also helped in comparing fungal DNA on root tips with that from the fruiting bodies, due to which many additional fungal genera could be assigned with EcM status (Gehring et al. 1998; Palfner and Agerer 1998a, b; Tedersoo et al. 2006a; Smith et al. 2007). Based on their study, Tedersoo et al. (2010) mentioned that 37 lineages in the Basidiomycota, 27 lineages in the Ascomycota and two lineages in the zygomycota form EcM.

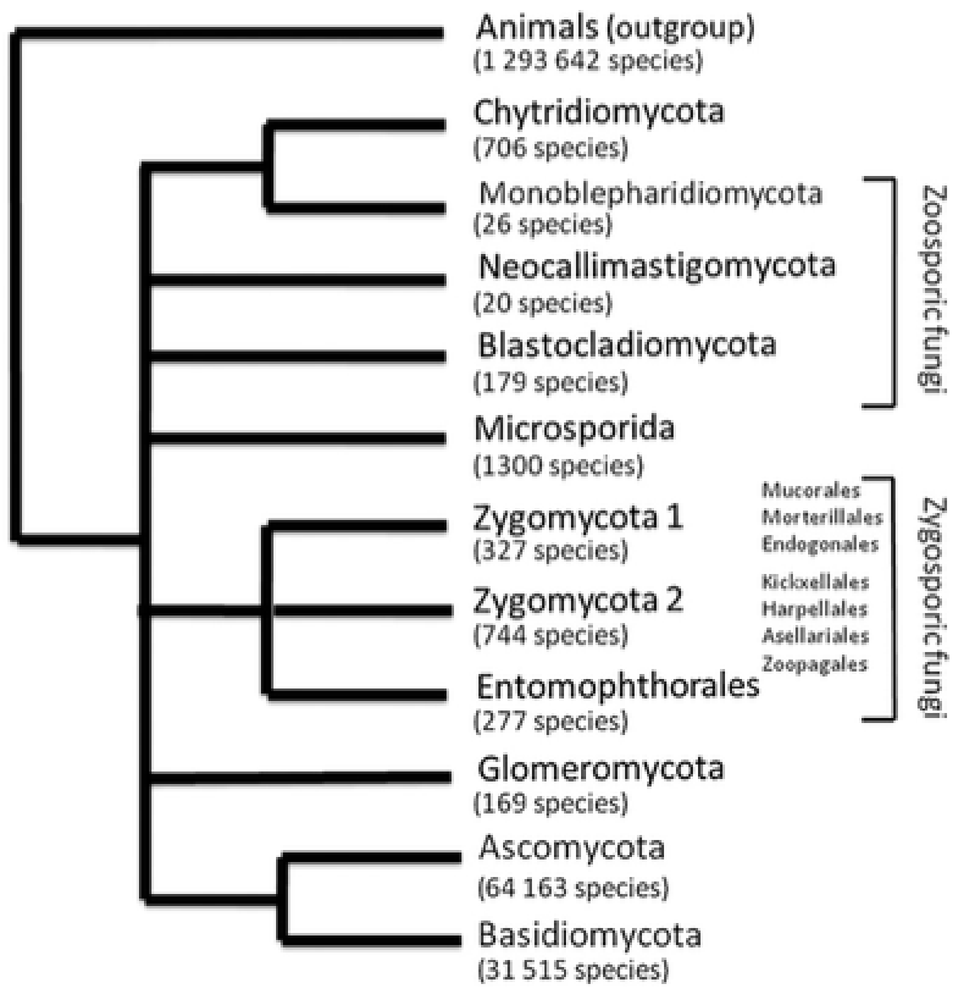


Figure 48. The phylogenetic tree shows the major fungal phyla with approximate number of species in each (from Blackwell 2011 and based on data from Kirk et al. 2008, Hibbett et al. 2007, and White et al. 2006).

Table 25. The number of genera in different fungal phyla for the world and India as given in Manoharachary (2005).

Phylum	World	India
Myxomycotina	450	380
Mastigomycotina	308	205
Zygomycotina	55	50
Ascomycotina	2000	745
Basidiomycotina	357	232
Deuteromycotina	4100	468
Total	7270	2080

Macrofungi as food

The fungal fruiting bodies present in the forest are one of the forest resources utilized by local people for culinary purposes. Some of the details provided by people regarding the fungi they collect from the forests have been provided in the "Village Survey" chapter. However, the use of macrofungi for food purposes is not an uncommon practice.

Semwal et al. (2014) mentioned that throughout the world, 1069 mushroom species have been reported for being used for food purposes (Boa 2004). On the other hand, Pant and Gupta (2004) indicated that out of a total of 60,000 species of fungi in the world, approximately 2000 are edible. Based on Kaul et al. (1978), Pant and Gupta (2004) reported that India has a total of 180 species (representing70 genera) of mushrooms.

Pant and Gupta (2004) mentioned that in India mushroom consumption has existed since 3000 B.C. (Pandey and Singh 1978). The authors further added that the "somras" mentioned in the Vedas is basically the extract of wild mushrooms (Butler and Bisby 1960). In many countries and cultures, mushrooms were associated with different religious beliefs. Charak Samhita (an early text of Ayurveda, the Indian traditional medicine) also gives some descriptive accounts of mushrooms. The authors wrote that the local name for morels is "Gucchi" in Himanchal Pradesh, Jammu and Kashmir and Uttarakhand, "Cheun" for Agaricus spp. in Uttarakhand, and "Khumbi" for Agaricus sp. in Uttarakhand and Punjab.

Semwal et al. (2014) conducted their study in two Himalayan states of India, namely Uttarakhand and Himanchal Pradesh, during 2000-2013. They indicated that a total of 23 species of mushrooms are considered edible or used for trade. Some of these mushrooms are more commonly collected and consumed than the others. The more commonly collected species belong to such genera as *Agaricus, Amanita, Astraeus, Hericium, Macrolepiota, Morchella,* *Pleurotus* and *Termitomyces*. On the other hand, species of *Auricularia*, *Cantharellus, Lactarius*, *Ramaria*, *Russula* and *Sparassis* are less commonly collected and consumed. According to these authors, misidentification of poisonous mushrooms as edible results in many casualties in the northwestern Himalayas (Himanchal Pradesh and Uttarakhand). However, local people frequently consume wild mushrooms without any ill effects. There isn't any specific test or characteristic that can help to differentiate between the edible and poisonous mushrooms. The local people identify a mushroom as poisonous only if someone fell sick or died after consuming it. Many of the edible fungi also form mycorrhizal associations with oaks and conifers of the region. For example, species belonging to *Amanita*, *Cantharellus*, *Lactarius*, *Russula* and *Ramaria* (*R. botrytis*).

Semwal et al. (2014) reported that people in this region also collect *Cordyceps sinensis*. This fungus has a high commercial value and therefore the villagers collect it mainly to sell it to local vendors who export this fungus to China and Nepal. The price varies from 55,000 to 80,000 INRs/kilogram. However, overexploitation of this fungus might result in its extinction in the region.

Negi (2006) mentioned that 18 species of *Morchella* have been reported from 28 countries; out of these, 14 species have been reported as edible and five have been used for medicinal purposes. According to Negi (2006), morels have 42% protein on a dry weight basis and they are also rich in minerals and have low calories. Morels have been used for clinical purposes, as they are believed to possess antitumor properties. He also indicated that India and Pakistan are the major producers for morels (each producing about 50 tons of dry morels), and they export almost all of their produce (FAO 2002). He also mentioned that the most common species of morel is *Morchella esculenta*, which is considered to be poisonous if it is consumed uncooked. The author mentioned that morels are common in temperate zones and the forests of Himanchal Pradesh, Punjab, Jammu and Kashmir and Uttarakhand. He also indicated that *M. semilibera* is present in oak forests. He also mentioned that mushrooms have been used for medicinal purposes or dietary supplements for more than 2000 years.

Negi (2006) further added that an analysis of various mushrooms with modern techniques has revealed the presence of numerous bioactive compounds. Some examples given by the author are as follows:

- Polysaccharides: Lentinan from *Lentinula edodes*,
- Immunomodulatory proteins: IZ-8 from *Ganoderma lucidum*, Fip-fve from *Flammulina velutipes*, Flip-vvo from *Volvariella volvacea*.
- Protein-bound polysaccharides: PSK and PSP from *Tricholoma* spp.

Moreover, Negi (2006) also mentioned that many of these compounds have anti-cancer and anti-tumor properties, which act by enhancing the immunity of the host rather than having a cytocidal effect (Etkin and Johns 1998). He also indicated that the extra cellular secretions from mushrooms have antibacterial and antiviral properties and they can also act against many protozoan pathogens, for example *Plasmodium falciparum* that is the causal organism for malaria.

Sharma et al. (2009) reported some of the wild mushrooms that are consumed as food supplements by local people. They listed a total of 11 mushrooms, out of which eight species are used in a processed form, whereas the remaining three are consumed raw. The list of mushroom species that are consumed after processing includes *Lycoperdon sp*., *Morchella conica* Pers. ex. Fr., *Morchella deliciosa* Fries., *Ramaria botrytoides* (Pers:Fr.) Ricken, *Morchella semilebra* DC., *Morchella esculenta* (L.) Pers. *Helvella compressa* (Synder) N.S. Weber, and *Lactarius* *delicious* (L. ex Fr.) S.F. Gray. The species that are consumed raw or unprocessed are *Rhizopogon rubescens* (Tal. & C. Tal.), *Rhizopogon luteolus* Fr., and *Rhigopogon vulgaris* (Vittad.) M. Lange.

The authors further mentioned that *Lactarius delicious* and the species of *Morchella* and *Rhizopogon* are most heavily consumed mushrooms. The authors also noted that *Rhizopogon* and *Morchella* grow during March and April, whereas *Lactarius, Helvella*, *Lycoperdon* and *Ramaria* grow during the rainy season.

Ectomycorrhizal fungi of the study region, as mentioned in previous studies

Pande et al. (2004) mentioned that ≥25% root biomass of forests can be attributed to ectomycorrhizal fungi and thus these fungi constitute a major structural component of below-ground forest ecosystems. They sampled the ectomycorrhizal fungi associated with the temperate forests of the Western Himalaya and reported 43 EcM fungal species in the oak forests and 55 in the conifer forests. The authors mentioned that the main host species in their study region included oaks (*Quercus leucotrichophora* and *Q. floribunda*), pines (*Pinus rorburghii* and *P. wallichiana*) and deodar (*Cedrus deodara*). The authors indicated that some of the fungal genera showed evident host preference. For example, *Russula* and *Boletus* were primarily associated with oaks, whereas *Amanita* was more prevalent in coniferous forests.

Also, as can be seen in (Table 26), all seven species of *Suillus* were present in coniferous forests. Out of four *Cortinarius* species, three were associated with conifers and one with *Betula*. Also, the authors mentioned that one species of *Hygrophorus* was found to be associated with *Rhododendron*.

Pande et al. (2004) indicated that for the hardwood and conifer forests of North America as well as the other temperate regions, the mid-point range of species richness (Schmit 1999, Allen 1995) of ectomycorrhizal fungi is 18-114 and the study done by the authors (Pande et al. 2004) also had values (i.e., 43 in oaks and 54 in conifer forests) which are in this range. In addition, other studies done in Kashmir and Nepal conifer forests in the Himalayan regions also have the species richness values (53 and 52 species, respectively) in this range. Pande et al. (2004) also listed the estimates provided by Molina et al. (1992) for major ectomycorrhizal genera and the number of species (globally) in each. These were *Cortinarius* (900), *Russula* (500), *Hygrophorus* (250), *Inocybe* (210), *Amanita* (200), *Lactarius* (200), *Entoloma* (160), *Boletus* (150), *Tricholoma* (150), and *Hebeloma* (120).

Table 26. Major fungal genera associated with oaks and conifers in the study by Pande et al. (2004).

Genus	Total mycorrhizal species	Percentage association with oaks	Percentage association with conifers
Amanita	15	20	80
Russula	13	80	20
Boletus	12	83.3	16.6
Lactarius	9	45.5	55.5
Suillus	7	0	100
Hygrophorus	4	25	75
Cortinarius	4	0*	75

*: The remaining 25% of *Cortinarius* were associated with *Betula*.

Kumar et al. (1990) gave a list of possible mycorrhizal associates for some of the major tree species of the northwestern Himalayas. For banj oak (*Q. incana* or *Q. leucotrichophora*), the possible EcM associates listed were *Agaricus angustus, Amanita caesarea*, *Amanita rubescens*, *Clitocybe gibba*, *Collybia fusipes*, *Hygrocybe* sp. nov., and *Leucoagaricus rubrotinotus*. For chir pine, the possible EcM associates listed were *Amanita berkeleyi*, *Amanita emilii*, *Amanita gemmata* and *Amanita vaginata*.

Pant and Gupta (2004) did their study on macrofungi in the Binsar wildlife sanctuary in the Kumaun Himalayas, Uttarakhand. Their study area had such trees as banj oak, kharsu oak, chir pine, utees (Nepalese alder), burans, and deodar. Macrofungi recorded by Pant and Gupta (2004) also included some ectomycorrhizal species, which were *Amanita corcea* (present in oak forests), *Amanita phalloides* (present in deciduous woody forests, especially oak forests), *Amanita fulva*, and *Russula claroflora* (both more common in pine or pine-oak mixed forests), *Leotia lubrica*, *Cantharellus crispa*, and *Suillus bovinus* (generally present in pine forests), *Boletus cavipes* (generally present in pine forests), *Amanita cothurnata* (present in banj oak forests in Himanchal Pradesh), and *Laccaria laccata* (present in banj oak and Burans (*Rhododendron arboretum)* forests of Himanchal Pradesh). The other mycorrhizal species mentioned in the paper were *Russula emetica*, *Russula fragilis,* and *Helvella crispa*.

Miller et al. (2005) described a species of *Russula* from Mukteshwar, Uttarakhand. This new species was named *Russula mukteshwarica* and according to the authors, it grows in close association with the species of oaks, *Rhododendron* and *Myrica.* Das et al. (2006) described four new species of *Russula* from the Himalayan region. All four species were discovered in the Uttarakhand state of India. The first species was named *Russula mayawatiana*. The authors mentioned that it is present in moist mixed temperate forests in close association of species of oak and *Rhododendron*. The second species, *R. dhakuriana*, also grows in the moist mixed temperate forests in close association with species of *Rhododendron*. The other two new species were named as *Russula appendiculata* and *R. puellaris*. *Rhododendron appendiculata* grows in mixed temperate forests, whereas *R. puellaris* grows in temperate deciduous to mixed forests. *Rhododendron appendiculata* was indicated to be a rare fungi, and it forms mycorrhizal associations with pine species. On the other hand, *R. puellaris* forms mycorrrhizal associations with oak and species of *Rhododendron*.

Das et al. (2004) described three new species from Uttarakhand, India, that are associated with banj oak forests. The names of those three species are *Lactarius sanjappae, L.* verbekenae, *and L. muketeswaricus*. Das et al. (2004) also mentioned that in India, 72 species of *Lactarius* have been reported.

Joshi et al. (2012) gave a detailed list of 105 taxa under the family Russulaceae that have been documented from Uttarakhand, India. Out of the total of 105 taxa, 95 were species and 10 were varieties. Ten of the listed species of *Lactarius* were new undescribed taxa. The majority of these taxa were associated with oak and pine species except two new (un-described) species of *Lactarius* that were collected from a *Shorea robusta* forest. All of the listed taxa belonged to either genus the *Lactarius* or the genus *Russula*.

Semwal (2005) reported three species of Amanita from Garhwal region, namely*, Amanita griseofarinosa* (was found under *Q. glauca*, *Cinnamomum jeylanicum* and *Cinnamomum tamala*), *Amanita sinensis* (found under Q. glauca), *Amanita umbrinolutea* (found under *Q. leucotrichophora* and *Pinus roxburghii*).

Dhancholia et al. (1991) sampled agarics in the Almora Hills, Uttar Pradesh (now Uttarakhand) from 1980-83. Listed below are some of the agarics listed by them, which also form ectomycorrhizal associations. *Amanita phalloides* (Vaill. : Fr.) Secr. was found in a chir pine forest, *Cantharellus* sp. was present in pine forests, *Cortinarius collinitus* Fr., (in a Binsar forest, Uttar Pradesh the forest type was not mentioned), *Laccaria caerulacea* Dhancholia, Bhatt and Pant (a new species described by the authors) was found in chir pine forests, *Laccaria tetraspora* f. major Singer (forest type not mentioned), and *Russula heterophylla* Fr. was present in the chir pine forests.

Kanwal et al. (2011) carried out a study of morels in the Western Himalayan region of India. They mentioned that the morels establish symbiotic relationships with trees in the form of mycorrhize but they can also act as saprotrophic. The authors also mentioned that species of *Morchella* grow abundantly in Jammu and Kashmir, Himanchal Pradesh and Uttarakhand states of India during March to May and August to September. They are commonly known as "Guchhi". The authors mentioned that two kinds of morels were common in their study region - yellow morels and black morels. Yellow morels consisted of mainly two species (*Morchella crassipes* and *M. spongiola*), whereas black morels consisted of four species (*M. elata*, *M. angusticeps*, *Morchella* sp. 2 (MR2) and *M. gigas*).

Purpose of the study

1. To observe and record the general diversity of macrofungi in the study region with more emphasis on ectomycorrhizal fungi.
2. To check the feasibility of identification of ectomycorrrhizal fungi present on root tip samples with the help of molecular techniques.

Methods and Data

Most of the banj oak forests are not very moist during much of the year, and that is the reason that species like banj oak have sclerophyllous leaves in order to survive water deficient conditions. However, heavy monsoon rains transform these forests and give them an appearance of a rainforest. During the monsoon, the oak forests are richer in moisture and humidity and become denser in terms of ground vegetation. The trees and ground become covered by various bryophytes. In addition, the epiphytes flourish well during the monsoon. Besides vegetation, the macrofungi diversity is also immensely enhanced. I did my field work during the pre-monsoon and monsoon period in the general study area and noticed a drastic difference between the fungal (macrofungi) diversity during the monsoon season and the non-monsoon season.

Only a few macrofungi (all decomposers) were noticed at the Magra site when this site was visited during 15-17 June 2010. Chir pine as well as banj oak forests were quite dry. On the other hand, the Jakholi site was visited during 9-11 July 2010 and a greater number of fungal fruiting bodies were noticed at this site, since the monsoon season had started.

A variety of fungal fruiting bodies were noticed at the Ghansali Oak site (Figure 60-

Figure 63). The site was visited on 12 July 2011. *Lactarius*, *Russula* and boletes were common ectomycorrhizal fungi. However, various other fungi, such as coral fungi, puffballs, shelf fungi and a number of decomposer mushrooms were noticed at the site.

The Badshahithaul (BT) oak forest (30.34°N, 78.42° E, elevation 1954 m) was visited a total of three times. On 28 June 2010 and 15 July 2012, only a few fungal fruiting bodies were noticed (Figure 64).

When the same site was visited after the first monsoon rain on 2 August 2012 (the monsoon was very delayed in 2012), >25 different types of fungal fruiting bodies were noticed on the same day at the same site. A lot of these were ectomycorrhizal fungi which were collected for the purpose of DNA analysis and identification. A chir patch was also visited close to the Chamba town (30.34575° N and 78.38642° E, elevation 1492 m) on 2 August 2012, and a total of nine different fungi were noticed. However, only those which were assumed to be ectomycorrhizal were collected. The images of fungi that were used for DNA analysis are in

Table 27, Figure 56 and Figure 57. For each fruiting body that was collected, detailed images were taken *in situ* as well as post collection (before drying) in order to record all major visible parameters and descriptive features. Each fruiting body was assigned a unique identification number and in order to avoid any mistakes, the name was labeled next to the fungi while taking its pictures. For the preservation of fresh fungal tissue, C-tab was put in 1.5 ml tube tubes. An effort was made to take out any uncontaminated tissue (the tissue was taken out from the inner portion of the stipe with the help of sterilized forceps and razor) from each fungal fruiting body, and this tissue was placed in individual 1.5 ml tube tubes that contained the C-tab. A mushroom dryer could not be arranged as it was not available in the market or for online purchase in India. Therefore, a structure was designed which could work like a mushroom dryer. The design was given to a carpenter who built the structure. A room heater was used to supply an adjusted amount of heat which was just enough for drying the fruiting bodies without cooking them (Figure 49).

Figure 49. (a)A room heater (b) The structure constructed to dry mushrooms as a substitute of a mushroom dryer.

There are very few studies which include a detailed list of ectomycorrhizal fungi associated with oaks and pines of my study area. Probably there are a lot of fungi species in my study region that have not been documented so far, and therefore they may be species new to science. The major difficulties in sampling and documenting the ectomycorrhizal fungi associated with the forests of this region were as follows:

1. The fungal fruiting bodies do not last very long. They come out soon after the rain and degrade within a few days. This doesn't give enough time and opportunity to document all species present in these forests unless different teams work simultaneously in different study sites.

2. Not all of the forests produce very many fungal fruiting bodies every year, so there is no guarantee of high success rate in terms of sampling.

3. Some sites are better than the others, so it is important to choose a good site for sampling during the monsoon season.

4. Many forests in the region are inaccessible as they are located on steep slopes. Especially during monsoons, it becomes very dangerous to conduct sampling in such forests, since they become very slippery as well.

5. Heavy monsoon rains result in landslides every year. This makes it difficult to reach the study sites when it is the best time for majority of the fungi to produce their fruiting bodies.

In addition to the reasons mentioned above, there can be lot of other challenges in sampling fruiting bodies. For example, although I documented the presence of fruiting bodies by taking images during 2010 and 2011, my goal was to collect the samples of fruiting bodies in 2012. Unfortunately, the monsoon was delayed and therefore I could find and collect the fruiting bodies only on 2 August 2012. Since I was in India for only a limited time in order to collect my data, time was a limitation for me and I had to return when I could finally get more opportunities to collect more samples.

To avoid all these problems, we can collect the root tips and carry out DNA analysis if the purpose is just to find which fungal species are associated with the trees. So far, no work has been done in my study area and probably the whole country (India) on the DNA analysis of root tip mycorrhizae. There can be multiple fungal species associated with a single tree; therefore, while doing the DNA analysis it is important to take individual root tip samples for the analysis. In order to find out the species associated with banj oak and chir pine using root tips, I collected a total of 117 samples from 100 different trees, 50 chir pine and 50 banj oak.

These 100 trees belonged to four different forests, two chir pine and two banj oak. An effort was made to collect 25 samples from each forest. The root tip samples were also preserved in 1.5 ml tube tubes with c-tab.

The root tip samples from 2012 did not remain in very good shape, as the C-tab quality was not good, and they were subjected to variant temperatures when transported from India. Therefore, I collected 100 more samples in December 2014. These samples belonged to total 25 trees, 15 banj oak and 10 chir pine.

Figure 50. a. Hemant nautiyal helping in root tip extraction. b. Ectomycorrhizal fungi on the roots of banj oak. (Photographs by the author)

DNA analysis

The first kit used for DNA extraction and amplification was REDExtract-N-Amp™ Plant PCR Kits by Sigma-Aldrich. I didn't obtain any result in the first attempt (I used 10 root tip samples). In second attempt, tissues from eight fungal fruiting bodies in the 1.5 ml tube was used for DNA extraction and amplification. None of the samples produced good bands. There were very faint bands which were barely visible.

The third attempt was made with four samples—LKRL03, BL10, BL14 and CHRL16. Only two (LKRL03 and RL16) showed bands where RL16 had brighter band and LKRL03 had a faint band (Figure 51).

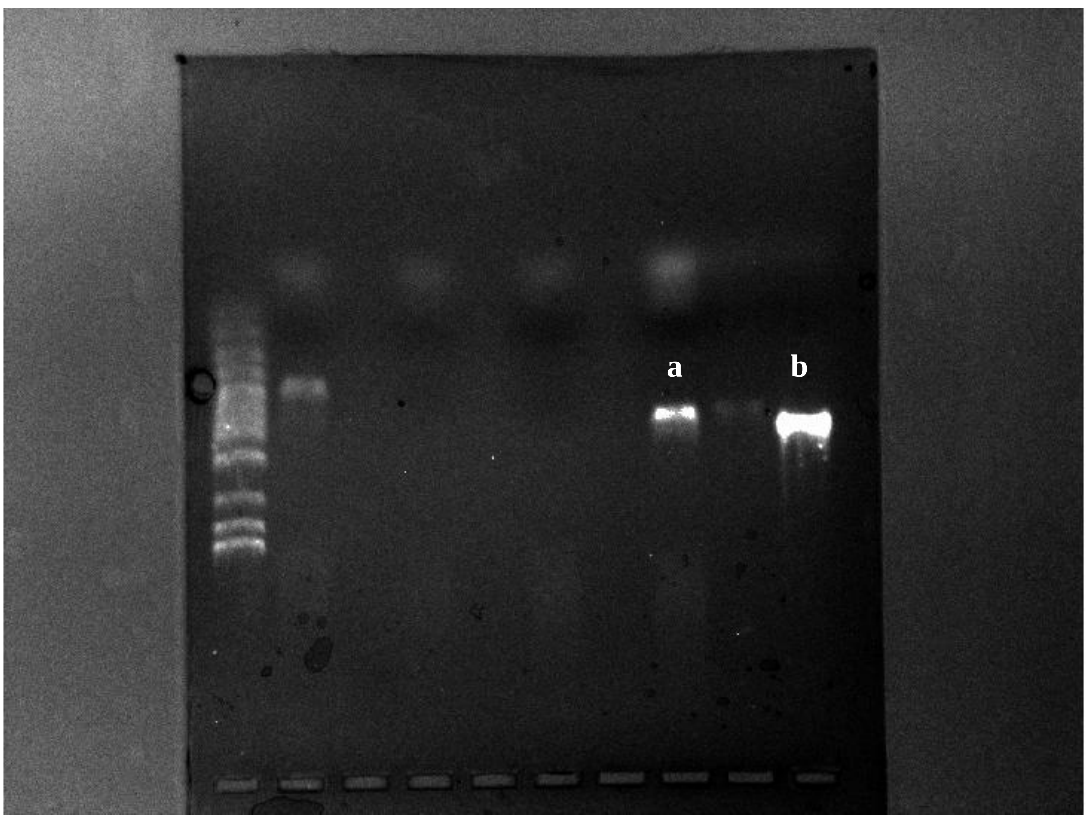


Figure 51. The gel image with positive result. (a) is LKRL03 and (b) is CHRL16

Only RL16 was sent for DNA sequencing at the DNA resource center (Division of Agriculture, University of Arkansas). However, the result obtained was of poor quality and therefore couldn't be used for a BLAST (Basic Local Alignment Search Tool) search of NCBI (National Center for Biotechnology Information). BLAST compares all the sequences submitted to the database and identifies the most closely resembling sequences. This helps in identification of the samples using their closest match. If the species doesn't show a good match with any other sequence, then either its DNA sequence has not been submitted to the database yet or it is a new species (assuming that there was no error during the PCR process).

Since a bright band is supposed to produce good sequencing results, but RL16 didn't therefore Qubit Fluorometer was used to check the DNA concentration in the PCR sample that showed a band but didn't produce a sequence. It was found that the DNA concentration was very low in my PCR sample, which was probably the reason behind the poor results.

The fourth attempt was done using tissue from dried fungal fruiting bodies. This time ten samples were used. None of the samples worked.

Since neither root tips nor dried or fresh tissue of fruiting bodies gave much results and the Qubit Flurometer also showed low concentration of DNA, a different kit (Invisorb spin plant mini kit) was tried in order to get better results. The Invisorb spin plant mini kit (By stratec molecular) gave good results and therefore rest of the DNA extractions were carried out using this kit.

After the extraction, DNA amplification was carried out using the thermocycler. Eighteen microliters of master mix and 2 µl of extracted DNA were added to PCR tubes for each sample. ITS1F and ITS4R (10 µM concentration each) were used as forward and reverse primers respectively.

ITS1F: CTTGGTCATTTAGAGGAAGTAA (Gardes et al. 1993)
ITS4: TCCTCCGCTTATTGATATGC (Anderson and Cairney 2004)

In the first attempt of DNA extraction with the new kit, dried samples were used. In the second attempt, fresh preserved tissues were used. The protocol for PCR of the first two attempts made for the DNA extracted by using an Invisorb spin plant mini kit was as follows:

Lid Temperature—105° C

Volume used—20 µl

Step 1—Initial activation

- 94° C for 3 minutes

Step 2—38 cycles of following steps

- 94° C for 1 minute (denaturation)
- 55° C for 45 seconds (annealing)
- 72° C for 45 seconds (extension)

Step 3—Final elongation

- 72° C for 10 minutes

Step 4—Final hold

- 7- 4° C for ∞

The third PCR was carried out, again using the extracted DNA from the fresh preserved tissues of all 14 fruiting bodies (using the Invisorb spin plant mini kit). The protocol outlined below was used for the third PCR.

Lid Temperature—105° C

Volume used—20 µl

Step 1—Initial activation

- 95° C for 2 minutes

Step 2—40 cycles of following steps

- 95° C for 30 seconds (denaturation)
- 52° C for 30 seconds (annealing)
- 72° C for 1 minute (extension)

Step 3—Final elongation

- 72° C for 5 minutes

Step 4—Final hold

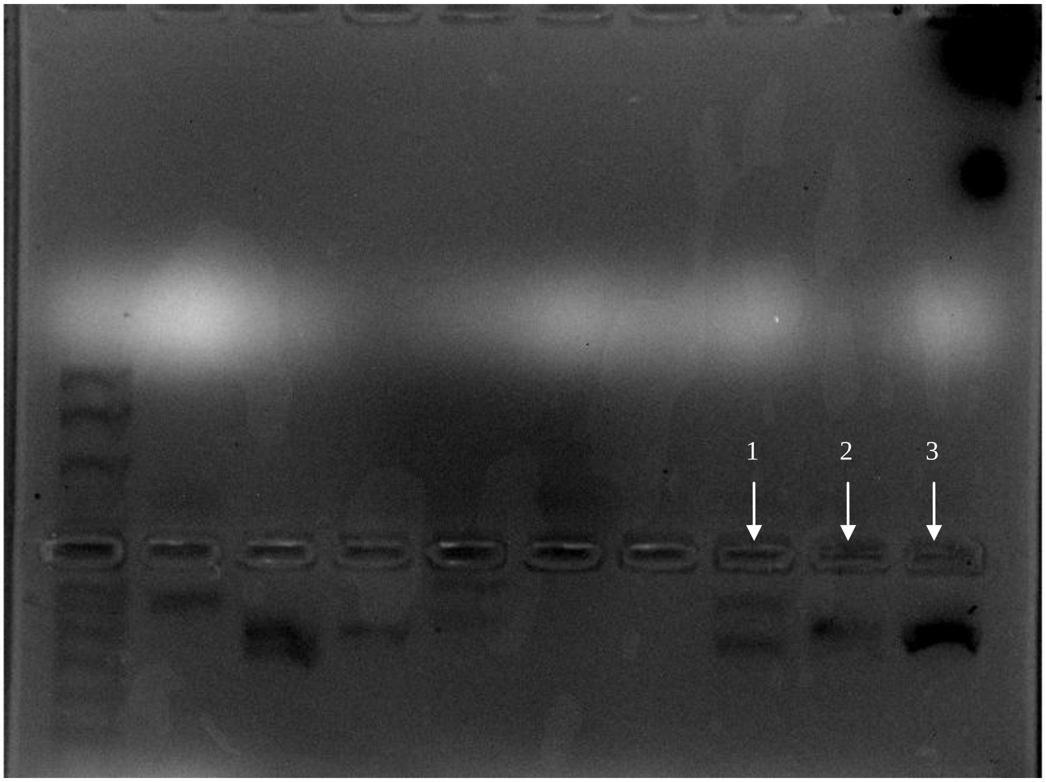
- 15° C for ∞

After PCR, gel electrophoresis was performed using a 1% agarose gel (1 gm Genepure LA Agarose/100 ml of 1×TA buffer). In the second and third PCR attempts, SYBR safe dye (1: 10000) was added in order to make the bands visible. Ten microliter PCR product (amplified DNA) was loaded on the gel for each sample. Electrophoresis was done at 120 Volts for about 20-30 minutes. After this the gel was examined under UV light to see the progress of bands. If the progress was satisfactory then gel picture is taken using Bio-Rad Imaging System.

After this, the PCR samples were purified using the purification kit from MSB Spin PCRapace (by Stratec Molecular). The best samples (after purification) were sent for sequencing to the DNA resource center (Division of Agriculture, University of Arkansas) following the instructions provided by them. After the sequences were received from the DNA resource center, Sequencher software program was used for reading and cleaning the sequence. Cleaning resulted in improving the quality. After this the files were saved in FASTA format which could then be used in BLAST (NCBI). The sequences were uploaded in BLAST. The first PCR attempt using the extracted DNA with Invisorb Spin Plant Mini Kit was done using ten samples from dried fruiting bodies. In this case Gel Red and a loading dye were used in place of SYBR Safe. A 990 µl amount of the Loading dye and 10 µl were mixed to prepare the final loading dye. Two µl of the Final loading dye was used along with 10 µl of each amplified DNA sample and then the mixture was loaded on the gel for electrophoresis. All samples except AK5 produced a band. (Figure 52). However, the sequence results were good for only three specimens.

The second attempt for DNA extraction using the new kit and PCR gave good results. A total of 14 fruiting bodies' fresh preserved tissue were used from the 1.5 ml tube tubes. All samples produced bands (Figure 53). For this extraction, the originally assigned ID number was used. For e.g. LKRL03 (LK stands for Lamkot [BT oak], the site where the sample was collected) is the band #3 and CHRL16 (CH stands for Chamba) is band #16. Although 16 samples were assumed to be ectomycorrhizal during field collection, two samples (#1 and #11) were not used since they did not seem to be ectomycorrhizal based on detailed observation. Another PCR was carried out, again using the extracted DNA from the fresh preserved tissues of fruiting bodies, in order to get brighter bands for those samples which produced faint bands in the first attempt. The result was good again (Figure 54).

The best bands were chosen by combining the results from both the PCR results. Sample 3, 6, 12 and13 were used from the first PCR, and 9, 15 and 16 were chosen from the second PCR. The chosen seven PCR samples were purified using MSB Spin PCRapace (by Stratec Molecular) and then sent for sequencing. Some of the samples gave good sequencing result however; the remaining ones had poor quality sequencing result. Therefore, the remaining samples were sent again to another sequencing place, Beckman Coulter Genomics.



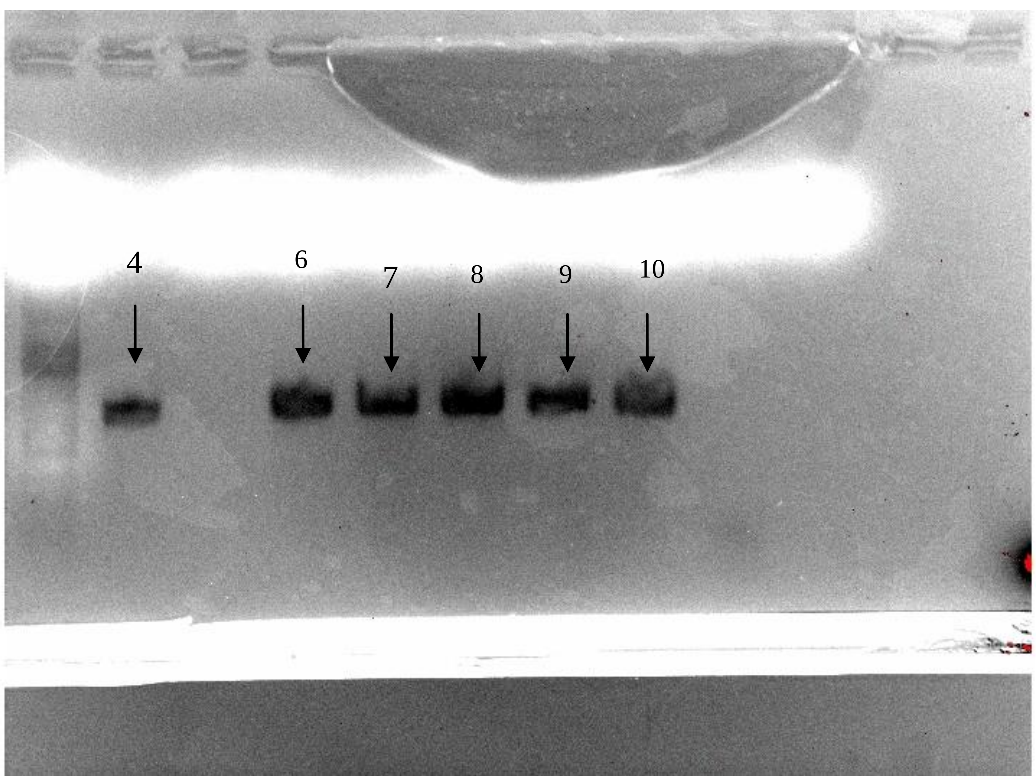


Figure 52. All samples except #5 showed a band in the gel image.

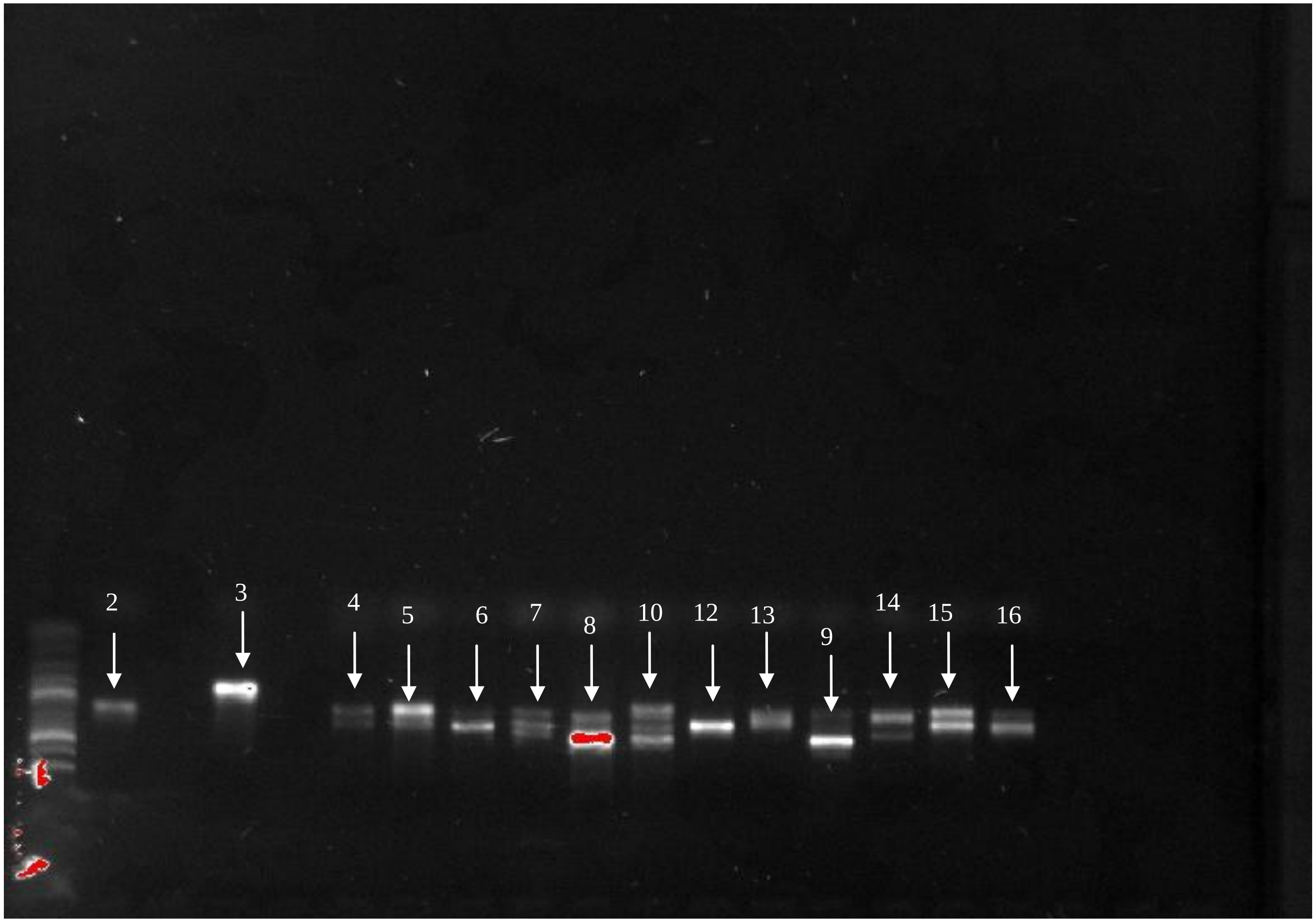


Figure 53. First successful attempt in which all samples produced bands. No.1 and 11 were not used (as they weren't ecotomycorrhizal).

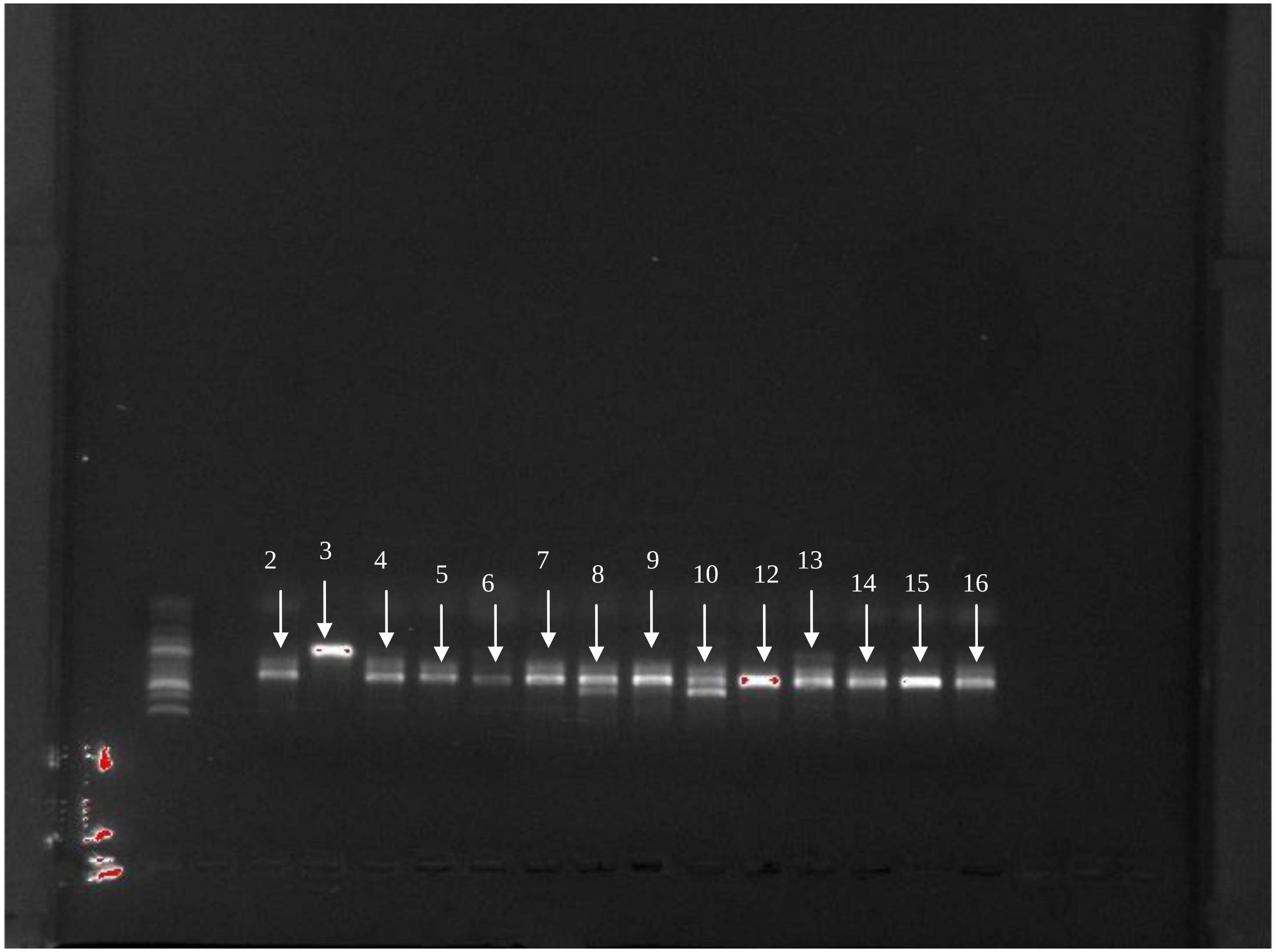


Figure 54. Bands for all samples. #1 and #11 were not used (as they weren’t ecotomycorrhizal).

Results

After cleaning the sequences using Sequencher and combining all the sequencing results, 8 out of 14 fruiting bodies had good sequencing result and thus could be used on BLAST for identification. Also, some root tip samples were also used for DNA extraction and amplification. Some of them showed positive result in gel electrophoresis which can be seen in Figure 55. Table 27 includes sequences for those 8 fruiting bodies and three root tip samples that could be used for idenification on BLAST. Remaining fruiting bodies that were used for DNA extraction are included in Figure 56, Figure 57 and Table 28.

Figure 58- Figure 69 display the fungal species noticed at the study sites. As we can see, a variety of fungal species that included shelf fungi, coral fungi, chanterelles, earth star, puffballs and jelly fungi were noticed at the study sites. In addition to fungi, a few slime mold images have been included in the images. Although they are protists and not fungi, however, often they are studied by mycologists, therefore, their images were also included.

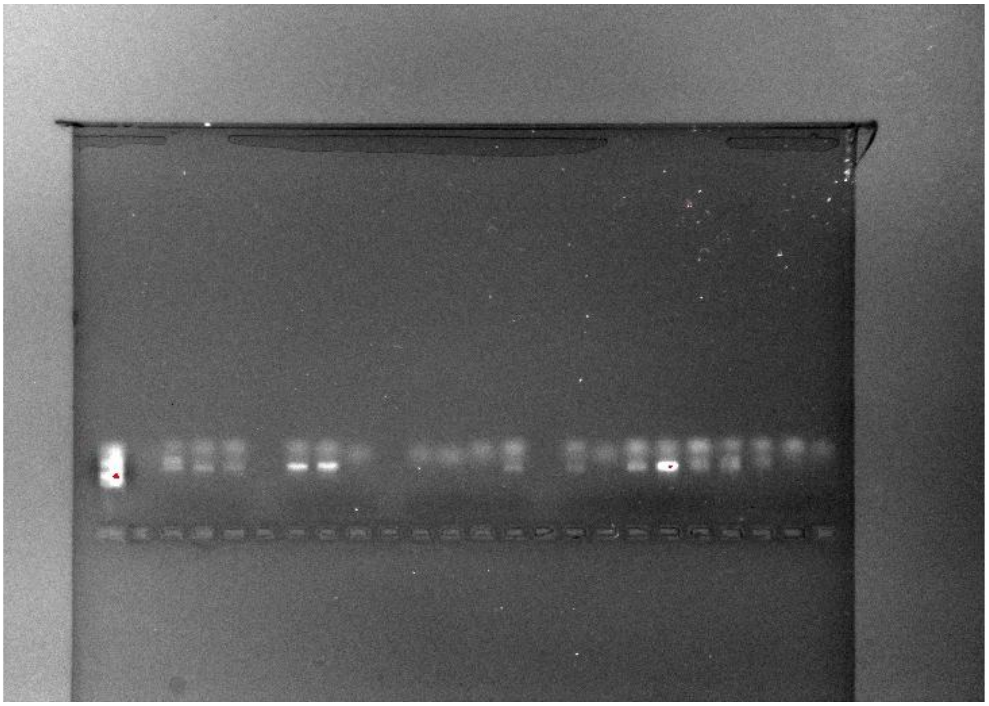


Figure 55. A gel image that shows bands for the root tip samples.

Table 27. The fruiting body and root tip samples that produced sequences that were able to be identified in BLAST.

Sample Name (Morphology based identification)	DNA Sequence	Best match on BLAST search and an image of the samples
KLRL04 (*Clitocybe* sp.)	AAGGGTCGTGCACNGCCTCGGTGCTYTCGTACAAAATCCATCTC ACCCCTTTGTGCATCACCGCGTGGGGACCCCTTTTGGCTAGTTC TGAAGGGGGTTTTCACGTTTTTATACAAACACCCTTTTAATGCA ATATGTAGAATGTCTTACTTTTTGCGATCACACGCAATTAATAC AACTTTCAACAACGGATCTCTTGGCTCTCGCATCGATGAAGAAC GCAGCGAAATGCGATACGTAATGTGAATTGCAGAATTCAGTGA ATCATCGAATCTTTGAACGCACCTTGCGCCCTTTGGCATTCCGA AGGGCACACCCGTTTGAGTGTCGTGACATTCTCAAA	*Russula livescens* 
LKRL05 (*Russula* sp.)	AGTAAAAGTCGTAACAAGGTTTCCGTAGGTGAACCTGCGGAAG GATCATTATCGTACCAAATGTGTTAGGCATGCGAGGGCTGTCGC TGACCTCAAGGTCGTGCACGCCGGAGCGTGTCCTCTCACATAAT GCAATCCATCTCACCCTTTGTGCACCACCGCGTGGGCCCCCTTT GGGGGGCTCGCGTTTTCACACAAAACCCCCCCCTTTAAAAGTGT AGAGTGACCTCATTTATGAAATCAATACAACTTTCAACAACGGA TCTCTTGGCTCTCGCATCGATGAAGAACGCAGCGAAATGCGATA CGTAATGTGAATTGCAGAATTCAGTGAATCATCGAATCTTTGAA CGCACCTTGCGCCCCTTGGTATTCCGAGGGGCACACCCGTTTGA GCGTCGTGAATACCTCAACCTCCTTGGTTTCTTCTGGAGACCGA AGGAGGCTTGGACTTTGGAGGCCCTTGCTGGTGTCTCTGCCAGC TCCTCTCAAATGAATTAGTGGGGTCCCCTTTGCCGATCCTTGAC ATGTGATAAGATGCTTCCGTGTCTCGGTTTCTGGCTCTGTTGCTT TTGGGACCCGCTTCTAATCGTCTAGACCTTGCGTCAAGACAATG TTCAAGCCACGTCTCCCTTGTCGGGAAATGTCCTTGACCTCATG AACCCTTGACCTCAAATCGGGTGAGACTACCCGCTGAACTTAAG CATATCATAA	*Lactarius chichuensis* 

Table 27. Cont.

Sample Name (Morphology based identification)	DNA Sequence	Best match on BLAST search and an image of the samples
LKLS06 (*Lactarius* sp.)	TTCTTGGTCATTTTAGAGGAAGTAAAAGTCGTAACAAGGTTTCC GTAGGTGAACCTGCGGAAGGATCATTATCGTACCAAATGTGTTA GGCATGCGAGGGCTGTCGCTGACCTCAAGGTCGTGCACGCCGG AGCGTGTCCTCTCACATAATGCAATCCATCTCACCCTTTGTGCA CCACCGCGTGGGCCCCCTTTGGGGGGCTCGCGTTTTCACACAAA ACCCCCCCCTTTAAAAGTGTAGAGTGACCTCATTTATGAAATCA ATACAACTTTCAACAACGGATCTCTTGGCTCTCGCATCGATGAA GAACGCAGCGAAATGCGATACGTAATGTGAATTGCAGAATTCA GTGAATCATCGAATCTTTGAACGCACCTTGCGCCCCTTGGTATT CCGAGGGGCACACCCGTTTGAGCGTCGTGAATACCTCAACCTCC TTGGTTTCTTCTGGAGACCGAAGGAGGCTTGGACTTTGGAGGCC CTTGCTGGTGTCTCTGCCAGCTCCTCTCAAATGAATTAGTGGGG TCCCCTTTGCCGATCCTTGACATGTGATAAGATGCTTCCGTGTCT CGGTTTCTGGCTCTGTTGCTTTTGGGACCCGCTTCTAATCGTCTA GACCTTGCGTCAAGACAATGTTCAAGCCACGTCTCCCTTGTCGG GAAATGTCCTTGACCTCATGAACCCTTGACCCTCAAATCGGGTG AGACTACCCGCTGAACTTAAGCAT	*Lactarius chichuensis* 
LKRL07 (*Cortinarius* sp.)	AAGTAAAAGTCGTAACAAGGTTTCCGTAGGTGAACCTGCGGAA GGATCATTATCGTACCAAATGTGTTAGGCATGCGAGGGCTGTCG CTGACCTCAAGGTCGTGCACGCCGGAGCGTGTCCTCTCACATAA TGCAATCCATCTCACCCTTTGTGCACCACCGCGTGGGCCCCCTT TGGGGGGCTCGCGTTTTCACACAAAACCCCCCCCTTTAAAAGTG TAGAGTGACCTCATTTATGAAATCAATACAACTTTCAACAACGG ATCTCTTGGCTCTCGCATCGATGAAGAACGCAGCGAAATGCGAT ACGTAATGTGAATTGCAGAATTCAGTGAATCATCGAATCTTTGA ACGCACCTTGCGCCCCTTGGTATTCCGAGGGGCACACCCGTTTG AGCGTCGTGAATACCTCAACCTCCTTGGTTTCTTCTGGAGACCG AAGGAGGCTTGGACTTTGGAGGCCCTTGCTGGTGTCTCTGCCAG CTCCTCTCAAATGAATTAGTGGGGTCCCCTTTGCCGATCCTTGA CATGTGATAAGATGCTTCCGTGTCTCGGTTTCTGGCTCTGTTGCT TTTGGGACCCGCTTCTAATMGTCTAGACCTTGGCGTCAAGACAA	*Lactarius chichuensis* 

Table 27. Cont.

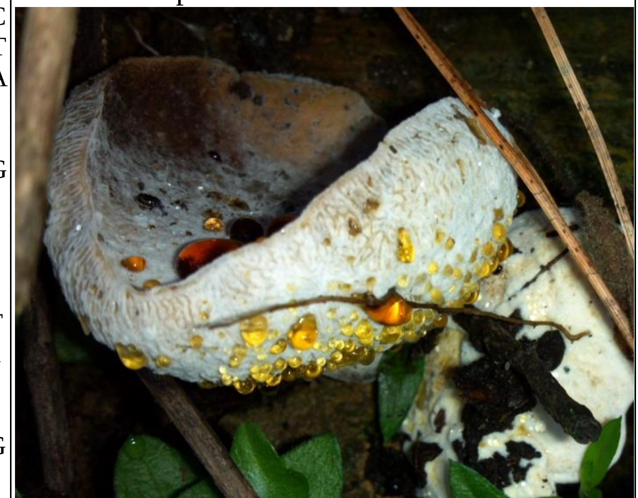
Sample Name (Morphology based identification)	DNA Sequence	Best match on BLAST search and an image of the samples
	TGTTCAAGCCACGTCTCCCTTGTCGGGCAAATGTCCTTGACCTC ATGAACCCTTGACCTCAAATCGGGTGAGACTACCCGCTGAACTT AAGC	
LKBL08 (*Boletus* sp.)	GATTTGATCTGAGAGGTAGAGAGACTGTGGCTGGCCGTCGATA CAAGACTGCATGTGCACGTCCCCTCACCTTTTCTAATTCTAATTC TAATTCTATCTACACACACCTGTGCACCTATTGTAGATCCCCCTT TGAAAGAGGGAGGGAACTATGCTTTTTTATCACATCACACATAA TGTATGTCCAGAATGTAATGTAATTTCATCGATCATTGGTTTGA TCAACGATGAAAACAAATGAAATGTAATACAACTTTCAGCAAC GGATCTCTTGGCTCTCGCATCGATGAAGAACGCAGCGAATTGCG ATAAGTAATGTGAATTGCAGATTTCCAGTGAATCATCGAATCTT TGAACGCACCTTGCGCTCCTTGGTATTCCGAGGAGCATGCCTGT TTGAGTGTCATTTAATTCTCAACCATTCTACTATTCTTCTTTCTT GGATTGATCTTGATCTATGAGAGGAGAGAGGGAAAGTATGGCT TGGAGTTGGGGGTTGCTGGCAGGAACTGTCAGCTCTCCTTAAAT GCATTAGCAATCGAGTTGGCTAGTCTTTGACGTGCACGGCTTCA GACGTGATAATGATCGTCTTAGCTGGAGTGTCTTTTCTAGACTA TGGTACATAGTAGATTGCTTCTAATCAGAATGGAAGAAAAAAA AGATAAGAGTCTAGAGTCTATCAAGCTTAGCTACTAGTCAGTCG AATTATTTATTCGAATGGCGAACACAAGCGAAAGAGAGGCGCT TGACCTTTCTTTTCTTTTCTTCT	*Xerocomus* sp. 
CHBL12 (*Boletus/Suillus*)	AAGTAAAAGTCGTAACAAGGTTTCCGTAGGTGAACCTGCGGAA GGATCATTAATGAAATTACAATTCGGCGAGGGAAAGGCGGAGA GTTGTAGCTGGCCGCCTAGGCATGTGCACGCTCTCTTCTGAACT TTTGTCGTTATGGGCGTGGGGGGGCGACCCTCCCGCGTCTTCAT ATACCTCTTCGTGTAGAAAGTCTTCGAATGTTATCATCATCATC GAGTCGCGACTTCTAGGAGACGCGATTCTTTGAGACAAAAGTT ATTACAACTTTCAGCAACGGATCTCTTGGCTCTCGCATCGATGA AGAACGCAGCGAATCGCGATATGTAATGTGAATTGCAGATCTA CAGTGAATCATCGAATCTTTGAACGCACCTTGCGCTCCTCGGTG TTCCGAGGAGCATGCCTGTTTGAGCGTCAGTAAATTCTCAACCC CCCTCGATTTGCTTCGAGAGGGTGCTTGGATGGTGGAGGCTGCC	*Suillus triacicularis*

Table 27. Cont.

Sample Name (Morphology based identification)	DNA Sequence	Best match on BLAST search and an image of the samples
	GGAGACCTGGATTCGTTCAGGACTTGGGCTCCTCTGAAATGAAT CGGCTTGCGGTCGACTTTCGACTTTGCATGACAAGGCCTTTTGG CGTGATAATGATCGCCGTTCGCCGAAGTGCACGACCGAATCGTC CCGCGCCTCTAATGCGTCGACGCCTTCTGGCGTCTTCCTTATTGA CGTTTGACCTCAAATCAGGTAGGACTACCCGCTGAACTTAAGCA TATCA	
CHBL15 (*Boletus/Suillus*)	TCTTGGTCNNNTTAGAGGAAGTAAAAGTCGTAACAAGGTTTCC GTAGGTGAACCTGCGGAAGGATCATTAATGAAATTACAATTCG GCGAGGGAAAGGCGGAGAGTTGTAGCTGGCCGCCTAGGCATGT GCACGCTCTCTTCTGAACTTTTGTCGTTATGGGCGTGGGGGGC GACCCTCCCGCGTCTTCATATACCTCTTCGTGTAGAAAGTCTTC GAATGTTATTATCATCATCGAGTCGCGACTTCTAGGAGACGCGA TTCTTTGAGACAAAAGTTATTACAACTTTCAGCAACGGATCTCT TGGCTCTCGCATCGATGAAGAACGCAGCGAATCGCGATATGTA ATGTGAATTGCAGATCTACAGTGAATCATCGAATCTTTGAACGC ACCTTGCGCTCCTCGGTGTTCCGAGGAGCATGCCTGTTTGAGCG TCAGTAAATTCTCAACCCCCCTCGATTTGCTTCGAGAGGGTGCT TGGATGGTGGAGGCTGCCGGAGACCTGGATTCGTTCAGGACTT GGGCTCCTCTGAAATGAATCGGCTTGCGGTCGACTTTCGACTTT GCATGACAAGGCCTTTTGGCGTGATAATGATCGCCGTTCGCCGA AGTGCACGACCGAATCGTCCCGCGCCTCTAATGCGTCGACGCCT TCTGGCGTCTTCCTTATTGACGTTTGACCTCAAATCAGGTAGGA CTACCCGCTGAACTTAAGCATAT	*Suillus triacicularis* 

Table 27. Cont.

Sample Name (Morphology based identification)	DNA Sequence	Best match on BLAST search and an image of the samples
CHRL16 (*Laccaria* sp.)	TCTTGGTNNNNTNAGAGGAAGTAAAAGTCGTAACAAGGTTTCC GTAGGTGAACCTGCGGAAGGATCATTATCGTACCAAATGTGTTA GGCATGCGAGGGCTGTCGCTGACCTCAAGGTCGTGCACGCCGG AGCGTGTCCTCTCACATAATGCAATCCATCTCACCCTTTGTGCA CCACCGCGTGGGCCCCCTTTGGGGGGCTCGCGTTTTCACACAAA ACCCCCCCCTTTAAAAGTGTAGAGTGACCTCATTTATGAAATCA ATACAACTTTCAACAACGGATCTCTTGGCTCTCGCATCGATGAA GAACGCAGCGAAATGCGATACGTAATGTGAATTGCAGAATTCA GTGAATCATCGAATCTTTGAACGCACCTTGCGCCCCTTGGTATT CCGAGGGGCACACCCGTTTGAGCGTCGTGAATACCTCAACCTCC TTGGTTTCTTCTGGAGACCGAAGGAGGCTTGGACTTTGGAGGCC CTTGCTGGTGTCTCTGCCAGCTCCTCTCAAATGAATTAGTGGGG TCCCCTTTGCCGATCCTTGACATGTGATAAGATGCTTCCGTGTCT CGGTTTCTGGCTCTGTTGCTTTTGGGACCCGCTTCTAATNGTCTA GACCTTGCGTCAAGACAATGTTCAAGCCACGTCTCCCTTGTCGG GAAATGTCCTTGACCTCATGAACCCTTGACCTCAAATCGGGTGA GACTACCCGCTGAACTTAAGCATAT	*Lactarius chichuensis* 
MGC9 (Root tip ectomycorrhizal fungi)	CCTCTTCGTGTAGAAAGTCTTCGAATGTTATTATCATCATCGAG TCGCGACTTCTAGGAGACGCGATTCTTTGATACAAAAGTTATTA CAACTTTCAACAACGGATCTCTTGGCTCTCGCATCGATGAAGAA CGCAGCGAATCGCGATATGTAATGTGAATTGCAGATCTACAGT GAATCATCGAATCTTTGAACGCACCTTGCGCTCCTCGGTGTTCC GAGGAGCATGCCTGTTTGAGCGTCAGTAAATTCTCAACCCCCCT CGATTTGCTTCGAGAGGGTGCTTGGATGGTGGAGGCTGCCGGA GACCTGGATTCGTTCAGGACTTGGGCTCCTCTGAAATGAATCGG CTTGCGGTCGACTTTCGACTTTGCATGACAAGGCCTTTTGGCGT GATAATGATCGCCGTTCGCCGAAGTGCACGACCGAATCGTCCC GCGCCTCTAATGCGTCGACGCCTTCTGGCGTCTTCCTTATTGAC GTTTGACCTCAAATCAGGTAGGACTACCCGCTGAACTTA	*Suillus triacicularis*

Table 27. Cont.

Sample Name (Morphology based identification)	DNA Sequence	Best match on BLAST search and an image of the samples
TC9 (Root tip ectomycorrhizal fungi)	CGAGCGTCAGATAAACAAAAAAATAAAAAGATGTCGTCGATAC CAGGTCCTCTTACTCAACTACTAATAGAACATAAATTCACAGGG TATATCTCGCGAATAGAAGCACACAGGGTTGCAGTGTCAGGTA CATTGTCCTCCCCCCCGATTGATAACTTCCTCTGCTTATGGATAT GTTCAAGTTCAGCGGGTATCCCTACCCGATTCKMAGGTCAAGTC TCATWGAATGTGGATTTCTAGGAACAGTCACRATTTCTAATCTG CCTRTACCAGCGAGTGAAAGTTCTTATCMCGTTGGGATAAAGC AGSCGTCWKACTATCTWTAATTTTGCARAGGGTAGAGGAGCTT GTTTCCATCTGCCTCTCTGACATGATCCAGGCCTGGCATCAAAG CCTAGCCTGATAGTTTCTGCTGACGCTGAGACGGGCATGCCCTA CGGATTAACCATAGGGCGCARTATGCGTTCAAAGACTCGATGA TTCAYTGAATTCTGCAATTCACATTAYTTATCGCATTTCGCTGCG TTCTTCATCGATGCAGGAGCCAARAGATCCGTTGTTGAAAGTTT TATTTTGAGAATTCAATCCCAATAGTTCAGACAAACATTTTAGT TTCCAAATACCCTCCCGCCGACCAACACCTCGGGTAGAGGTAA ATGGTCGACGGARGCAACAAAGGTAAGGWCAACAAAGGGGTC AAAGCATGATAAAAGCCGAAGCTTTCGATAATGATCCTTCCGC AGGTTCACCTACGSARRCCTTGTTACGACTTTTACTTCCTCTAAA TGACCAAGAACCTCCTGAAAGGACATAGATTGTTCTCTGCATGT CAAACTCTGTTTCTTTGTGTCCTATGGGAAGGTTGATGATACTT GAT	*Delastria* sp.
TC21	ACCCTTTACCCCTTCTGTGTATTTTACCTGTTTTTGGATGATGGA ATTAGTAAAATATTCCATAGAACAAATATTTTAAACTATTATTC ATAATGATATTAGTCTGATTTTGTATAAATAAAAGTTAAAACTT TCAACAACGGATCTCTTGGTTCTCGCATCGATGAAGAACGCAGC GAAATGCGATAAGTAGTGTGAATTGCAGAATTCAGTGAATCAT CGAATCTTTGAACGCACATTGCGCCTTCTAGTATTCTGGGAGGC ATGTCTGTTTGAGTGTCATTAAATCTTACTCTGGCAGTTTTGCTT GGATATGAAGGAAGAGCACATATAAAGGCTCTCTTTTGAAATG TATTAGTAGATGTAAAGTTGTGAATTACACTGTTTTGA	*Trichophaea woolhopeia*

Table 28. The morphology based identification of the fungi displayed in Figure 62 and 63..

Sample Name	Morphology based identification
LKRL02	*Russula* sp.
LKRL03	*Russula* sp.
LKBL9	*Suillus* sp.
LKBL10	*Suillus* sp.
CHRL13	*Lactarius* sp.
CHBL14	*Suillus* sp. (parasitized)

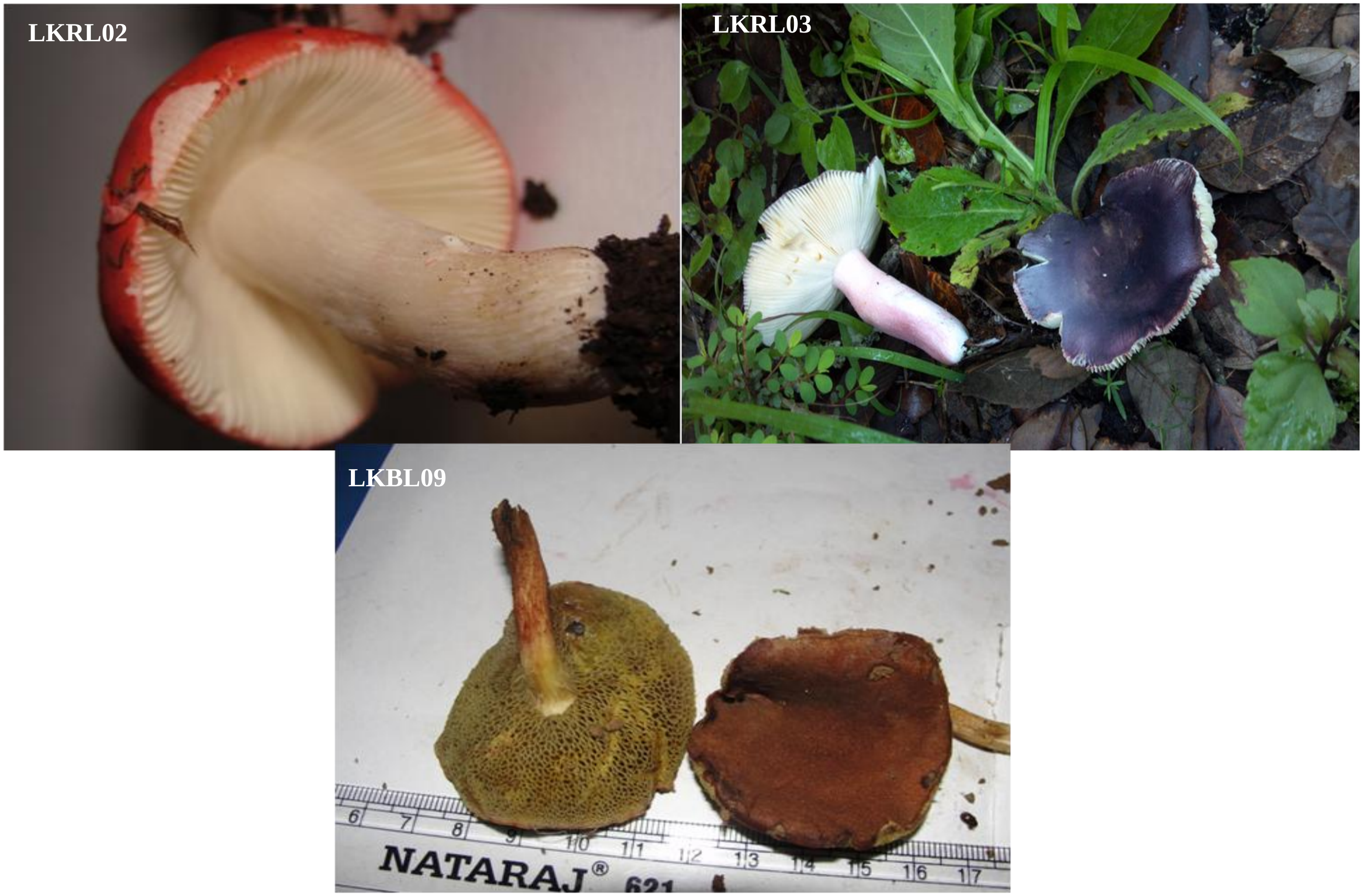


Figure 56. Remaining fruiting bodies that were used for DNA analysis

Figure 57. Remaining fruiting bodies that were used for DNA analysis

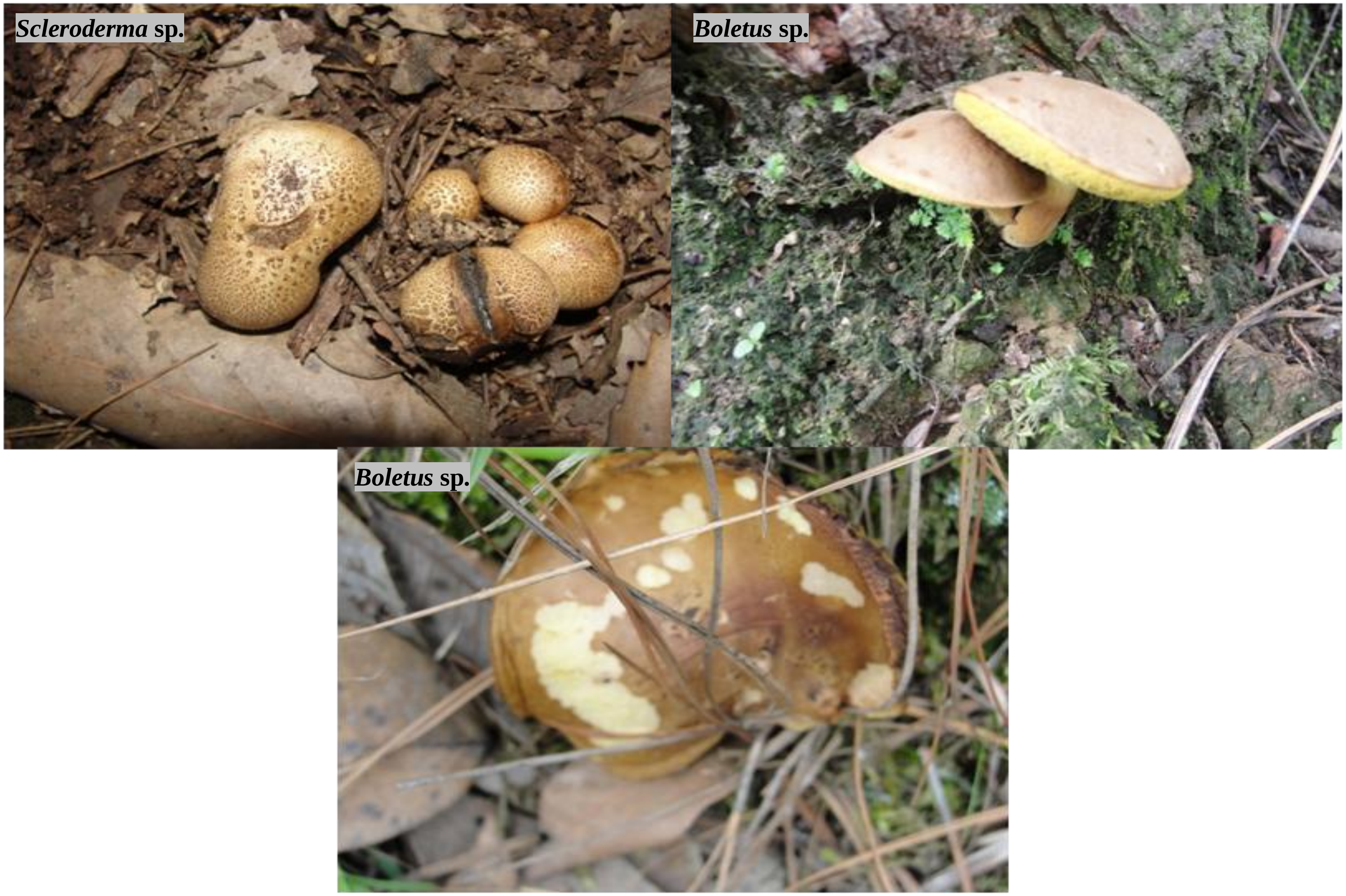


Figure 58. Fungi present at the Jakholi site.

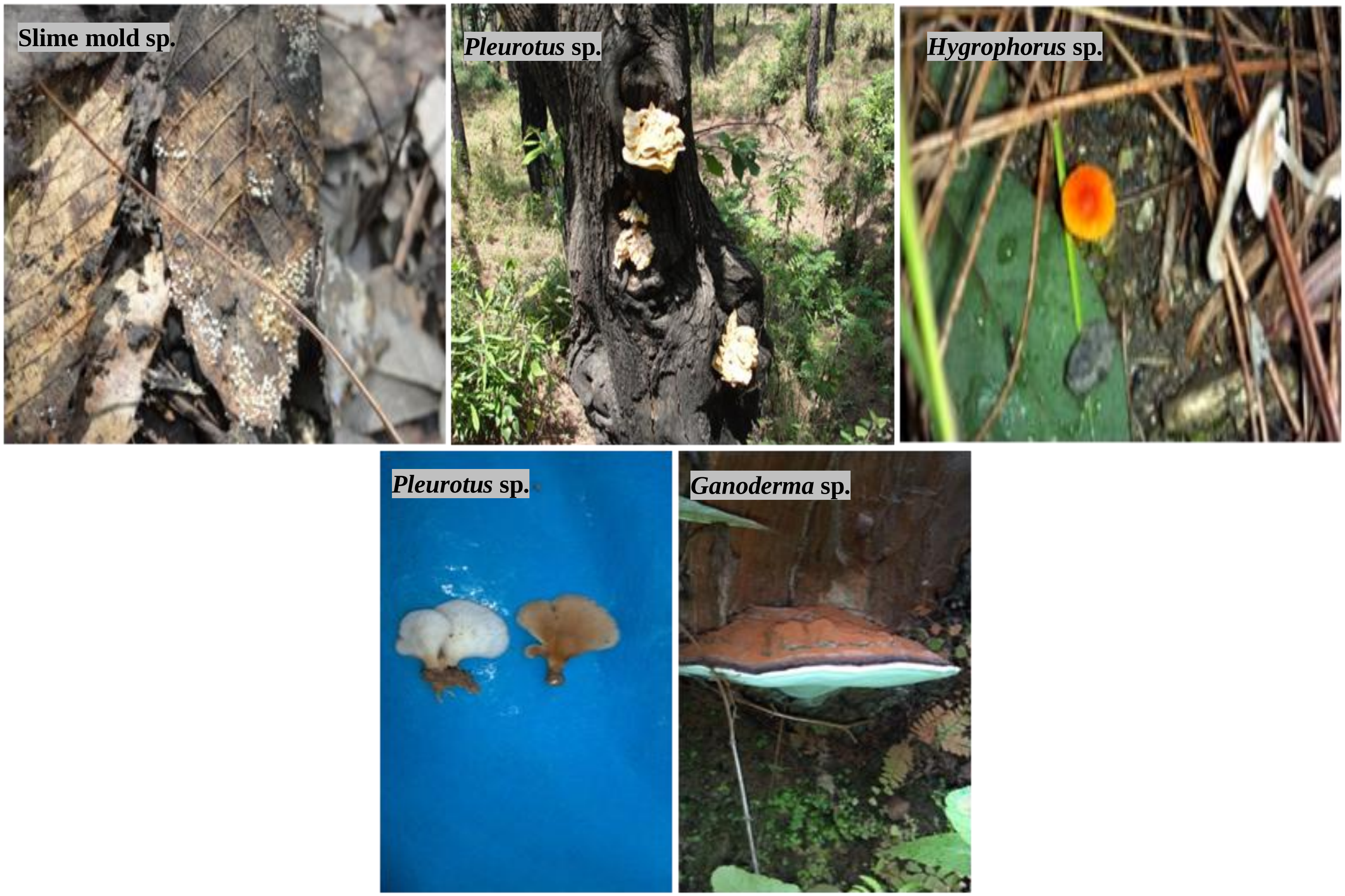


Figure 59. Images of fungi present at the Chamba site.

Figure 60. Macrofungi in the Ghansali oak forest.

Figure 61. A,C,D E were the fungi in Ghansali Oak forest. B was present in Ghansali Pine forest.

Figure 62. Macrofungi around oak forests at Ghansali site.

Figure 63. Macrofungi around oak forests at Ghansali site.

Figure 64. BT Oak site before monsoon.

Figure 65. BT oak site after monsoon.

Figure 66. BT oak site after monsoon.

Figure 67. BT oak site after monsoon .

Figure 68. Tehri Pine forest fungi before monsoon (One of the sites where root tips were collected in 2012).

Figure 69. Magra site macrofungi before monsoon.

Conclusions

Based on this study, the banj oak and chir pine forests are rich in terms of fungal diversity which includes ectomycorrhizal fungi as well. The BLAST results indicated that LKRL05, LKRL06, LKRL07 and CHRL16 had closest match with *Lactarius chichuensis.* As we can see in Table 27, none of these four species resemble each other. Therefore, the identification cannot be true for all four of them. One of the reasons behind the same identification match for morphologically different species can be that we need to use more specific primers or a different PCR protocol. The other reason can be that my study region is not well represented in terms of fungal DNA sequences available in Genbank (NCBI) database.

CHBL12 and CHBL15 showed best match with *Suillus triacicularis*, which is a new species described from the neighboring state of Uttarakhand (Verma and Reddy 2014). However, the species described by the authors (Verma and Reddy) looked very different from both of these species (Figure 70). CHBL12 and CHBL15 were found in a chir pine forest patch. *Suillus triacicularis* is the only species known to be associated with *Pinus roxburghii* in the Northwestern Himalaya (Verma and Reddy 2014). There are other *Suillus* species but they are associated with other conifers. Therefore, there is a good chance that these samples belong to either a new species or they are new records from this region of India. Pande et al. (2004) recorded the presence of seven different species of *Suillus* during their field work in the Western Himalaya, but none of them were present in the oak forests. Sarwar et al. (2011) mentions the presence of *Suillus* species (*S. brevipes* [Peck] Kuntze) in oak (*Quercus incana*) forests of the Himalayan region. However, the *Suillus* species observed in banj oak forest during my field work looked completely different from *S. brevipes* (Figure 71). Therefore, the *Suillus* species present at my banj oak forest site (LkBL08, LKBL09 and LKBL10) could be new species or a new record as well.

The sequenced data for the fungi present on root tip samples was identified as mycorrhizal species on BLAST (Table 27). Therefore, we can conclude that the identification of ectomycorrhizal species associated with banj oak and chir pine forest of this region is feasible with the use of root tip samples.

There are limited studies done on the ectomycorrhizal fungi present in this region and therefore, a number of species are possibly new to the science. There is a need for more research in order to understand the fungal diversity present in the region and to document the undefined new species. Moreover, such studies will be helpful in providing better representation of this region. in terms of fungal diversity.

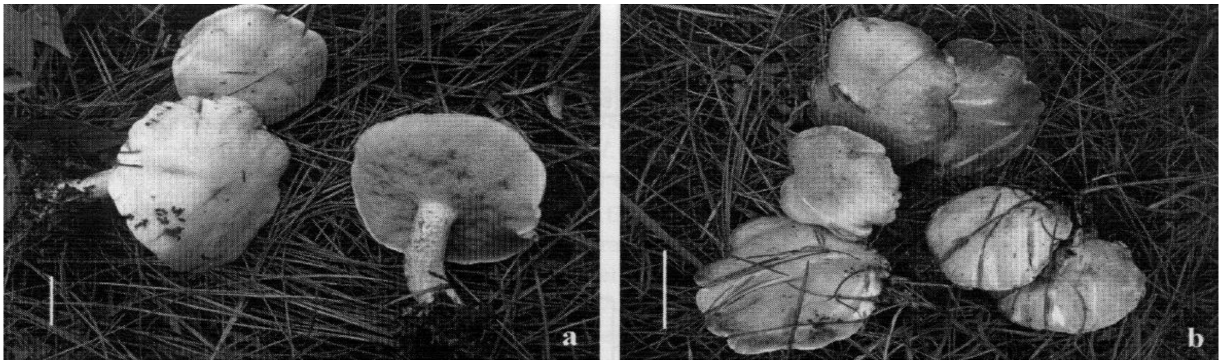


Figure 70. *Suillus triacicularis*. Source: Verma and Reddy 2014.

Figure 71. *Suilus brevipes*. Source: Sarwar et al. 2011.

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CHAPTER 8. DEPENDENCIES OF LOCAL PEOPLE ON THE FOREST RESOURCES AND THEIR AWARENESS REGARDING THE FORESTS OF THE STUDY REGION

The social survey was conducted in the Garhwal region of Uttarakhand state of India. The purpose of this survey was to understand the dependency of people on the banj oak and chir pine. Also, people were asked various questions regarding the ongoing conversion of banj oak into chir pine. Forests are an integral part of the life of people in the study region. Therefore, an efficient conservation strategy cannot be developed without a thorough understanding of socio-economic importance of the forests of this region. Although at present, local people are the main reason behind exploitation of banj oak forests, yet only local people can make any conservation and restoration efforts successful.

According to Sati (2012), "The Garhwal Himalaya is an economically underdeveloped and ecologically fragile region of the country. Due to the high proportion of the area under perpetual snow, steep slopes, forest, pasture, grazing and waste lands, only 12% area is put under cultivation." The author mentioned that the per capita net sown area in the region is 0.089 ha compared to 0.166 ha for of all India, and small and marginal holdings below 1 ha constitute more than 85% of the total holdings.

Five major categories of land holdings are marginal (below 1 ha), small (1-2 ha), semi-medium (2-4 ha), medium (4-10 ha), and large (10 ha and above). The study sites for my Ph.D. work were located in the Tehri Garhwal and Rudraprayag Districts of the Garhwal region. According to the Agricultural census of 2010-2011, in the Rudraprayag

District, there was just one holding (that too was a joint holding) which qualified for the large category with an area of 16 ha.

In the Rudraprayag District, there were total 27,093 holdings with a total area of 20,511 ha. Out of these, under the marginal category, there were 19,159 holdings with a total area of 7,290 ha and under the small category, there were 5,980 holdings with an area of 7,634 ha. This means that under small and marginal categories, there were a total 25,139 holdings with an area of 14,924 ha. Thus, 92.8% holdings were under the marginal and small categories with 72.8% of the total land area.

Four out of five sites are in the Tehri Garhwal District. So, if we look at agricultural census data from the Tehri District, the total number of holdings was 86,433, with a total area of 67,222 ha. Out of these, only 18 holdings were under the large category, with a total area of 248 ha. The marginal category had 64,922 holdings, with a total area of 29,988 ha, and the small category had 16,449 holdings with an area of 22,402 ha. Therefore, there were a total of 81,371 holdings under the small and marginal categories, which made up 94.1% of the total holdings in this district, and the total area covered under these two categories was 52,390 ha, which represented 77.9%. Looking at these data, it is evident that more than 90% of the holdings are less than 2 ha.

Uttarakhand was declared as the first organic state of India in 2001. Most of Uttarakhand is hilly, and the agriculture is rainfed and mostly organic by default. . Due to the mountainous terrain, terrace farming is practiced to avoid soil erosion (Figure 72-Figure 73).

The terraced fields in this region are not rich in humus and therefore only organic fertilizers are suitable since synthetic fertilizers are ineffective in the absence of irrigation whereas the organic fertilizers increase the water holding capacity of the soil and make the rainfed agriculture feasible (Somanathan 1991).

In addition, the hilly terrain makes it difficult to use heavy machines. Also, since most of the farmers have marginal or small holdings, it is also not economically viable to use advanced machines, synthetic fertilizers and modern irrigation techniques. Moreover, there is not much awareness and knowledge among farmers of this region about different insecticides, fungicides, and herbicides. However, the farmers of this region show a sound indigenous knowledge of farming.

The farmers of the Garhwal region follow subsistence farming. Instead of using fertilizers, they use manure, which they get from their own livestock. The fodder for the animals is generally collected from the forests. In addition, the local farmers also practice polyculture and crop rotation

Although the agriculture in this region is mostly rainfed, yet some villages located close to streams or water canals do receive irrigation water, especially for paddy crops.

The average rainfall is 1395 mm; the Mean minimum temperature is 14.8°C; the mean maximum temperature is 29.3°C; the net sown area is 562.06 km^2; the net irrigated area is 7913 ha; the actual irrigated area through canals is 4182 ha; the forest area is 322051 ha; the net sown area is 56206 ha; the production of food grains is 117970 Mt. Figure 74shows the land use distribution for Tehri district.

The cereal crops and pulses grown in this region includes wheat, paddy, soybeans/kala bhatt, ogal/kuttu/buckwheat, makka/bhutta/corn, rajma/kidney beans, koda/ragi/mandua/finger millet, kaudi, urad, jhangora/Indian barnyard millet,

Figure 72. An example of terrace farming as viewed from one of my study sites.

Figure 73. A village in the general study area.

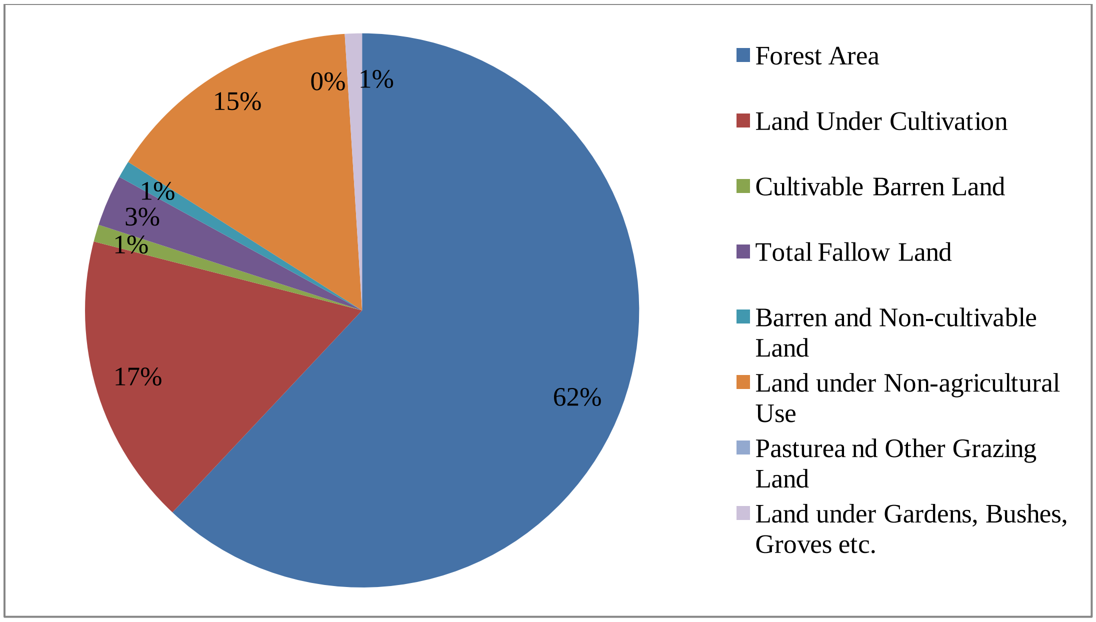

Figure 74. Land Usage in Tehri District. Source: Central Ground Water Board June 2011 report.

chaulai/raamdana, tor/arhar/pigeon pea, naurangi/nauranga/rains, gahath/horse gram, lobia/black eyed pea, masoor, and jau/barley.

Common vegetables/oil crop grown in this region include the potato, tomato, cabbage, cauliflower, rai/mustard, ginger, colocasia, radish, peas, chillies, capsicum, cabbage, cucumber, beans, ginger, garlic, leafy vegetables, pumpkin, turmeric, and bottlegourd. Fruits cultivated in the region are apricot, walnut, mandarin orange, malta (a blood orange), peaches, pears, apples, plums, lemons, and lime.

Most of the villages in the central Himalayan region are located in close proximity of oak forests. It is not a mere coincidence. People established their settlements around these forests as the oak forests are full of natural resources used by the local people. The leaves provide fodder for animals. The wood is used for making agricultural tools and also as fuelwood, whereas they also are the source of other resources such as wild fruits (e.g., kafal, scientific name *Myrica* *esculenta*), medicinal plants and edible fungi. In addition, the oak leaves are also used as a source of fertilizer.

Bhatt and Sachan (2004) did a study about firewood consumption in Garhwal Himalayas along an elevational gradient. They concluded that the per capita, per day consumption of firewood in kilograms was 2.80, 2.00, 1.42, 1.10 and 1.07 for >2000, 1500-2000, 1000-1500, 500-1000 and <500 m elevation. It can be noticed that as the elevation increases, the per capita firewood consumption also goes higher. The reason behind this increment in fuelwood consumption could be the lower temperature at higher altitudes and less accessibility to other fuel alternatives at higher elevations due to limited transportation facilities. According to Bhatt and Sachan (2004), "On average, the fuelwood consumption was 2.0–3.0-fold higher in winter than summer (considering 265 days as winter and 100 days as summer)." Sati (2005) conducted a survey of five villages in the Uttarakhand state of Central Himalaya and provided the information about firewood consumption in those villages which is listed in Table 29.

During this Ph.D. project, it was noticed that there were large canopy gaps in the banj oak (*Quercus leucotrichophora* A. Camus) forest due to lopping done by the local people. Also, there were not many banj oak seedlings as there were animals freely grazing and mowing inside the forests. In some of the forests, the exploitation was done to such a great extent that the banj oak trees had a woodland type of appearance in place of a dense canopy forest. Also, in such forests, chir pine invasion could be noticed. In addition, in some of the forests, banj oak was present in a shrub-like form due to coppicing and inability to grow further in presence of re-occurring disturbances. Singh and Singh (1992) and several other studies suggested that heavy exploitation of banj oak can result in degeneration of these forests and their replacement by chir pine forest.

Table 29. Firewood consumtion in five vilages in the Central Himalayas (data from Sati 2005).

Village	Elevation (m)	Distance from road head (km)	No. of families	Forest Type	Firewood consumption/ day (kg)		Ratio (per family consumption) (S+W)
					Summer	Winter	
Dimri	550	1	145	Scarce pine and bush	200	580	6.8
Kaiwar	1,200	2	150	Pine	350	900	10.6
Khainoli	1,900	11	150	Oak, Buransh Tilong and pine	500	1,400	16
Kwarad	2,200	15	130	Conifer	450	1,300	17
Lolti	1,800	0	120	Oak	300	840	12

Although the oaks of the region are exploited heavily by the local people, even the pine forests are not in a healthy condition either. The pine trees were heavily damaged for resin extraction. Some of the tree had deep and large scars. Some of the cuts made on these trees almost reached the pith of the trees. Chaudhari et al. (1988) did a study to compare the 'Rill' method and the 'Cup and Lip' methods, and they found that the Rill method (developed by Dr. V.P. S. Verma) is far less damaging than the previously followed 'Cup and Lip' method. The healing rate was found to be just 4.8 to 12.2 cm^2 in case of Cup and Lip method, whereas the healing rate for blazes caused by Rill method was 19.2 to 51.3 cm^2 per year.

Although chir pine is a fire tolerant species, unnatural frequent fires do affect it adversely. Resin extraction makes the trees vulnerable to more damage due to presence of large wounds. A recent study by Kumar et al. (2013) suggested that there is a decline in most of the soil nutrients (soil organic carbon, nitrogen, and phosphorous) post fire. Potassium decreased in most of the cases after the fire but increased in some cases. The authors also compared pre- and post-fire understory vegetation and they found out that the density of understory species declined after fire. This implies that although fire can help in releasing the seeds from the cones, too frequent occurrence of fire can result in reducing the soil nutrients as well as changing the vegetation composition of the pine forests.

Chir pine (*Pinus roxburghii* Sargent) forests are commercially important as they provide timber for construction of houses and furniture and also produce resin. In addition, their leaves are used as animal bedding and the grasses that grow in these forests serve as fodder for animals. Moreover, some medicinal plants and edible fungi can be found in these forests. Sometimes they support shrubs like *Rubus ellipticus* (yellow Himalayan raspberry, local names hisar or hisalu), which are source for delicious fruits for local people. However, generally, pine wood is not preferred for fuelwood if oak wood is available, as the former produces more smoke (based on comments by local people).

Although the wood obtained from chir pine is of a poor quality and thus not durable, local people still use it as timber. According to the local people, it is easily infected by termites. In addition, only a fixed quota of wood is allowed per family. Therefore, people do not obtain timber from these forests on regular basis. Furthermore, the resin from chir pine forests is sold commercially to contractors by the forest department. Therefore, local people do not receive any benefit from that either. However, the presence of resin in the wood increases its inflammability, which helps when it is used as fuelwood. Pine trees are also used during some religious ceremonies and festivals.

Although human interference has resulted in affecting the chir pine forests adversely, it has also caused expansion of these forests at the cost of broad leaved species like banj oak. As covered in the history of the forests of this region, chir pine was promoted during the British era for resin and timber. At present, although this species is no longer being planted, yet due to continuous exploitation of banj oak trres, canopy gaps have formed in the banj oak forests, which lead to the entry of chir pine. Also, most of the banj oak seedlings and saplings do not survive to grow into a tree, as they get grazed by livestock. On top of it, frequent fire in the chir pine forests also hinders the natural process of succession by making situations unfavorable for the establishment of oak seedlings.

People are highly dependent on the forests in the Central Himalayan region for various resources. The health of the forests in this region depends a lot on the level of human disturbances in these forests. Therefore, in order to understand these forest ecosystems better, it is very important to understand the level and nature of dependency of the local people on these forests. In order to do so, along with sampling vegetation and fungi and collecting tree cores, a social survey was conducted during the summers of 2011 and 2012. During the social survey, people from different villages were asked questions to fill out questionnaires.

The questionnaire (Figure 94) was prepared based on the experience gained during the ‘Rural Agricultural Work Program (RAWE)’ component carried out during the B.Sc. Agriculture (undergraduate degree). In that component, I (along with my classmates) spent about a month’s time with villagers and filled out some questionnaires to understand the household economics of those villagers. In addition, input for relevant questions was taken from the local people, and further improvements were made by the suggestions provided by my major professor Dr. Steven L. Stephenson, who has worked in the Central Himalayan region and is aware of the geography and human societies of the region. The rough draft for the questionnaire was first prepared in English but was translated to the Hindi language afterwards, as most of the village people do not speak/understand English. Most of the people speak or at least understand Hindi. The dialect spoken by most of the villagers is ‘Garhwali.’ Some villagers were not comfortable in speaking any other language besides ‘Garhwali’ (although they did understand Hindi). Therefore, knowledge of the ‘Garhwali’ dialect was required in order to conduct a survey in this region. The questionnaire had a total 33 questions, with some of the questions having further divisions. Therefore, the questionnaire consisted of 12 pages and included a wide range of questions. For example, some of the questions were related to the economics of the household and others related to their (the villagers’) dependency on the forests (i.e. for resources they obtain from the forests), their knowledge relating to ongoing changes in the forests and the causes behind these changes, and their opinions regarding forest conservation. Villagers were chosen randomly for this social survey. An attempt was made to include people from different villages in order to get different perspectives as well as an idea about the general dependency of the local people in the study region on these forests

Villages located close to the study sites were chosen, based on a random selection. However, it was found that often people belonging to different villages were present in another larger village for the sake of better job opportunities. A total of 58 people were given a questionnaire, which as already noted had 33 questions. Only 13 out of 58 people surveyed had an income ≥10,000 Indian rupees per month, which is equivalent to only about $163 at the current conversion rate (24th January 2015). This indicates that the villagers in the region are economically not sound and that is why they migrate to larger villages, towns and cities for better job opportunities. Most of the villages in the Garhwal region are scattered and not very populated. The people surveyed belonged to 33 different villages (Table 30).

During the village survey, it was noticed that people in the hilly region are highly dependent on the forest resources. People mentioned that they collect fodder for their animals from the banj oak forests as well as the chir pine forests, although most people showed a preference for banj oak forests as a fodder source. Banj oak tree leaves serve as a fodder source for the livestock. Oak wood is used as fuelwood and for manufacturing agricultural tools. Burans *(Rhododendron* spp.) and kafal (*Myrica* esculenta) are co-dominant species in banj oak forests. Burans flowers are used in this region for making squash and the wild fruits of kafal are very popular among the local people.

From the pine forest local people obtain grasses as fodder and pine needles for animal bedding. Chir pine wood is used as timber wood (the wood is not of a very good quality, however) and sometimes as fuelwood. The cones of chir pine are used for decorative purposes.

Chir pine tree twigs are also used during wedding ceremonies and other religious occassions. Chir pine is also a source of resin, which increases its commercial value.

Some people mentioned that they find it safer to live closer to the banj oak forest due to better climate in the vicinity of oak forest and also because it is less prone to fires as compared to the chir pine forests, which, along with fuel load of dry needles, also contains resin that promotes fire. The banj oak forests also provide a variety of other resources to the local people. For example, wild fruits (e.g. kafal (*Myrica esculenta*) and yellow Himalayan raspberry (*Rubus ellipticus*)) wild edible mushrooms, and medicinal herbs. Not only this, people associate presence of natural springs with banj oak forests and even though most of the people in the villages have a water supply in their homes, they still prefer to drink water from natural springs as they prefer its flavor and consider it more pure.

It is common to find water springs in vicinity of a banj oak forest, and that is the reason that many villages have been carved out of the banj oak forests. Out of a total of 58 people interviewed, all 58 had water supply. However, 23 mentioned that they also used natural springs as a water source, and two mentioned a ‘well’ as their alternative water source.

Despite of having LPG (liquefied petroleum gas) cylinders at their homes, people prefer to rely mostly on fuelwood from the forests, as the LPG cylinders are quite expensive relative to the earning of people in this region. Also, not only do they get fodder from the forests, people mostly rely on manure for their agriculture, which they get from the livestock grazing on the fodder. Because of this, as well as decaying animal bedding or fodder being used as a fertilizer, forests are the ultimate source of manure. Also, forests help in maintaining hydrological cycle of the region. Unfortunately, many households do not have basic facilities of toilets and thus they use forests for that purpose as well.

Table 30. Number of people (58 total) surveyed and their respective villages, and the preference of people between chir pine and banj oak forest.

Village Name	Number of People Surveyed	Age	Oak Preference	Pine Preference	Prefer Both Forest Types
Bada Syunta	1	44	1		
Bajra	3	55, 68, U	3		
Barsir	2	U	2		
Beed	1	30	1		
Bhowna	1	U	1		
Budkot	1	U			1
Chaksari-Dhanari	1	41			1
Chamiyala	1	40	1		
Chanji	6	50, U	6		
Cheintadbagi	1	51	1		
Chirbatiya	1	61	1		
Ganuwadi	1	70			1
Gorti	1	U	1		
Hadiyala Malla	1	U	1		
Haleda Malla	1	U	1		

Table 30. Cont.

Village Name	Number of People Surveyed	Age	Oak Preference	Pine Preference	Prefer Both Forest Types
Haleda Talla	1	U	1		
Haweli (Patti Saklana)	1	43			1
Kapdiyan	6	U	4	1	1
Kholi Hadiyana, Hindaw	1	70	1		
Lagwe	3	42, 58, 75	1	1	1
Luthyar	2	33, 58	2		
Mishwand	1	U	1		
Mod (Patti-Kunjdi)	1	29	1		
Molno	2	50, 61	2		
Nawa Gaon-Satyo-Saklana	1	18	1		
Pokhal	7	25, 40, 41,53, 56, U	5	-	2

Table 30. Cont.

Village Name	Number of People Surveyed	Age	Oak Preference	Pine Preference	Prefer Both Forest Types
Pujar	1	43	1		
Sawli	2	42, 52	1		1
Sukhtal	2	35, 40	2		
Suman Colony, Chhati	1	U			1
Titrana (Nailchami, Tehri)	1	58			1
Uroli-Ijra	1	39			1
Ijra	1	63	1		
Total = 33	**58**		**44**	**2**	**12**

* The ‘U’ in the table means unknown.

Figure 75. Villagers participating in the social survey (Photograph by Shashank Bhatt.Used with permission)

Figure 76. A local woman answering the questions asked by one of the volunteers (Mrs. Usha Nautiyal) during the social survey (Photograph by the author).

According to the local people, chir pine and banj oak forests are also home for a number of wild animals. The animals observed by the local people in these forests include deer/stags, leopards, tigers, monkeys, bears, langoors, wild boars, rabbits, wild cats, porcupines, jackals, foxes, snakes, spotted deer, and neelgai.

The common birds noticed in the forests by the local people are crows, cuckoos, warblers, hawks, parrots, sparrows, teetar (grey falcolins), owls, woodpeckers, ghughuti (turtle doves), crows, wild fowl, chakor/chukar, eagles, kites, monal, wild pigeons, batair (quails), house sparrows, red billed blue magpies, fakhta (doves), hilans, chatak (pied crested cuckoos), baaz (falcons), Himalayan monal, kafu (night czars), and mynahs.

Common livestock in the villages surveyed were cows, bullocks, buffalo, goats, chickens and hens. Various fodder sources mentioned by the villagers were banj, burans, khilonka (*Ficus nemoralis* Wall. Ex Miq.), moru oak, kharsu oak, kandali (*Urtica dioica*), straws of wheat, kadwei (*Litsea polyantha*), bhimal (*Grewia optiva* J. R.Drumm. ex Burret [syn *G. oppositifolia* Buch.-Ham. ex D.Don]), khadik (*Celtis australis* L.), daikan, timla/timila (*Ficus auriculata* Lour. Syn. *F. roxburghii*), kachnar (*Phanera variegata* (L.) Benth}, maalu {Bauhinia vahlii (Wt. and Arn.) Benth} padam/payan (*Prunus cerasoides* Don.), chamlai (*Desmodium elegans* D.C.), chanchari (*Ficus subincisa*), aiyar (*Lyonia ovalifolia* [Wall.] Drude), utees (*Alnus nepalensis* D. Don) and khagsu (*Boehmeria macrophylla* Horn.), various grasses, crop residue and ground grains (soaked or cooked).

The majority of the villagers described chir timber as having a poor quality and mentioned that is it weak and more prone to damage by termites. They preferred wood of sheesham and deodar as compared to chir. Most of the people surveyed had little knowledge of the existence of forest councils in their village. Most of the people believed that there was no restriction in harvesting the fodder leaves and collecting dry wood, yet the trees themselves cannot be cut.

The 41 year old villager from Chaksari-Dhanari, was one of those who believed that they (villagers) have the right to collect fodder and dead wood or woody debris but cannot cut the trees. He also mentioned that there is no forest council in his village. On the other hand, the teenager student from Nawan Gaon (Satyo Saklana), mentioned that the forest council was present in their village and they have the right to take fodder leaves from the forest. One of the villagers from Kapdiyan, was among those who said that the village council/panchayat existed in their village. He also mentioned that the forest boundaries were delimited under forest (vanikaran) policies and they have the right to collect fodder leaves.

According to one of the villagers from Luthyar, in his village, the forest council is more responsible than the forest department. There is not much cooperation from the forest department, and they are careless. He believes that the villagers do not have any right to collect fodder and fuelwood from the forest. He further mentioned that they (villagers) do not harvest live/green wood from the forest as it takes more time to dry up. He also mentioned that no one objects to them collecting fodder from the forest, and the forest department does not take responsibility.

Although most of the villagers said that they rely on forest fodder leaves, there were some villagers who used leaves from cultivated species as well. For example, a woman from Chanji village, told us that in addition to banj leaves she feeds bhimal and khadik leaves and grass to her livestock. Similarly, another villager (Lagwei Village), also mentioned that they use bhimal and khadik leaves along with banj and burans. Also, a middle aged woman from

Figure 77. An old house in one of the villages in the study area.

Figure 78. A picture taken in one of the villages with a local woman (Photograph by Mayank Bhatt.Used with permission).

Figure 79. A local woman lopping a banj oak tree (Photograph by the author).

Figure 80. Local women carrying the fodder, pine needles and fuelwood collected by them from the forest (Photograph by the author).

Figure 81. A pile of fuelwood at one of the villages.

Figure 82. The use of fuelwood to heat water.

Kapdiyan was among those who grew their own fodder trees as well. She mentioned that although she and her family collect banj, aiyar (*Lyonia ovalifolia* [Wall.] Drude), kadwei (*Litsea polyantha*), kafal, bhimal, khilonka and burans leaves from the forest they also grow bhimal, timla and mulberry trees for animal fodder. A resident of Pokhal village told us that he uses the following plants as the fodder sources: banj, kandali (*Urtica dioica*), gwiryal/Qwiral/kachnar (*Phanera variegata* (L.) Benth}, chanchari (*Ficus subincisa*), maalu {Bauhinia vahlii (Wt. and Arn.) Benth}, bhimal and khadik.

An illiterate woman from Sukhtal told us that she and her husband depend upon agriculture, which gives them an income of just 10,000 INR a year. They live in a house made of stone, mud, wood and tin. They use banj and moru oak, utees and khagsu leaves, green grass, crop residue and grains to feed their buffalo. She mentioned that there is no Forest Council in their village. According to her, they have right to collect fodder from the forest; however, for timber wood; they need to seek permission from the forest department.

The amount of fodder collected by the villagers varied depending on their distance from the forest and the number/kind of livestock they had. For example, a local woman from village Gorti told us that the amount of banj leaves she collects from the forest is approximately 20 kg/day. On the other hand, a villager from Chaksari-Dhanari, mentioned that his family collects 30-40 kg of moru and padam/payan leaves every day. The 43 year old man from Haweli (Saklana Patti), told us that everyday his family collects 40-50 kg of banj oak, chamlai and green grass from the forest. A woman from Sukhtal village said that the amount of fodder leaves that she collects from the banj oak forest is 50 kg/day.

Although for most of the people, the amount of fodder collected from the forest was below 50 kg/day, yet there were a few villagers who mentioned that they collect up to 200 kg of fodder from the forest every day. The 58 year old man from Titrana, Nailchami was one of them. He mentioned that his family collects around 200 kg of fodder from the banj oak forest, and during rainy season about 100 kg of green grass is collected from the chir pine forest.

Only a few people had purchased and tried cattle feed from the market, and they said that they noticed an improvement in the milk quality. Out of the people surveyed, very few agreed that they collect mushrooms ("Chyun" in the Garhwali dialect) from the forest. Surprisingly, none of the people surveyed was able to name the mushrooms they collected. In fact, some of them simply associated the edibility of a particular mushroom with its color. This oversimplification of mushroom edibility criteria could be an important reason behind the mortalities associated with wild mushroom consumption. Although the incidence of deaths associated with poisonous wild mushroom consumption is not very high, yet it is not uncommon to hear about such incidences.

A villager from Pokhal, believes that white mushrooms are edible, whereas those, which are poisonous, turn red. According to the villager from Haweli, Saklana Patti, "A white capped mushroom is pure whereas the one with a black cap is poisonous. One of the villagers from Sawli-Suryadhar also believed that the white-capped mushrooms are edible and black capped ones are poisonous. In addition, the villager from Pujar Gaon had the same opinion that white mushrooms are the ones which are edible. A woman from Kapdiyan, was also among those people who mentioned that they collect mushrooms from the forest and consider the white mushroom edible and the red ones as poisonous.

However, the villager from Chaksari-Dhanari had a bit different opinion from the others. He mentioned that he collects mushrooms and considers the white mushroom poisonous and the red as edible.

The 70 year old man from Ganuwadi said that he consumes mushrooms from forest. He mentioned that he has observed various colored mushrooms such as, white, brown and yellow. He said that he can identify whether a mushroom is edible or poisonous. The 39 year old villager from Uroli said that he collects mushrooms from the forest, but he had a misconception that the mushrooms that produce froth upon addition of salt are the poisonous ones.

Based on the study done in the oak and pine dominant zones in the Garhwal Himalayas, Arya et al. (2011) listed total 42 different plant species that are used in pine and oak dominated zones. Eleven species were common between pine and oak forests. Banj oak dominated zone had total 28 fodder species, out of which 15 are wild species, 16 domestic and 7 grass species. On the other hand, chir pine dominated zone included 25 fodder species, out of which only four were wild species, 12 were domestic and 9 were grasses. During the social survey, people showed a clear preference for banj oak over chir pine. The main reason for their preference was their dependency on banj oak forests for a number of different resources. Also, they associate the presence of oak forests with a better climate and natural springs.Figure 83 shows that 76% of the people showed a preference for banj oak forests, whereas 3 % showed a preference for pine forests and the remaining 21% said that they like both of these forest types.

The reasons given by local people in favor of chir forests are as follows:

- Source of timber
- Source of fuelwood and leaf manure
- Purifies air

The reasons given by local people in favor of banj forest are as follows:

- Source of fodder, fuelwood and leaf manure
- Source of wood for agricultural tools

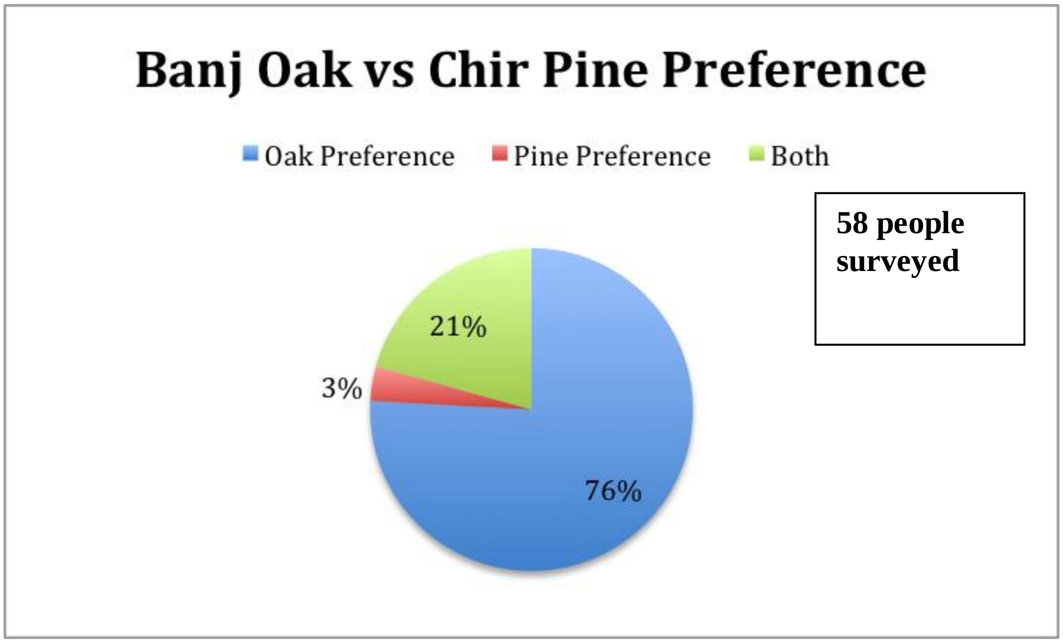

Figure 83. Villagers' preference (out of 58 people) for banj oak versus chir pine forest.

- Source of water/maintains water sources
- Source of medicinal plants and wild fruits
- Less fear of fire in the vicinity of forest
- Nice breeze/temperature
- Maintains greenery

The central Himalayan forests are rich in medicinal plants, which are used in various Ayurvedic medicines and have an immense commercial value too. In the past, local people used to rely on the medicinal plants and home remedies for curing most of the ailments. Therefore, the traditional knowledge of medicinal plants was very rich. Although people do not rely that much on the medicinal plants anymore yet even at present, the villagers use some of the traditional knowledge regarding medicinal plants, which has been passed on from generations.Table 31 has a list of some of the medicinal plants collected from the forests and their uses, as mentioned by local people during the social survey.

Table 31. Medicinal plants obtained from the forests and their uses by the local villagers.

Medicinal Plant (common name)	Uses by local people
Kadwei	Constipation, stomach ache
Kingod	Eye infections, diabetes
Vajradanti	For cleaning teeth, tooth ache
Haradi	General body aches
Baheda	Cold, cough and fever
Neelkanthi	Stomach ache
Chirayata	Fever, stomach problems, diabetes
Patharchatta	kidney stones, diabetes
Pashanbhed	kidney stones
Utees	Stomach problems, aches
Koot	Fever
Banjleesh	Stomach problems
Bhakundara Grass (Jhula dharu)	Source of dye and medicinal importance
Burans	The squash made out of flowers is of medicinal importance
Gilon/ Bel	Stomach problems
Timru/temru	cleaning teeth/dental hygiene
Nair/Thunair	Medicinal, as an incense for worship
Mol/Mehal	Stomach problems

Table 31. Cont.

Hisar/hisalu (yellow Himalayan raspberry)	Good for health
Kunja	Ear ache
Brahmi	Headache
Kadoi	Aches
Khair	Bark used for medicinal purposes

Figure 84. Pashanbhed, a medicinal plant for kidney stones.

Figure 85. Vajradanti, a medicinal plant for dental health.

People were asked if they observed any decline in the banj oak forest. Many people agreed that they have observed that banj oak forests are declining or becoming reduced in extent. Listed below are the reasons behind banj oak forest decline, according to local people:

- Decline in banj oak forests due to lopping/cutting and fire
- Declining due to population growth
- Declining due to diseases
- Chir pine forests are extending in area
- No thinning by the government
- Chir pine forests expanding at the cost of banj oak forests
- Forest fires
- Pollution
- Lack of rainfall
- Climate warming/change
- Illegal felling/lopping
- Spread of fire from chir pine forest into banj oak forest
- Chir pine inhibits productivity of other plants and trees
- Lack of proper care as people are leaving the villages
- Chir pine spreads rapidly and other plants cannot grow under it
- Because of the warming of climate chir pine is spreading
- Higher temperatures increased chir pine productivity
- Chir pine grows faster than the banj oak
- Chir pine seed dispersal is through wind
- Drying of natural springs

- Increased number of craftsmen
- Reduction in growth of plants and trees.
- Cutting of small plants and trees by humans to fulfill their requirements.
- Increase in gas prices has resulted in increase in use of fuelwood from the forest
- Forests are declining due to government corruption

Below are the remedial measures suggested by the local villagers for banj oak forest conservation:

- Appointing forest guards and avoiding damaging forest by burning and cutting
- Preventing fire, conserving rain water and cutting/removal of chir pine trees on time
- Numbers of chir pine trees should be reduced
- Plantation
- Awareness among public
- Proper lopping/pruning of leaves and training by the government for proper way of felling/lopping
- Reducing dependency on the forests for fodder
- Government should limit the chir pine forests
- There is need of improvement in forest management
- People should have consciousness
- Preventing spreading of chir pine seeds
- Taking proper care
- Controlling the number of craftsmen
- Van panchayat (forest council) should control forest exploitation

- Local people should be given the responsibility to take care of the forest by creating awareness among them
- Not cutting younger plants and trees and not cutting the new branches of bigger trees
- Promoting van panchayats, rewarding them for good work. Van panchayats should make decisions regarding forest fires.
- Making people aware about controlled/proper use of fuelwood
- Preventing killing of younger plants and trees for fodder

Although, most of the people (79%) agreed that they observed a decline in banj oak forests, there were some (14%) who believed that the condition of banj oak forests is better than that in the past, and the remaining (7%) think that the banj oak forests has been unchanged (Figure 86).

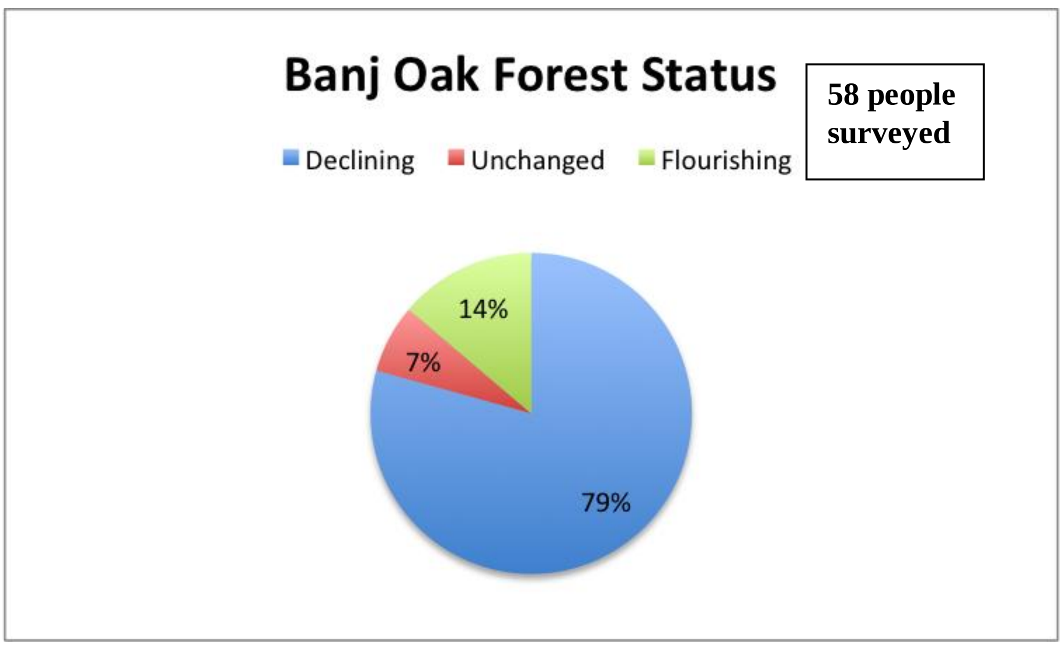

Figure 86. People's opinion regarding the status of banj oak forests in present as compared to the past (sample size = 58).

During the social survey, local villagers expressed their views about the current condition of the banj oak and chir pine forests. Listed below are some of the comments made by the villagers and conclusions made about their views:

The 43 year old villager from Haweli (Saklana Patti) thinks that banj forests are increasing in extent due to availability of gas (for cooking). The 41 years old villager from Chaksari- Dhanari also believes that the banj oak forests have increased in extent because of availability of gas, as there is reduction in lopping for fuelwood. He also mentioned that for past 2-4 years, forest fires have been under control. People who said that the banj oak forests are flourishing gave following observations in support of their opinion:

- Forests are receiving better care by the local people
- Forest department is more actively managing the forests
- Trees are taller and healthier which is resulting in denser forests
- Availability of gas has reduced the dependence on the forest for fuelwood
- Forest fires have been prevented for past 2-4 years

However, the majority of people mentioned that they observed a decline in banj oak forests. For example, one of the villagers (58 years old), who was a forest department employee believes that banj is declining and other broad leaved trees are reducing in number. He mentioned spreading of chir pine, climate change and use of banj oak as fodder as the possible causes behind decline of oak and other broad leaves trees.

When a 70 year old agriculture labor from Ganuwadi was asked about his opinion on changes in the forest, he replied that: “There is a reduction in growth of plants and trees and many plants and trees have become extinct.” When he was asked about his opinion on reasons behind banj oak decline, he said, “Cutting of small plants and trees by humans to fulfill their requirements.” For conservation of banj oak forest, he suggested that, “It is possible to do conservation by not cutting younger plants and trees to fulfill our needs and not cutting the new branches of bigger trees.” A 33 year old villager who owned a small business mentioned that, “Banj oak forests are reducing and the forests now have both chir and banj trees. It has happened due to the planting of other tree species in place of banj oak. Also, fire in chir pine forests impacts the banj forests. Banj trees dry up with even little heat exposure from the forest fire. Also, the trees cannot rejuvenate if lopped extensively. He mentioned that all the villagers go to extinguish the fire in event of forest fire.

A high school (12^{th} standard) student from Nawa Gaon, mentioned that chir pine has increased in extent. He also indicated that chir pine adversely affects other forest species as it inhibits productivity of other plants and trees. A 58 years old restaurant owner from Luthyar villager gave some suggestions for banj oak forest conservation, which are: awareness among public, proper lopping/pruning of leaves and training by the government for proper ways of felling/lopping.

Fires are frequent phenomenon in the chir pine forests of Central Himalayas. Although the healthy adult chir pine trees are fire tolerant, but the neighboring broadleaved forests and the young seedlings of broadleaved species like banj oak get heavily damaged due to fire. Also, the frequency of fire is not natural. And in most of the cases, it is induced by the local people in order to enhance the grass growth, which acts as fodder for their animals.

Since fire negatively impacts the oak forests, therefore people were asked questions about reasons behind fire and whether fire is good or bad in their opinion (Figure 87-Figure 91).

Below is the summary of reasons given against fire as well as the causes behind fire according to the local villagers.

Reasons given by people against fire in chir pine forests:

- Fire is bad for the timber wood of pine trees
- Young plants die and even the seeds get destroyed
- Fodder grass burns
- Animals and birds lose their nest/homes
- Animals and birds die due to forest fires
- Many plants burn and many species undergo extirpation
- Fire causes Pollution
- Larger trees also become weak
- Fire destroys resin and trees
- The needle leaves which serves as animal bedding burns
- Trees and leaves burn

Reasons behind fire in the chir pine forest-

- Forest department set the fire
- Carelessness of smoking travelers and villagers who leave burning matchsticks, beedi (tobacco wrapped in "tendu" leaves and smoked like a cigarette), or cigarettes behind on the forest floor
- Villagers burn their crop debris, shrubs and weeds (which they call as "aada") and that fire spreads to a neighboring forest
- Mischievous kids set the fire intentionally
- Spreads from the agricultural fields where villagers set fire to get rid of shrubs or bushes

- For rain some people do it intentionally (superstition)
- Spark from stone friction
- Intentionally by people to increase fodder growth
- Excessive needle leaves fall in pine forest. Pine needles accumulate (fuel load) and facilitate in forest fire
- Due to carelessness of villagers and forest department. For example, forest department employees set fire to the forest but do not extinguish it.

One argument in favor of fire:

- Good for growth of fodder

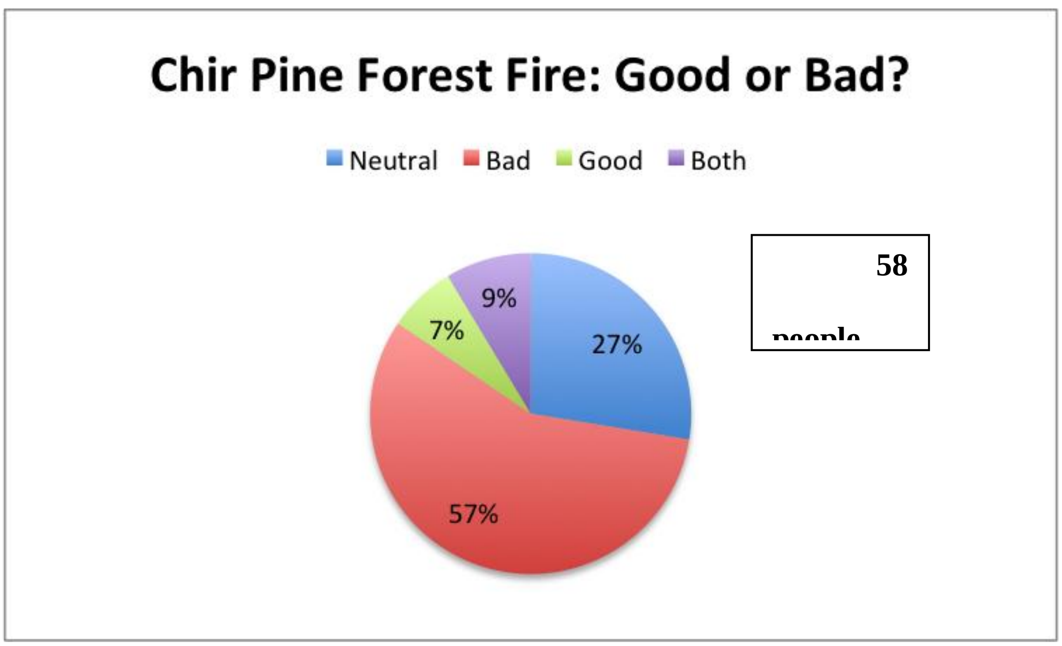

Figure 87. People's opinion about forest fire in chir pine forest.

Figure 88. Forest fire on the way to one of the study areas.

Figure 89. Ground cover was completely burned after the fire in this chir pine forest.

Figure 90. Banj oak and other broadleaved species get negatively affected by the fire.

Figure 91. Grass production is increased after forest fire in chir pine forests (Photograph by Akshay Uniyal. Used with Permission).

Since warmer temperatures might support hardy species like chir pine, people were asked if they observed any changes in the climate of their region. Fifty percent answered and remaining 50% either didn't answer or they were not sure. All of those who responded indicated that they observed changes in the climate. Below is the summary list of their observations.

The local woman from Gorti village said that the climate is changing and the reasons are deforestation, population increase and also the natural disasters caused as an outcome of wrong intentions and deeds of people. According to a villager from Kapdiyan, "Temperature of June month has increased and it is mostly foggy all around." Whereas, the 39 year old man from Uroli-Ijra believes that the temperature has increased but the rainfall is constant, although there used to be more snowfall earlier. Moreover, a villager from Chaati, who was a teacher by profession mentioned that occasionally there are untimely rainfall and draughts.

Summary of people's observations/opinion regarding climate change in the region-

- Warming of climate, there is a great difference in summer temperature of present and that of a decade ago
- Population growth, pollution etc. are causing rise in temperature
- Natural springs are drying
- Low productivity in Agriculture
- Adverse effect on forests
- Reduced rainfall
- Reduced snowfall
- Occasionally, untimely rainfall and draughts

Guha (2001) mentioned that banj oak trees, which are more valuable for local people, are getting replaced by chir pine trees, which are a more commercially important species. This author also mentioned that banj oak provides fodder, fuelwood and leaf manure to the local people, whereas chir pine is source of timber and resin. The author suggested that there can be serious implications of this transition. He mentioned that banj oak forest has a thick undergrowth which helps in more water absorption during the heavy monsoon season. This water percolates slowly down the hills, resulting in the presence of springs which provide good quality drinking water sources for the local villagers. On the other hand, the chir pine forest floor is covered with needles which have low water absorption capacity. Therefore, on the hillsides where chir pine is dominant, water rushes down with a rapid speed, causing soil erosion. Also, the water running down the hill carries debris and rocks, in addition to the soil, and thus contributes to floods.

Mira Behn was an English woman who joined Gandhi in 1926. She was adopted by Gandhi and given the name 'Mira Behn.' She actively participated and played a crucial role in the freedom struggle of India, and was even jailed several times due to that. She moved to the Ganges nearby Rishikesh in 1947, and from 1952-1959 she lived in the interior Himalaya (in the Bhilangana Valley). In 1959 she went back to Europe. Since she lived in the Garhwal region, she noticed the ecological changes happening in the forests of the region, and thus expressed her concern about this issue.

Guha (2001) quoted Mirabehn as follows:

> "It is not merely that the Forest Department spreads the chil [*sic*] pine," she said, "but largely because the Department does not seriously organize and control the lopping of the banj trees for cattle fodder, and ... is glad enough from

the financial point of view to see the banj dying out and the chil pine taking its place. When the banj trees grow weak and scraggy from overlopping, the chil pine gets a footing in the forest, and once it grows up and starts casting its pine needles on the ground, all other trees die out." Mira Behn continued: "It is no good putting all the blame on the villagers.... The villagers themselves realize fully the immense importance of these banj forests, without which their cattle would starve to death, the springs would dry up, and flood waters from the upper mountain slopes devastating their precious terraced fields on the slopes of the valleys. Indeed, all these misfortunes are already making their appearance on a wide scale. Yet each individual villager cannot resist lopping the banj trees in the unprotected Government forests, thinking 'if I do not lop the trees someone else will, so why not lop them, and lop them as much as possible before the next comer.'"

Guha (2001) indicated that the loss of community control may have resulted in short sighted behavior of the hill peasant towards the maintenance of forest cover, and this tendency was enhanced due to the commercial inclination of the forest department.

Mira Behn wrote (Guha, 2001) that-

"The problem is not without solution, for if trees are lopped methodically, they can still give a large quantity of fodder, and yet not become weak and scraggy. At the same time, if the intruding chil pines are pushed back to their correct altitude (i.e. between 3,000 and 5,000 feet), and the banj forests are resuscitated, the burden on the present trees will, year by year, decrease, and precious fodder for the cattle will actually become more plentiful. But all this mean winning the trust and co-operation of the villagers, for the Forest Department, by itself, cannot save the situation. Nor can it easily win the villagers' trust, because the relations between the department and the peasantry are very strained, practically amounting to open warfare in chil pine areas. Therefore, in order to awaken confidence in the people, some non-official influence is necessary.With the aid of local constructive workers, it should become possible to organize village committees and village guards to function along with the Forest Department field staff which should be increased and also given special training in a new outlook towards peasantry. In this way it should be feasible to carry out a well balanced long term project for controlled lopping and gradual return of the banj forests to their rightful place, by systematic removal of chil pines above 5,500 feet altitude to be followed by protection of the young banj growth. The banj forests are the very centers of the nature's economic cycle on the southern slopes of the Himalayas. To destroy them is to cut out the heart and thus bring death to the whole structure."

Guha (2001) mentioned that Mira Behn sent reports of her findings and photographs to then Prime Minister, Jawaharlal Nehru. They were passed on to the concerned officials by Mr. Nehru. However, the forest department didn't take any crucial steps in this regard and the poor condition of the banj forest continues to be the same.

Recent monsoons (in 2013), were devastating for the Garhwal region. Several thousand people died and there was great economic loss too, as numerous buildings and roads were washed away. One national newspaper (Figure 92) blamed ecological changes happening in the Himalayan region for this situation. They especially quoted Mira Behn regarding the replacement of banj oak by chir pine in order to explain how we could have avoided such situation.

Conclusions

Based on this survey, a greater number of people showed preference for banj oak over chir pine (76% and 3% respectively). Majority of people agreed that banj oak forests are declining (79%). Many of the reasons given by them behind banj oak decline were scientifically true, which shows that they have awareness regarding decline of banj oak. Although they get benefited by the grass growth after fire in chir pine forests, yet many of them (57%) agreed that it is not good for banj oak forests as well as animals residing in chir pine as well as banj oak forests. However, 7% thought that fire is good mainly because it increases fodder growth and 9% said it is good as well as bad, whereas remaining 27% were neutral. People told us the reasons behind forest fire. They also provided their suggestions for conservation and recovery of banj oak.

Local people are an integral part of the ecology of the forests in this region. They are responsible for disturbances, but in the past, people of this region had also played a role in conserving the forests (e.g. the Chipko movement of Garhwal region). Therefore, it must be realized that any conservation strategy or efforts cannot be a success until the local people are also part of it.

After undergraduation, I worked with an NGO, RACHNA, which works in the field of environment conservation in this region. Manoj Bhatt who is the Executive Director of RACHNA told us that they planted about 4500 saplings, out of which approximately 80% belonged to either oak or other fodder species and the

Hindustan Times
July 02, 2013

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Uttarakhand floods: The prophecy that was…

The devastation was inevitable in the Uttarakhand flash floods. There were signs, few subtle, most others blaring. Many an article was written in the press through the decades which highlighted that disaster was in the making. Mira Behn, a prominent environmentalist and a household name in Garhwal, wrote many articles in the press as well as letters to prime minister Rajiv Gandhi bringing to the notice the dire consequences of neglecting the ecological system in the Himalayan region.

Unwittingly, she became one of the torch-bearers of modern India's environmental movement.

The following are **excerpts** of her article published in The Hindustan Times on June 5, 1950 titled **'Something is wrong in the Himalaya'**

"Year after year the floods in the North of India seem to be getting worse, and this year they have been absolutely devastating. This means there is something radically wrong in the Himalaya, and that "something" is without doubt, connected with the forests.

I have become painfully aware of a vital change in the species of trees which is creeping up and up in the southern slopes — those slopes which let down the flood waters on the plains below.

This deadly changeover is from Banj (Himalayan Oak) to Chil (sic) pine. It is on at an alarming speed and because it is not a matter of deforestation, but change from one kind of forest to another, it is not taken sufficiently seriously. In fact the quasi-commercial forest department is inclined to shut its eyes to the phenomenon, because the Banj brings them in no cash for the coffers, whereas the Chill pine is very profitable, yielding as it does both timber and resin.

But what are these crores of revenue worth if all, and more than all of the amount of money, has to be spent each year on trying to repair the damages caused by floods?

The Banj leaves, falling as they do, year by year, create a rich black mould in which develops a thick tangled mass of undergrowth (bushes, creepers, and grasses), which in their turn add to the leaf-mould deposit and the final result is a forest in which almost all the rain water becomes absorbed. Some of it evaporates back into the air and the rest percolates slowly down to the lower altitudes.

The Chil pine produces just the opposite effect. It creates with its pine needles a smooth, dry carpet, which

absorbs nothing, and which at the same time prevents the development of any undergrowth worth the name. In fact often the ground in Chil pine forest is as bare as a desert.

But why are Banj forests disappearing so fast? It is not merely that the forest department spreads Chil pine, but largely because the department does not seriously organize and control the lopping of the Banj trees by the villagers for cattle fodder.

When Banj trees get weak and scraggy, from overlopping, the Chil pine gets a footing in the forest, and once it grows up and starts casting its pine needles on the ground, all other trees die out.

If the intruding Chil pine is pushed back to their correct altitude, and the Banj forests resuscitated, the burden on the present trees will, year by year, decrease, and precious fodder for the cattle will actually become more plentiful

The Banj forest are very centres of nature's economic cycle on the southern slope of the Himalayas. To destroy them is to cut out the heart and thus bring death to the whole structure.

The forest of the Himalaya are the Guardians of the Northern Plains, which, in their turn, are the Granary of India. Surely such guardians deserve the utmost care and attention that the Government can give them."

By Mira Behn

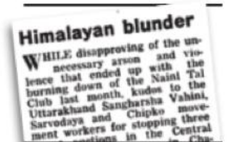
http://www.hindustantimes.com/StoryPage/Print/1085553.aspx

fromthepast

Warnings have appeared in Hindustan Times since 1950

June 05, 1950

"Deforestation, water logging and soil erosion". Written by noted Gandhian Mira Behn, the piece talks about how deforestation, water logging and soil erosion will ravage the country.



December 5, 1977

'Himalayan Blunder'. It talked about the importance of mountains and suggested several methods for regenerating the lost glory of the hills including a ten year moratorium on tree-felling.

August 23, 1998

"Pilgrims' destiny had no fury like nature scorned". Chandi Prasad Bhatt talks about how "in the name of pilgrim tourism, we are defying the terrain boundary condition in the Himalayas.

Figure 92. An article published in one of the National Newspaper regarding changes in forest and floods in Uttarakhand

remaining 20% were deodar saplings. Their emphasis was on fodder species since they wanted to promote social forestry. Due to livestock grazing, they had almost zero survival rates for banj oak and other fodder species. The deodar saplings survived initially since they are probably not preferred by the livestock, however as the scarcity of fodder increased during the winter, they consumed even the deodar saplings, due to which even deodar saplings could not achieve a good survival rate. This example reiterates that any restoration program cannot succeed without the cooperation from the local people.

Fire and grazing results in failure of establishment and survival of broadleaved species like banj oak. This hampers the process of succession and therefore the gradual transition of chir pine forest into a mixed broadleaved forest is inhibited. Furthermore, the canopy gaps in broadleaved forests are leading to entry and establishment of chir pine trees. This is leading to reverse succession where chir pine is replacing the broadleaved species. If all these disturbances keep prevailing then the chir pine monoculture will keep expanding. This could lead to great amount of damage to ecosystem, wild life, local people and even geological balance of these fragile mountains.

Due to their heavy dependency on the banj oak forests and their emotional attachment with these forests, the local people will not prefer decline or displacement of banj oak forests. However, in absence of alternatives for the resources they get from the forests and lack of sense of responsibility, it is not possible to encourage them for banj oak conservation. Even if it is not feasible to completely prevent all sorts of exploitation and disturbances in the forests, better management strategies can make a big difference by reducing the extent of damage. There is a need to develop a sense of community responsibility among local people so that the banj oak forests do not suffer due to the ‘Tragedy of commons.’ Also, the local people should be provided with alternatives so that their dependency on these forests can be reduced, and awareness should be created by educating the local people about how they are causing damage to the forest ecosystem and what its impact will be on them. Local people are very dependent on these forests, so even they will not prefer to completely devastate these forests. Although during the survey it was noticed that people are aware about the decline of banj oak forests and possible reasons behind it. However, in most of the cases, they are unaware of the extent of the damage they are causing and/or they do not know how they can prevent it since they are highly dependent on the forest resources. At present, majority of the banj oak forests exist only in form of small patches. Various studies, including the current one, suggest that the banj oak forests are declining. Under current circumstances, the only way to protect these forests is if the villagers and the government work together. NGOs can act as connecting link between the local people and the forest department. Participation by local communities is a must for successful conservation of banj oak forests.

Figure 93. Heavily lopped oak trees.

प्रश्नावली

दिनांक.................

ग्रामः– ....

1. नामः– ....

2.

परिवार के सदस्य	शैक्षिक स्तर (साक्षर, हाईस्कूल,इण्टर, बी0एस0सी0 इत्यादि)	व्यवसाय	मासिक आय

3. **जल आपूर्ति के साधनः– सही(√) का निषान लगाये**

क. कनेक्शन **ख.** हैण्डपम्प **ग.** नदी / नाला **घ.** अन्य(बताऐं) ....

4. **आपके पास लगभग कितनी भूमि है? नाली / बीघा / एकड़ में बताऐं ....**

खेती के लिए सिंचाई के साधन–

क. वर्षा

ख. ट्यूबवेल

ग. नहर

घ. अन्य (बताऐं)

Figure 94. Questionnaire used for the social survey.

5. खेतों में उगाये जाने वाली फसलें एवं उनकी पैदावार (कि0ग्रा0में)

क्र0सं0	फसलें	पैदावार

6. घर के निर्माण हेतु किन–2 चीजों का प्रयोग करते हैं?

मकान का प्रकार	**निर्माण में प्रयोग में आने वाली चीजें**
कच्चा मकान	
पक्का मकान	

निर्माण के प्रयोग में लायी जाने वाली लकड़िया– देवदार, चीड़, शीशम इत्यादि।

लकड़ी का नाम	**स्थायी**	**कमजोर**	**कारण**

7. आपके द्वारा इस्तेमाल किया जाने वाला ईंधन– सही(√) का निषान लगाये

खाना बनाने के लिए– **क.** लकड़ी **ख.** गैस **ग.**कैरोसिन **घ.** गोबर गैस **ड.**उपले

अन्य उपयोगों के लिए– **क.** लकड़ी **ख.** गैस **ग.**कैरोसिन **घ.** गोबर गैस **ड.**उपले

Figure 94. Cont.

8. किस प्रकार की लकड़ियों का प्रयोग ईंधन के तौर पर किया जाता है?

लकड़ी	मात्रा (कि0ग्रा0)	लाभ	ळानि

9. क. आपके पास कितने व कौन–2 से पालतु पशु हैं?

ख. पशु पालन में ज्यादातर कौन से चारे का प्रयोग करते हैं?

10. आपके पशु किस प्रकार का चारा खाते हैं?

पशु	चारा	प्रतिदिन की मात्रा (कि0ग्रा0)
गाय		
भैंस		
बैल		
ब्करी		
भेड़		
अन्य (बताऐं)		

Figure 94. Cont.

11. क्या आप गोबर का प्रयोग खाद की तरह करते हैं?

12. आप गोबर की खाद का प्रयोग कितनी मात्रा में करते हैं? जैसे–एक नाली खेत में कितनी गोबर की खाद डालते हैं?

13. क्या आप गोबर का प्रयोग ईंधन की तरह करते हैं? यदि हां तो लगभग कितना कि0ग्रा0 गोबर आप प्रतिमाह ईंधन के प्रयोग में लाते हैं?

14. आप किन–2 पेड़ पौधों का प्रयोग चारे की तरह करते हैं?

प्राप्ति श्रोत	पेड़/पौधों का नाम
जंगल से प्राप्त	
आप द्वारा उगाये जाने वाले	

15. आप निम्नलिखित वनों से क्या–2 वस्तुऐं प्राप्त करतें हैं?

वन का प्रकार	वनों से प्राप्त वस्तुएँ
चीड़ के वन	
बांज के वन	

16. बांज के जंगल से आप किन–किन पेड़ पौधों को चारे हेतु प्रयोग में लाते हैं? कृपया नीचे दिये गये रिक्त स्थान में पौधे अथवा पेड़ का नाम व उससे प्राप्त किये जाने वाले चारे की प्रतिदिन की मात्रा लिखिए।

चारे का श्रोत	प्रतिदिन की मात्रा

Figure 94. Cont.

17. क्या आप चीड़ के जंगल से चारे हेतु घास एकत्रित करते हैं? यदि हां तो चारे की मात्रा भी लिखिए (कि0ग्रा0 में)।

18. क्या चीड़ के जंगल में आग लगने के पश्चात चारे की उपज बढ़ जाती है?

19. क्या चीड़ के वनों में बहुत बार आग लगती है?......................

20. क्या आपको लगता है कि यह लाभदायक है या हानिकारक है?................

क्यों? ....

आपके अनुसार आग लगने के क्या कारण हो सकते हैं?

21. निम्नलिखित वनों से प्राप्त की जाने वाली जड़ी–बूटियों के नाम व उनके उपयोग लिखिए।

बांज के वन

जड़ी–बूटियों के नाम	उपयोग

Figure 94. Cont.

चीड़ के वन

जड़ी–बूटियों के नाम	उपयोग

22. क्या आप चीड़ अथवा बांज के वनों से कोई मशरूम/च्यूं प्राप्त करते हैं? .... यदि हां तो कृपया बताईये कि आप उन्हे कैसे पहचानते हैं अथवा वह कैसे दिखते हैं? (जैसे वह खाने योग्य हैं या जहरीले/विषाक्त हैं? उदाहरण दीजिए)

23. आप बांज के वनों को पसन्द करते हैं या चीड़ के? क्यों?

24. क्या आपके गांव में वन प्रबन्धन समिति है? .... आपके गांव के आस–पास के जंगलों की देखभाल व प्रबन्धन ग्राम सभा/ग्राम पंचायत के अन्तर्गत है या वन विभाग के? इस सम्बन्ध में आपके पास कोई जानकारी/अभिलेख उपलब्ध है?

25. क्या आपको वन से चारा व लकड़ी इत्यादि लेने का अधिकार है? विस्तार में बताऐं।

Figure 94. Cont.

26. **क्या आपने कभी बाजार से चारा खरीदा है? .... क्या इससे दूध की मात्रा या क्वालिटी/ गुणवत्ता में आपने कोई सुधार देखा?**

27. **यदि आप किसी और द्वारा एकत्रित किये गये चारे व लकड़ी को खरीदना चाहे तो आपको कितना मूल्य देना पड़ता है?**

चारा	**मूल्य (प्रति कि0ग्रा0)**
क. बांज	क. ....
ख.	ख. ....
ग.	ग. ....
घ.	घ. ....

लकड़ी	**मूल्य (प्रति कि0ग्रा0)**
क. बांज	क. ....
ख.	ख. ....
ग.	ग. ....
घ.	घ. ....

28. **क्या आपको लगता है कि आपके क्षेत्र की जलवायु परिवर्तित हो रही है?........ क्या आपको लगता है कि तापमान, वर्षा या बर्फ इत्यादि में कुछ बदलाव आये हैं? कृपया मौसम परिवर्तन के अपने अनुभव विस्तार में बताऐं।**

Figure 94. Cont.

29. **क्या बांज व चीड़ के वनों में गत वर्षों में कोई परिवर्तन आया है? .... यदि हां तो आपके विचार में इसके पीछे क्या कारण हो सकते हैं?**

30. **नीचे दिये गये वनों में कौन से पशु/पक्षी मिलते हैं? उनके बारे में विस्तार से बताऐं।**

चीड़ के वन

पशु	विस्तृत जानकारी

पक्षी	विस्तृत जानकारी

Figure 94. Cont.

बांज के वन

पशु	विस्तृत जानकारी

पक्षी	विस्तृत जानकारी

31. क्या आपके अनुभव में ऐसे पशु/पक्षी हैं जो विलुप्त हो रहे हैं?

चीड़ के वन–

पशु	विस्तृत जानकारी

Figure 94. Cont.

पक्षी	विस्तृत जानकारी

बांज के वन–

पशु	विस्तृत जानकारी

पक्षी	विस्तृत जानकारी

Figure 94. Cont.

पक्षी	विस्तृत जानकारी

बांज के वन–

पशु	विस्तृत जानकारी

पक्षी	विस्तृत जानकारी

Figure 94. Cont.

32. **क्या आपने विगत वर्षों में कुछ नये जंगली पशु/पक्षी देखें हैं जो पहले नही हुआ करते थे?**

चीड़ के वन–

पशु	विस्तृत जानकारी

पक्षी	विस्तृत जानकारी

बांज के वन–

पशु	विस्तृत जानकारी

पक्षी	विस्तृत जानकारी

Figure 94. Cont.

33. क्या आपने अनुभव किया है कि बांज के वन धीरे–2 कम होते जा रहे हैं?........ क्या आप इसका कोई कारण बता सकते हैं?

आपके विचार में बांज के वनों का संरक्षण कैसे किया जा सकता है?

Figure 94. Cont.

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CHAPTER 9. CONCLUSIONS

Tiwari (2000) mentioned that, "The Himalayas are geo-dynamically unstable, ecologically sensitive and economically underdeveloped."Forests are very crucial for maintaining hydrological as well as geological balance in the Central Himalayan region. In addition, as described in the "Village Chapter," the hill economy is also highly dependent on the forests. And they are clearly important for biodiversity conservation. According to Haigh et al. (1988), deforestation is the biggest environmental problem of Uttarakhand. It is almost impossible to estimate the extent of overall damage caused by degradation or decline of forests, since the forest ecosystems are not only delicate but also very complex. Therefore, any disturbance caused is not a solitary event, but has manifold impacts.

Although more than 64% of Uttarakhand is forested land, a large portion of this forested area is degraded. Prabhakar et al. (2006) used satellite images from May 1998 covering a 20,000 km^2 area in the Central Himalayan region to measure forest degradation in that region. The degradation was measured in terms of crown cover. The authors found that the percentage of degraded forest was much higher based on their study as compared to that provided by the Forest Survey of India (FSI).

Having a large forested area is not of much help if it is in degraded form. Somanathan (1991) suggested that the degradation caused due to various human activities results in a decline in crown cover of oak trees and continuous deterioration could leave just scrub. Prabhakar et al. (2006) mentioned that they treated the scrub as degraded forest since in the area they considered, scrub doesn't occur naturally other than small areas of juniper above the tree line (Singh and Singh, 1987).

During my research project, I came across some forests, which were either converting into scrub or already looked like scrub. Some people could argue that it is a naturally occurring form of the forest; however, as mentioned in the previous paragraph (Prabhakar et al., 2006), the scrubs in this region are actually degraded forests. Based on the 25 m^2 plot data estimations, the stem density for banj oak was 13100 per hectare in the chir pine plot of Jakholi. This number is very high and can be misleading. Just looking at this big quantity, it can be assumed that banj oak is flourishing well in this forest and in future it will replace the chir pine forest (as should happen in case of natural succession). However, this conclusion will be faulty since the reason behind higher number of stem count is not healthy regeneration but coppicing growth. As explained in the vegetation chapter, this site was probably a banj oak forest which got replaced by a chir pine forest. And unfortunately, the tree ring data of mixed forest of Jakholi suggest that chir pine trees present inside the oak forest are outcome of human disturbances. Since, the DBH classes data also suggest that this oak population is declining. It is very likely that in future, this oak forest at Jakholi site will get replaced by chir pine forest.

The local people of Central Himalayan region are heavily dependent on banj oak forests, therefore, the degradation and decline of these forests will incur social and economic losses to the people of this region. During this study, various signs of disturbances were noticed in banj oak forests and it was discovered that the two banj oak forest sites which were relatively less disturbed (Magra and Ghansali) did not show the declining population pattern (in DBH data) that was present in the remaining three sites. This indicates that since the decline of banj oak is not natural but human induced, if the exploitation of these forests is alleviated, the banj oak forests might recover back.

According to Singh et al. (2014) whole tree felling has significantly reduced after the green tree felling was banned in many parts of the Indian Himalaya in the early 1980s. However, lopping for fodder and fuelwood has been persistent in the region. Therefore, although the damage due to human disturbances is not measurable in terms of change in forest area, the quality of forest has been adversely affected by lowering the productivity and ecosystem carbon.

Singh and Singh (1986) cited the work done by Rawat (1983), Negi et al. (1983), Tiwari and Singh (1984), Rana and Singh (1984) and Rana (1985), who provided biomass estimates and a productivity range for oaks, indicated that the total forest biomass (dry matter) across nine oak forests was in the range of 294-787 t/ha, with an average of 447 t/ha. The highest value exceeded not only the values reported for other Central Himalayan forests but also other oak forests of temperate zones of the world. In these forests, 98.6% of the forest biomass was found to be in tree layer. Singh and Singh (1986) further mentioned that according to Troup (1921) banj oak is more resistant to tree fall among the oaks as they have comparatively more extensive root system. The biomass of the banj oak root system accounted for 24% of the tree biomass, whereas the root system of rianj and tilonj (moru) oak made up only 17-18%. In addition, the authors mentioned that a tilonj (moru) oak forest, with negligible biotic disturbance, was found to have a net primary productivity of 27.8 tons/ha/year. Therefore, the authors indicated that this higher value can be assumed as potential for the net primary productivity of the Central Himalayan oaks. The highly productive communities of the world range between 20-30 t/ha/year (Lieth 1975, Whittaker 1975). Thus, it can be concluded that if excessive exploitation and disturbances in the Central Himalayan oak forests is avoided, then they can easily achieve the range of the most highly productive communities of the world.

In this study, the soil of banj oak was generally found to be richer than the chir pine in terms of major nutrients and soil organic carbon. Banj oak forests are not only better than chir pine forests in terms of soil fertility, but also in terms of rain water interception, water holding capacity, infilteration and percolation. Therefore, these forests are more efficient in maintaining hydro-geological balance. Being a light demanding species, the canopy in chir pine forest is very open as compared to the dense canopy in case of a healthy banj oak forest. Chir pine usually makes monodominant stands which is not the case for banj oak forests. The vegetation density in oak forests is much higher as compared to the chir pine forests**.** Based on their study, Loshali and Singh (1992) mentioned that due to presence of more vegetational strata than is the case for the chir pine forests, banj oak-tilonj oak forest showed lower surface run off than the chir pine. Loshali and Singh (1992) noticed that the interception of bulk rainfall by leaf litter was maximum in a mixed banj oak-tilonj forest, followed by a mixed banj oak- chir pine forest and was least in the chir pine forest. The authors mentioned that Dabral et al. (1963) and Pathak (1983) also reported that broadleaf litter intercepts a greater amount of bulk precipitation as compared to the needle leaf litter.

As mentioned earlier, the chir pine forest canopy is not as dense as the canopy of a healthy banj oak forest. Therefore, the conversion of banj oak forest into chir pine forest will result in more open canopy and reduction in tree density. According to Haigh et al. (1988), reduction in vegetation cover results in making soil more compact and more prone to erosion. Due to the decline in vegetation more water reaches the ground in a shorter period of time, which leads to more frequent run offs and, therefore, more rapid soil erosion. Also, the amount of evapotranspiration declines. In addition, due to soil erosion, the soil depth decreases, which lowers the water holding capacity of the soil, which results in further reduction in water infilteration into the ground. This produces deeper water tables, dried natural springs and desertification of land surfaces. The problem is aggravated with the death of tree roots in the soil, which made steep hill slides more prone to frequent landslides. The soil and rubble from landslides result in a rapid rise of river and stream beds. Haigh et al (1988) further mentioned that the lack of a ground water supply and addition of surplus debris has converted many of the perennial streams into more ephemeral streams, as there is neither enough water nor enough flow.

Deforestation and road construction have made this region more prone to erosion and landslides, especially during monsoon rains, which result in increased sediment loads in the rivers and this ultimately causes more intense monsoon floods (Figure 95). In addition to all these factors, climate change can also worsen the flood situation in this region. Sudmeier-Rieux et al. (2012) suggested that climate change is responsible for more frequent flash floods. Flash floods result in immense damage to stream embankments, roads, orchards and terraces (IPCC 2014). Xu et al. (2009) mentioned that since the Himalayas region is glacier dependent, excessive runoff and flooding will threaten the livelihoods of the people of the region (IPCC 2014). Also, the increased weather hazards due to climate change will endanger tourists (Nyaupane and Chhetri 2009, as mentioned in IPCC 2014). Uttarakhand is one of the major pilgrimage centers in India and it is also famous for tourism and adventure sports. During the floods in Uttarakhand in 2013, 100,000 people were rescued but still more than 5700 people died. The majority of the people trapped due to floods and landslide were pilgrims and/or tourists. Therefore we can conclude that more frequent floods in the Himalayan region can result in ecological, hydrological and economic damage on a large scale, and they can result in even fatalities in this region.

Based on work done by various researchers (e.g. Government of India 1984; Swaminathan 1988; Chadha 1988; Dewan 1988), Tiwari (2000) concluded that if the current rate of deforestation and soil erosion is continued, it may lead to desertification of Indo-Gangetic plain within 50 years.

Although, based on the dendrochronology work done during this project, we can conclude that increase in summer rainfall will adversely affect the chir pine species, however we do not know how and to what extent the change in precipitation amount will affect the banj oak. Therefore, it cannot be predicted clearly whether the increase in summer precipitation will help in further expansion of chir pine at the cost of banj oak or not. However, since banj oak forests prevent run off and soil erosion, it can be assumed that the degradation and decline of banj oak forests will worsen the flood situation in the region.

According to Singh and Singh (1986), the oak forests have been converted or replaced by farmland, orchards, grasslands, shrublands and chir pine forest. As noted previously, many of the oak forests are also infected with invasive plants (e.g., *Lantana camara*), and some suffer disturbances due to various types of construction inside them. These changes in oak forests have also impacted the local people who are heavily dependent on these forests. Grass fodder is generally available only during the rainy season. Therefore, the conversion of oak forests into grassland has resulted in fodder scarcity. According to Singh and Singh (1984), people need to cover longer distances to collect fodder than previously (Singh and Singh 1986). Not only this, but it has also been observed that those villages where emigration was an easy possibility, people abandoned agricultural activities due to the depletion of forests (Singh 1985a, as mentined in Singh and Singh 1986). Because of the scarcity of fodder from the forests, people try to reduce

Figure 95 (a). A road safety sign which can be seen very frequently while travelling during monsoon season in this region. (b). A landslide covering a portion of the road on the way to Ghansali study site.

livestock populations, which results in low amounts of manure input and therefore lower productivity in agriculture, due to which people are forced to quit their agricultural activities.

Singh and Singh (1986) mentioned a study done by Singh et al. (1985) in which the authors (Singh and Singh 1985) indicated that if the biotic pressure is not continuous, then the young trees of banj oak have the capacity to coppice well even in case of clear cutting. The authors also suggested that the smaller size class trees and saplings, which are major component of the banj oak populations in forests, might be the outcome of coppicing.

Many villages in the Central Himalayan region are located in close vicinity of banj oak forests since these forests supply various resources like fodder, fuelwood, herbal medicines, edible fungi and wild fruits. In addition to that, people also associate these forests with better climate and natural springs (based on social survey). According to the study done by Sharma et al. (2009), the forest biomass fulfills about 75% fuel and fodder requirement of mountain villages (Singh et al. 2014).

It was noticed during the social surveys that the people in the study region are not economically sound. Social surveys indicated that the local people were aware of the ongoing degradation of banj oak forests and the reasons behind it. However, they cannot afford to avoid the use of banj oak forests until they have affordable alternatives. Complete prevention of banj oak forest exploitation will be the best option in order to conserve these forests. However, at least better management practices should be adopted until proper alternatives are developed or discovered which can be beneficial for the forests as well as the villagers. One of the better management techniques includes hand cutting of fodder rather than animal grazing. Nautiyal and Babor (1985) quoted work done by other researchers such as Ashish (1981) and Jackson (1981, 1983). Ashish (1981) mentioned that the Himalayan areas where grazing has been prevented have the capacity to produce three to four times more fodder and grass for hand cutting. Jackson (1981) demonstrated that if the grazing is reduced and stall-feeding is increased, the productivity of uncultivated land could be restored. In another work by Jackson (1983), as cited by Nautiyal and Babor (1985), it was suggested that the use of better feeding practices can improve the milk yield of Himalayan cattle. It was indicated that leaf fodder is richer in protein than the grass and also stays green in the dry season. Therefore, stall-feeding and practices like the use of chopped tree fodder in mangers were recommended in order to improve milk yield. In addition, stall-feeding leads to an increase in the amount of dung collected, which can be used as manure on the farms.

Singh et al. (2014) suggested some remedial steps for better forest management and conservation. They mentioned that if fast growing fodder species such as *Pennisetum purpureum* and *Thysanolaena* species are planted and protected on degraded areas and common lands, they can yield green fodder between 25-42 Mg ha^{-1} yr^{-1} (Integrated Fodder and Livestock Development Project [IFLDP] 2011). Plantation of fodder species can reduce the pressure on the forests for fodder, which might result in a healthier tree canopy. Singh et al. (2014) also suggested that use of fuel alternatives like biogas, cooking gas and electric stoves will reduce the amount of lopping for fuelwood and also will be helpful for the health of local people (especially women) since the traditional cooking practices produce high concentrations of harmful emissions and particulate matter (Smith et al. 2009). However, as mentioned earlier, the hilly region of the Central Himalaya is economically backward and that is the reason behind higher dependence on the forests for free natural resources. The other fuel alternatives should be subsidized or the villagers should be facilitated for production of fuel alternatives like “gobar gas” (biogas produced using cattle dung).

During the current study, species richness, vegetation structure and composition of the two forest types was found to be different. Therefore, it can be assumed that the organisms inhabiting these two forest types should also vary. There is a need to study the differences between chir pine and banj oak forest in terms of faunal diversity as well so that we can understand the extent of damage to the biodiversity that will be caused by decline and replacement of banj oak forests.

Based on the fungal work done during this study, it can be concluded that the study region is very rich in terms of fungal diversity. We were successful in sequencing and identification of ectomycorrhizal fungi present on the root tips collected from the study region. Therefore, we can conclude that molecular techniques can be used in identification of ectomycorrhizal fungi present on the root tips of the trees in this region. Also, the current study indicated that there is need of more research studies in the study region in order to document the fungal diversity, as there is a possibility that a number of species in the region are yet to be identified and could be completely new to the science

Based on this study we can also conclude that the application of dendrochronology can be helpful to differentiate between a natural mixed forest and a banj oak forest that has been encroached by chir pine due to various forms of disturbances. After identification of human caused chir pine-banj oak mixed forests, suitable restoration techniques should be adopted which should include removal of chir pine seedlings and saplings and chir pine leaf litter from the forest and if possible, removal of adult trees as well. However, the canopy gaps will continue to create suitable conditions for establishment of chir pine seedlings. Therefore, a continuous supervision is needed to prevent chir pine encroachment and ensuring banj oak re-establishment. In presence of the current level of disturbances, it is very unlikely that the banj oak forests will sustain for a long time, at least with their natural, dense canopy. Therefore, it is essential to conserve these forests by preventing all sorts of disturbances.

Zobel and Singh (1997) described Himalayan forests as extensive, diverse and highly endemic. The author mentioned that the trees present in the Himalayan forests represent the major families of not only the temperate regions but also the tropics. Himalayan region is underrepresented in databases. The generalizations based on researches done in other regions of the world can be misleading as the knowledge earned in other parts of the world might not be applicable to the Himalayan region. For example, rhododendron is a shrub in North America but it is a tree in the Himalayan region. In fact, it is state tree of Uttarakhand, India. Another example is that the maple and oak trees which are deciduous in North America are evergreen in the Himalayan region. Zobel and Singh (1997) also mentioned that different regions differ in economics and the nature of the society. Although conservation and management strategies can be developed based on ecological information and conclusions, the implementation and success of these strategies also depend upon how well the social and economic components are considered while developing such strategies. For example, the conservation of banj oak forest is impossible without cooperation from the local people. Although they are the biggest reason behind the current degradation of the banj oak forests, yet, the decline of banj oak forests will affect them most and therefore, they will feel more motivated to protect these forests if the sense of responsibility and belonging can be re-developed which used to be there in the past. Based on visual observations, size class distribution, negligible seedling count, coppice growth and tree age estimations, the current study suggests that the banj oak forests are declining, therefore there is a need to develop conservation strategies and remedial steps for the recovery of banj oak forests before they are completely degraded or displaced by the chir pine.

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APPENDIX

Table 32. Composition of the small trees (2.5 cm ≤ DBH < 10 cm) for the Badshahithaul study site.

Forest Type	**Species**	**Absolute Density (No./ha)**	**Relative Density**	**Absolute Basal Area (m^2/ ha)**	**Relative Basal Area**	**Importance Value**
Pine	*Pinus roxburghii*	54.0	100.0	2.5	100.0	100.0
	Total	54.0	100.0	2.5	100.0	100.0
Oak	*Quercus leucotrichophora*	8.0	8.5	0.4	13.0	10.8
	Rhododendron sp.	79.0	84.0	2.7	79.6	81.8
	Myrica esculenta	7.0	7.5	0.2	7.4	7.4
	Total	94.0	100.0	3.4	100.0	100.0
Mixed	*Pinus roxburghii*	3.0	21.4	0.1	13.7	17.6
	Quercus leucotrichophora	11.0	78.6	0.6	86.3	82.4
	Total	14.0	100.0	0.7	100.0	100.0

Table 33. Composition of the small trees (2.5 cm ≤ DBH < 10 cm) for the Chamba study site.

Forest Type	**Species**	**Absolute Density (No./ha)**	**Relative Density**	**Absolute Basal Area (m^2/ ha)**	**Relative Basal Area**	**Importance Value**
Pine	*Pinus roxburghii*	None				
	Total					
Oak	*Quercus leucotrichophora*	91.0	100.0	2.7	100.0	100.0
	Total	91.0	100.0	2.7	100.0	100.0
Mixed	*Quercus leucotrichophora*	116.0	92.8	4.4	90.5	91.7
	Pinus roxburghii	6.0	4.8	0.3	6.6	5.7
	Rhododendron sp.	3.0	2.4	0.1	2.8	2.6
	Total	125.0	100.0	4.8	100.0	100.0

Table 34. Composition of the small trees (2.5 cm ≤ DBH < 10 cm) for the Ghansali study site.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Pine	*Pinus roxburghii*	9.0	100.0	0.5	100.0	100.0
	Total	9.0	100.0	0.5	100.0	100.0
Oak	*Quercus leucotrichophora*	91.0	100.0	2.7	100.0	100.0
	Total	91.0	100.0	2.7	100.0	100.0
Mixed	*Pinus roxburghii*	8.0	72.7	0.2	57.2	65.0
	Quercus leucotrichophora	3.0	27.3	0.1	42.8	35.1
	Total	11.0	100.0	0.3	100.0	100.0

Table 35. Composition of the small trees (2.5 cm ≤ DBH < 10 cm) for the Jakholi study site.

Forest Type	**Species**	**Absolute Density (No./ha)**	**Relative Density**	**Absolute Basal Area (m^2/ ha)**	**Relative Basal Area**	**Importance Value**
Pine	*Pinus roxburghii*	19.0	100.0	0.5	100.0	100.0
	Total	19.0	100.0	0.5	100.0	100.0
Oak	*Quercus leucotrichophora*	86.0	50.3	3.3	57.0	53.7
	Rhododendron sp.	7.0	4.1	0.3	5.2	4.6
	Ficus nemoralis	3.0	1.8	0.1	1.2	1.5
	Myrica esculenta	27.0	15.8	1.1	18.6	17.2
	Lyonia ovalifolia	27.0	15.8	0.6	11.1	13.4
	Pyrus pashia	1.0	0.6	0.1	1.1	0.9
	Symplocos chinensis	20.0	11.7	0.3	5.8	8.7
	Total	171.0	100.0	5.7	100.0	100.0
Mixed	*Quercus leucotrichophora*	157.0	46.3	5.7	51.1	48.7
	Pinus roxburghii	3.0	0.9	0.2	1.6	1.2

Table 35. Cont.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Mixed	*Rhododendron* sp.	75.0	22.1	2.4	21.0	21.6
	Myrica esculenta	52.0	15.3	1.6	14.6	15.0
	Lyonia ovalifolia	38.0	11.2	1.1	10.2	10.7
	Symplocos chinensis	12.0	3.5	0.1	1.1	2.3
	Pyrus pashia	1.0	0.3	0.0	0.3	0.3
	Chyuda (local name, 2901)	1.0	0.3	0.0	0.2	0.2
	Total	339.0	100.0	11.2	100.0	100.0

Table 36. Composition of the small trees (2.5 cm ≤ DBH < 10 cm) for the Magra study site.

Forest Type	**Species**	**Absolute Density (No./ha)**	**Relative Density**	**Absolute Basal Area (m^2/ ha)**	**Relative Basal Area**	**Importance Value**
Pine	*Coriaria nepalensis*	1.0	100.0	0.0	100.0	100.0
	Total	1.0	100.0	0.0	100.0	100.0
Oak	*Quercus leucotrichophora*	62.0	72.1	2.3	71.5	71.8
	Rhamnus virgatus	1.0	1.2	0.0	0.6	0.9
	Quercus floribunda	11.0	12.8	0.4	12.0	12.4
	Abelia triflora	1.0	1.2	0.1	1.8	1.5
	Coriaria nepalensis	1.0	1.2	0.1	2.0	1.6
	Pyrus pashia	3.0	3.5	0.2	4.8	4.1
	Cornus macrophylla	4.0	4.7	0.1	3.6	4.1
	Cornus capitata	3.0	3.5	0.1	3.7	3.6
	Total	86.0	100.0	3.3	100.0	100.0
Mixed	*Quercus leucotrichophora*	42.0	71.2	1.5	84.7	77.9

Table 36. Cont.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Mixed	*Celtis australis*	1.0	1.7	0.0	0.7	1.2
	Toona serrata	13.0	22.0	0.2	10.8	16.4
	Pyrus pashia	2.0	3.4	0.0	2.7	3.0
	Cornus macrophylla	1.0	1.7	0.0	1.2	1.5
	Total	59.0	100.0	1.7	100.0	100.0

Table 37. Composition of the large trees (≥10 cm) for the BT study site.

Forest Type	**Species**	**Absolute Density (No./ha)**	**Relative Density**	**Absolute Basal Area (m^2/ ha)**	**Relative Basal Area**	**Importance Value**
Pine	*Pinus roxburghii*	121.0	100.0	24.1	100.0	100.0
	Total	121.0	100.0	24.1	100.0	100.0
Oak	*Quercus leucotrichophora*	94.0	77.7	26.2	86.2	82.0
	Rhododendron sp.	23.0	19.0	3.4	11.2	15.1
	Myrica esculenta	4.0	3.3	0.8	2.6	3.0
	Total	121.0	100.0	30.4	100.0	100.0
Mixed	*Pinus roxburghii*	73.0	73.0	19.5	71.8	72.4
	Quercus leucotrichophora	27.0	27.0	7.7	28.2	27.6
	Total	100.0	100.0	27.2	100.0	100.0

Table 38. Composition of the large trees (≥10 cm) for the Chamba study site.

Forest Type	**Species**	**Absolute Density (No./ha)**	**Relative Density**	**Absolute Basal Area (m^2/ ha)**	**Relative Basal Area**	**Importance Value**
Pine	*Pinus roxburghii*	41.0	100.0	35.1	100.0	100.0
	Total	41.0	100.0	35.1	100.0	100.0
Oak	*Myrica esculenta*	5.0	6.0	3.3	13.4	9.7
	Quercus leucotrichophora	79.0	94.1	21.2	86.6	90.3
	Total	84.0	100.0	24.5	100.0	100
Mixed	*Quercus leucotrichophora*	132.0	90.4	23.7	79.2	84.8
	Pinus roxburghii	12.0	8.2	6.0	19.9	14.1
	Rhododendron sp.	2.0	1.4	0.3	0.9	1.1
	Total	146.0	100.0	29.9	100.0	100.0

Table 39. Composition of the large trees (≥10 cm) for the Ghansali study site.

Forest Type	**Species**	**Absolute Density (No./ha)**	**Relative Density**	**Absolute Basal Area (m^2/ha)**	**Relative Basal Area**	**Importance Value**
Pine	*Pinus roxburghii*	85.0	100.0	20.4	100.0	100.0
	Total	85.0	100.0	20.4	100.0	100.0
Oak	*Quercus leucotrichophora*	118.0	86.1	41.5	81.5	83.8
	Pyrus pashia	2.0	1.5	0.7	1.3	1.4
	Rhododendron sp.	6.0	4.4	3.8	7.5	6.0
	Symplocos chinensis	1.0	0.7	0.3	0.6	0.6
	Lyonia ovalifolia	9.0	6.6	4.4	8.7	7.6
	Ilex dipyrena	1.0	0.7	0.2	0.4	0.6
	Total	137.0	100.0	50.9	100.0	100.0
Mixed	*Pinus roxburghii*	9.0	52.9	24.0	87.2	70.1
	Quercus leucotrichophora	3.0	17.7	0.7	2.5	10.1

Table 39. Cont.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ha)	Relative Basal Area	Importance Value
Mixed	*Rhododendron* sp.	3.0	17.7	2.6	9.3	13.5
	Lyonia ovalifolia	2.0	11.8	0.3	1.0	6.4
	Total	17.0	100.0	27.6	100.0	100.0

Table 40. Composition of the large trees (≥10 cm) for the Jakholi study site.

Forest Type	**Species**	**Absolute Density (No./ha)**	**Relative Density**	**Absolute Basal Area (m^2/ ha)**	**Relative Basal Area**	**Importance Value**
Pine	*Pinus roxburghii*	41.0	100.0	25.0	100.0	100.0
	Total	41.0	100.0	25.0	100.0	100.0
Oak	*Quercus leucotrichophora*	117.0	70.9	17.7	71.2	71.1
	Rhododendron sp.	7.0	4.2	0.9	3.5	3.9
	Myrica esculenta	36.0	21.8	5.7	23.0	22.4
	Lyonia ovalifolia	5.0	3.0	0.6	2.3	2.7
	Total	165.0	100.0	24.8	100.0	100.0
Mixed	*Quercus leucotrichophora*	104.0	61.2	17.6	62.9	62.0
	Pinus roxburghii	10.0	5.9	4.3	15.5	10.7
	Rhododendron sp.	23.0	13.5	2.3	8.1	10.8
	Myrica esculenta	30.0	17.7	3.5	12.5	15.1
	Lyonia ovalifolia	3.0	1.8	0.3	1.0	1.4
	Total	170.0	100.0	28.0	100.0	100.0

Table 41. Composition of the large trees (≥10 cm) for the Magra study site.

Forest Type	**Species**	**Absolute Density (No./ha)**	**Relative Density**	**Absolute Basal Area (m^2/ ha)**	**Relative Basal Area**	**Importance Value**
Pine	*Pinus roxburghii*	15.0	100.0	24.3	100.0	100.0
	Total	15.0	100.0	24.3	100.0	100.0
Oak	*Quercus leucotrichophora*	87.0	64.0	16.5	61.9	62.9
	Quercus floribunda	11.0	8.1	2.1	8.0	8.0
	Coriaria nepalensis	15.0	11.0	3.9	14.5	12.8
	Pyrus pashia	5.0	3.7	0.8	3.1	3.4
	Lyonia ovalifolia	2.0	1.5	0.4	1.3	1.4
	Cornus macrophylla	7.0	5.2	0.9	3.2	4.2
	Cornus capitata	7.0	5.2	1.9	7.1	6.1
	Viburnum coriaceum	2.0	1.5	0.3	1.0	1.2
	Total	136.0	100.0	26.6	100.0	100.0

Table 41. Cont.

Forest Type	Species	Absolute Density (No./ha)	Relative Density	Absolute Basal Area (m^2/ ha)	Relative Basal Area	Importance Value
Mixed	*Quercus leucotrichophora*	43.0	70.5	9.4	26.8	48.6
	Pinus roxburghii	14.0	23.0	24.7	70.7	46.8
	Morus alba	1.0	1.6	0.3	1.0	1.3
	Cornus capitata	1.0	1.6	0.1	0.2	0.9
	Pyrus pashia	1.0	1.6	0.3	1.0	1.3
	Coriaria nepalensis	1.0	1.6	0.1	0.4	1.0
	Total	61.0	100.0	35.0	100.0	100.0

Table 42. Smaller woody stems/shrubs/vines (1 ha) B.T. pine plot (28th June 2010).

Plant species	Number of stems per ha	Relative Density
Berberis aristata	200	2.44
Pyrus pashia	1600	19.5
Randia tetrasperma	6000	73.17
Rubus ellipticus	400	4.88
Total	8200	

Table 43. Smaller woody stems/shrubs/vines (1 ha) B.T. mixed plot (30th June 2010).

Plant species	Number of stems per ha	Relative Density
Berberis sp.	2200	6.36
Pyrus pashia	1900	5.49
Quercus leucotrichophora	2900	8.38
Randia tetrasperma	26100	75.43
Rhus wallichii	500	1.45
Rubus ellipticus	100	0.29
Smilax spinosa	100	0.29
Spiraea canescens	800	2.31
Total	34600	

Table 44. Smaller woody stems/shrubs/vines (1 ha) B.T. oak plot (29th June 2010).

Plant species Relative Density	Number of stems per ha	Relative Density
Berberis asiatica	1500	2.11
Colebrookea oppositifolia	2100	2.95
Myrica esculenta	2000	2.81
Myrsine africana	28000	39.33
Myrsine semiserrata	300	0.42
Pyrus pashia	4600	6.46
Quercus leucotrichophora	600	0.84
Randia tetrasperma	14100	19.80
Rhododendron sp.	1500	2.11
Rubus ellipticus	1400	1.97
Smilax aspera	800	1.12
Smilax spinosa	900	1.26
Spiraea canescens	13200	18.54
Vitis himalayana	200	0.28
Total	71200	

Table 45. Smaller woody stems/shrubs/vines (1 ha) Chamba pine plot (5th June 2011).

Plant species	Number of stems per ha	Relative Density
Berberis asiatica	7300	13.35
Berberis lyceum	200	0.37
Daphne papyracea	200	0.37
Myrica esculenta	2400	4.39
Myrsine africana	30500	55.76
Pyrus pashia	3900	7.13
Quercus leucotrichophora	1300	2.38
Randia tetrasperma	4700	8.59
Rubus ellipticus	3300	6.03
Smilax sp.	600	1.10
Viburnum cotinifolium	200	0.37
Vitis himalayana	100	0.18
Total	5470	

Table 46. Smaller woody stems/shrubs/vines (1 ha) Chamba mixed plot (4th June 2011).

Plant species	Number of stems per ha	Relative Density
Berberis asiatica	1700	7.56
Caryopteris odorata	400	1.78
Leptodermis lanceolata	400	1.78
Myrica esculenta	300	1.33
Myrsine africana	7800	34.67
Pyrus pashia	1900	8.44
Quercus leucotrichophora	2000	8.89
Randia tetrasperma	4900	21.78
Rhododendron sp.	400	1.78
Rhus parviflora	400	1.78
Rubus ellipticus	100	0.44
Smilax spinosa	1100	4.89
Symplocos chinensis	1100	4.89
Total	22500	

Table 47. Smaller woody stems/shrubs/vines (1 ha) Chamba oak plot (3rd June 2011).

Plant species	Number of stems per ha	Relative Density
Artemisia vulgaris	900	2.73
Berberis asiatica	700	2.12
Berberis lyceum	300	0.91
Caryopteris odorata	5200	15.76
Cotoneaster microphyllus	100	0.30
Eupatorium adenophorum	5700	17.27
Ficus racemosa	100	0.30
Leptodermis sp.	500	1.52
Myrica esculenta	500	1.52
Prunus cerasoides	2300	6.97
Pyrus pashia	1900	5.76
Quercus leucotrichophora	7200	21.82
Randia tetrasperma	7500	22.73
Solanum torvum	100	0.30
Total	33000	

Table 48. Smaller woody stems/shrubs/vines (1 ha) Ghansali pine plot (11th July 2011).

Plant species	Number of stems per ha	Relative Density
Citrus sp.	700	3.43
Indigofera heterantha	19700	96.57
Total	20400	

Table 49. Smaller woody stems/shrubs/vines (1 ha) Ghansali mixed plot (12th July 2011).

Plant species	Number of stems per ha	Relative Density
Berberis sp.	4500	17.11
Cotoneaster bacillaris	5700	21.67
Lyonia ovalifolia	2500	9.51
Pinus roxburghii	3600	13.69
Pyracantha crenulata	300	1.14
Pyrus pashia	700	2.66
Quercus leucotrichophora	3500	13.31
Rhododendron sp.	1400	5.32
Symplocos chinensis	3500	13.31
Viburnum cotinifolium	400	1.52
Vitis himalayana	200	0.76
Total	26300	

Table 50. Smaller woody stems/shrubs/vines (1 ha) Ghansali oak plot (12th July 2011).

Plant species	Number of stems per ha	Relative Density
Berberis sp.	600	6.12
Cornus macrophylla	300	3.06
Cotoneaster bacillaris	600	6.12
Daphne papyracea	300	3.06
Desmodium elegans	1000	10.20
Desmodium multiflorum	500	5.10
Hedera nepalensis	500	5.10
Ilex dipyrena	500	5.10
Jasminum humile	500	5.10
Leptodermis lanceolata	200	2.04
Lindera pulcherrima	1100	11.22
Litsea umbrosa	500	5.10
Quercus leucotrichophora	400	4.08
Rosa moschata	300	3.06
Sarcococca saligna	400	4.08
Smilax sp.	1000	10.20
Symplocos chinensis	200	2.04
Symplocos sp. 2 (5964)	600	6.12
Viburnum mullaha	100	1.02
Vitis himalayana	200	2.04
Total	9800	100

Table 51. Smaller woody stems/shrubs/vines (1 ha) Jakholi pine plot (10th July 2010).

Plant species	Number of stems per ha	Relative Density
Berberis sp.	2300	4.12
Flemingia bracteata	7800	13.98
Myrica esculenta	3900	6.99
Pyracantha crenulata	2700	4.84
Pyrus pashia	2900	5.20
Quercus leucotrichophora	13100	23.48
Randia tertasperma	12500	22.40
Rhododendron sp.	2000	3.58
Rubus ellipticus	1500	2.69
Smilax sp.	600	1.08
Symplocos chinensis	6400	11.47
Vitis himalayana	100	0.18
Total	67700	100

Table 52. Smaller woody stems/shrubs/vines (1 ha) Jakholi mixed plot (11th July 2010).

Plant species	Number of stems per ha	Relative Density
Berberis sp.	400	1.43
Caryopteris odorata	200	0.71
Cotoneaster microphylla	200	0.71
Daphne papyracea	100	0.36
Dicliptera sp.	3400	12.14
Elaeagnus sp.	200	0.71
Ficus nemoralis	800	2.86
Flemingia bracteata	1100	3.93
Lespedeza stenocarpa	1000	3.57
Lyonia ovalifolia	300	1.07
Myrica esculenta	200	0.71
Pyracantha crenulata	900	3.21
Pyrus pashia	4300	15.36
Quercus leucotrichophora	600	2.14
Randia tetrasperma	4000	14.29
Rhododendron sp.	100	0.36
Rubus sp.	300	1.07
Smilax sp.	1500	5.36
Spiraea sp.	300	1.07
Strobilanthes atropurpureus	5000	17.86

Table 53. Smaller woody stems/shrubs/vines (1 ha) Jakholi mix cont.

Plant species	Number of stems per ha	Relative Density
Viburnum cylindricum	100	0.36
Symplocos chinensis	3000	10.71
Total	28000	100

Table 54. Smaller woody stems/shrubs/vines (1 ha) Jakholi oak plot (9th July 2010).

Plant species	Number of stems per ha	Relative Density
Berberis asiatica	300	0.85
Berberis lycium	700	1.97
Dioscorea deltoidea	100	0.28
Ficus nemoralis	800	2.25
Lyonia ovalifolia	100	0.28
Myrsine africana	1700	4.79
Pinus roxburghii	100	0.28
Pyrus pashia	1300	3.66
Randia tetrasperma	7500	21.13
Rhamnus sp.	100	0.28
Rhododendron sp.	200	0.56
Smilax spinosa	2500	7.04
Strobilanthes atropurpureus	2700	7.61
Symplocos chinensis	1100	3.10
Viburnum coriaceum	100	0.28
Vitis himalayana	16200	45.63
Total	35500	100

Table 55. Smaller woody stems/shrubs/vines (1 ha) Magra pine plot (17th June 2010).

Plant Species	Number of stems per ha	Relative Density
Asparagus sp.	100	1.67
Berberis sp.	700	11.67
Caryopteris grata	1700	28.33
Coriaria nepalensis	300	5.00
Pinus roxburghii	1000	16.67
Prunus cerasoides	300	5.00
Pyrus pashia	200	3.33
Randia tetrasperma	100	1.67
Rhus wallichii	200	3.33
Rubus ellipticus	1200	20.00
Rubus niveus	100	1.67
Toona serrata	100	1.67
Total	6000	100

Table 56. Smaller woody stems/shrubs/vines (1 ha) Magra mixed plot 1 (16th June 2010).

Plant species	Number of stems per ha	Relative Density
Abelia triflora	100	0.00
Berberis asiatica	1200	0.00
Cornus capitata	200	0.00
Cornus macrophylla	100	0.00
Indigofera heterantha	9400	34.12
Jasminum humile	400	0.00
Phyllanthus sp.	1900	0.00
Pinus roxburghii	100	0.47
Pyrus pashia	100	0.47
Quercus leucotrichophora	100	0.00
Randia tetrasperma	200	0.00
Rhus wallichii	600	0.00
Rubus ellipticus	400	1.90
Rubus nivens	100	0.00
Sterculia villosa	200	0.00
Smilax spinosa	900	1.42
Toona serrata	100	0.00
Vitis himalayana	1500	1.90
Wikstroemia canescens	3500	2.84
Total	21100	100

Table 57. Smaller woody stems/shrubs/vines (1 ha) Magra oak plot (15th June 2010).

Plant species	Number of stems per ha	Relative Density
Abelia triflora	200	0.40
Berberis asiatica	800	1.19
Caryopteris grata	4500	5.56
Cornus capitata	900	0.40
Cornus macrophylla	500	0.40
Daphne papyracea	400	0.00
Ficus scandens	1600	0.00
Hedera nepalensis	1200	4.76
Hypericum oblongifolium	1300	0.79
Indigofera heterantha	1100	0.79
Lonicera quinquelocularis	100	0.40
Lyonia ovalifolia	300	1.19
Myrsine africana	400	1.59
Pyrus pashia	100	0.40
Quercus floribunda	200	0.00
Quercus leucotrichophora	2100	2.78
Rhus wallichii	900	0.79
Rosa moschata	200	0.79
Rosa moschata	100	0.40
Rubus niveus	200	0.00

Table 57. Cont.

Plant species	Number of stems per ha	Relative Density
Smilax spinosa	1100	0.00
Spiraea canescens	500	1.98
Viburnum coriaceum	300	1.19
Vitis himalayana	1000	2.78
Wikstroemia canescens	5200	5.56
Total	25200	100

Table 58. Ground Cover per ha for B.T. pine plot

Category	% Ground Cover/ha
Bryophyte	0
Rocks	0
Bare Soil	5
Woody Debris	4.75
Lespedeza juncea	6.25
Grass 1993	10.5
Eupatorium adenophorum	0.75
Flemnegia bractiata	2.75
Carex sp.	1
Grass 1995	14.5
Erigeron sp.	0.25
Fragaria indica	0.25
Desmostachya bipinnata	11.5
Salvia lanata	3.25

Table 59. Ground Cover per ha for B.T. mixed plot

Category	% Ground Cover/ha
Bryophyte	7
Rocks	6
Bare Soil	27.5
Woody Debris	8.75
Anaphalis royleana	3.5
Reinwardtia indica	0.25
Arundinella bengalensis	8.25
Heteropogon contortus	15.25
Lespedeza juncea	6.25
Silene sp.	0.5
Herb 2232	0.25
Cynoglossum sp.	1.5
Gerbera gossypina	0.25
Oxalis corniculata	0.5
Ajuga bracteosa	1.75
Rhus wallichii	1.5
Taraxacum officinale	2.25
Salvia lanata	0.25

Table 60. Ground Cover per ha for B.T. oak plot

Category	% Ground Cover/ha
Bryophyte	10
Rocks	1.5
Bare Soil	30.75
Woody Debris	18
Eupatorium adenophorum	4.25
Solanum nigrum	1.75
Herb 2154	1.5
Reinwardtia indica	1.25
Oplismenus sp.	3
Origanum vulgare	1.75
Desmodium elegans	0.25
Viola serpens	0.5
Herb 2162	0.5
Spiraea_canescens	0.25
Sedge 2166	0.5
Arundinella nepalensis	0.25
Salvia lanata	0.5
Fimbristylis dichotoma	1.5

Table 60. Cont.

Category	% Ground Cover/ha
Arundinella sp.	2
Unknown herb	0.25
Pilea sp.	3.75
Quercus leucotrichophora	0.25
Themeda anathera	3.75

Table 61. Ground Cover per ha for Chamba pine plot

Category	% Ground Cover/ha
Bryophyte	0.25
Rocks	3.25
Bare Soil	4.25
Woody Debris	3
Scutellaria scandens	1.75
Origanum vulgare	1.75
Eupatorium adenophorum	9
Sedges	0.5
Grass 4565	3.25
Grass A (Pic not labeled)	0.25
Geranium wallichianum	0.5
Pyrus pashia	0.25
Reinwardtia indica	0.25
Oplismenus sp.	1.75
Ajuga bracteosa	2.25
Grass 4547	0.75
Herb 4553	0.5
Grass 4554	5.5

Table 61. Cont.

Category	% Ground Cover/ha
Galium aparine	0.5
Caryopteris odorata	0.75
Grass 4556 4557	2.25
Lespedeza gerardiana	0.25
Agrimonia pilosa	0.25
Pilea scripta	0.75
Fern	1.5
Grass B (pic not labeled)	0.25
Leptodermis lanceolata	0.25
Acacia mollissima	1.5
Rubus sp.	0.25

Table 62. Ground Cover per ha for Chamba mixed plot

Category	% Ground Cover/ha
Bryophyte	12.75
Rocks	3
Bare Soil	11.25
Woody Debris	5.75
Sedges	1.75
Strobilanthes purpurea	2
Eupatorium adenophorum	0.75
Artemisia roxburghiana	0.5
Ainsliaea aptera	0.25
Veronica cineraria	0.5
Galium aparine	1.25
Oplismenus compositus	2.5
Ficus racemosa	0.75
Galium rotundifolium	0.25
Reinwardtia indica	1.75
Grass 4386	6.5
Grass 4387	2
Taraxacum officinale	1.5

Table 62. Cont.

Category	% Ground Cover/ha
Fragaria indica	0.25
Fern	0.25
Origanum vulgare	1.5
Myrica esculenta	0.25
Lyonia ovalifolia	1.75
Myrsine africana	0.25
Bergenia ciliata	0.25
Grass 4400	5.75
Lespedeza juncea	2
Unknown seedling (too tiny)	0.25
Anaphalis triplinervis	0.25

Table 63. Ground Cover per ha for Chamba oak plot (based on 1 m^2 plot samplings).

Category	% Ground Cover/ha
Bryophyte	17.5
Rocks	1
Bare Soil	13.75
Woody Debris	8.25
Cowdung	1.5
Lespedeza juncea	0.75
Fragaria indica	0.5
Erigeron karvinskianus	0.25
Reinwardtia indica	0.75
Oplismenus compositus	1.75
Senecio nudicaulis	0.25
Grass 4260	2.25
Grass 4261	2
Myrsine africana	2
Solanum torvum	0.25
Galium aparine	4
Thalictrum foliolosum	0.25
Sedges	0.5

Table 63. Cont.

Category	% Ground Cover/ha
Scutellaria scandens	0.25
Randia tetrasperma	0.25
Justicia sp.	0.25
Micromeria biflora	0.5
Salvia lanata	0.25
Bergenia ciliata	0.25
Origanum vulgare	0.25
Leucas lanata	0.25
Grass 4387	6.5
Fern	0.25

Table 64. Ground Cover per ha for Ghansali pine plot

Category	% Ground Cover/ha
Bryophyte	6.25
Rocks	14.5
Bare Soil	9.5
Woody Debris	4.5
Evolvulus alsinoides	8.5
Grass 5664, 5671	25.25
Sedges	9
Grass 5665	20.25
Oxalis corniculata	0.75
Medicago sp.	1.25
Barleria cristata	1.75
Eupatorium sp.	0.75
Cynodon dactylon	6
Oplismenus compositus	0.5
Micromeria biflora	0.25
Senecio nudicaulis	0.25
Flemingia macrophylla	0.5

Table 64. Cont.

Category	% Ground Cover/ha
Herb 5682	0.25
Fern	0.25
Uraria picta	1.5
Stachys sp.	0.25
Indigofera heterantha	7.25

Table 65. Ground Cover per ha for Ghansali mixed plot

Category	% Ground Cover/ha
Bryophyte	1.75
Rocks	2
Bare Soil	9.5
Woody Debris	7.5
Eupatorium adenophorum	7.5
Indigofera heterantha	1.5
Debregeasia hypoleuca	1
Fern	6
Roscoea purpurea	8
Galium triflorum	1.75
Sedges	15.5
Valeriana wallichii	0.5
Herb 6084	1.25
Lantana camara	1.25
Gnaphalium sp.	2.25
Geranium wallichianum	4
Viola canescens	0.25
Pouzolzia sp.	5

Table 65. Cont

Category	% Ground Cover/ha
Origanum vulgare	6.5
Grass 6074	7.75
Taraxacum officinale	1.75
Oplismenus sp.	0.5
Leptodermis lanceolata	1.75
Oxalis corniculata	0.75
Blumea sp.	0.5
Indigofera heterantha	1.5
Artemisia annua	0.75
Erigeron karvanskianus	1.5
Micromeria biflora	0.5
Polygala sp.	1.5
Cynodon dactylon	1.5

Table 66. Ground Cover per ha for Ghansali oak plot

Category	% Ground Cover/ha
Bryophyte	11
Rocks	0.25
Bare Soil	10.5
Woody Debris	11.75
Fern	16.5
Viola serpens	8.25
Elsholtzia frutescens	12.5
Thalictrum foliolosum	3.5
Oplismenus compositus	0.75
Sedges	9.75
Commelina benghalensis	4
Herb 5985	0.25
Blumea sp.	0.25
Roscoea purpurea	1.5
Gerbera gossypina	0.5
Grass 5990	0.5
Rubia cordifolia	0.25
Agrimonia pilosa	0.25

Table 67. Ground Cover per ha for Jakholi pine plot

Category	% Ground Cover/ha
Bryophyte	9.5
Rocks	1.38
Bare Soil	11.75
Woody Debris	5
Eupatorium adenophorum	3.75
Grass 2625	32.5
Pilea sp.	1.5
Dicliptera sp.	0.5
Elucine indica	2.5
Oplismenus compositus	1.75
Stellaria sp.	3.75
Taraxacum officinale	3.5
Herb 2627	3.25
Veronica sp.	4.5
Dioscorea deltoidea	0.25
Desmodium triflorum	3.5
Oxalis corniculata	0.75

Table 67. Cont.

Category	% Ground Cover/ha
Herb 2638	0.5
Arisaema tortuosum	0.75
Commelina benghalensis	1.75
Fragaria indica	0.25
Indigofera sp.	1.75
Bupleurum sp.	0.5
Sedge 2639	5
Pyrus pashia	1
Anaphalis triplinervis	1.5
Herb 2648	0.25
Myrsine africana	0.25
Flemingia bracteata	2.5
Agrimonia sp.	2.5
Bergenia sp.	0.5
Lespedeza stenocarpa	0.5
Galium aparine	1.75
Desmodium elegans	0.25

Table 67. Cont.

Category	% Ground Cover/ha
Sagittaria sp.	0.25
Bergenia ligulata	0.25
Galium rotundifolium	0.25
Potentilla microphylla	0.25
Grass 2664	1.75
Valeriana jatamansi	0.25
Gerbera sp.	0.25
Apluda mutica	0.25

Table 68. Ground Cover per ha for Jakholi mixed plot

Category	% Ground Cover/ha
Bryophyte	6.75
Rocks	0
Bare Soil	10.25
Woody Debris	8.25
Apluda sp.	2
Arundinella nepalensis	1.75
Sedge 2843	0.5
Ageratum conyzoides	2
Origanum vulgare	0.25
Flemingia bracteata	4.5
Spiraea sp.	0.25
Commelina benghalensis	0.5
Sedge 2848	1.75
Desmodium gangeticum	0.25
Sedge 2850	1.75
Strobilanthes atropurpureus	5
Eupatorium adenophorum	3.75

Table 68. Cont.

Category	% Ground Cover/ha
Smilax sp.	0.5
Calathea sp.	2.25
Oxalis corniculata	0.25
Sedge 2854	0.25
Coccinia grandis	1.5
Cynodon dactylon	0.25
Berberis sp.	0.5
Dicliptera sp.	4
Ficus nemoralis	1.5
Blumea sp.	0.25

Table 69. Ground Cover per ha for Jakholi oak plot

Category	% Ground Cover/ha
Bryophyte	7
Rocks were absent. Big gravels	2.25
Bare Soil	8
Woody Debris	7.5
Herb 2571	1.75
Myrsine africana	0.75
Grass 2574	0
Sedge 2575	2
Desmodium triflorum	0.25
Eupatorium adenophorum	4.75
Dicliptera sp.	2.5
Symplocos cretaegoides/chinensis	0.25
Strobilanthes atropurpureus	4.5
Calathea sp.	1.75
Dioscorea deltoidea	5.25
Smilax sp.	0.25
Caryopteris grata	1.75

Table 70. Ground Cover per ha for Magra pine plot

Category	% Ground Cover/ha
Bryophyte	0
Rocks	1.75
Bare Soil	2.5
Woody Debris	13
Eupatorium adenophorum	12.5
Eriophorum comosum	5.75
Oplismenus sp.	1.25
Erigeron sp.	2.25
Agrimonia sp.	0.5
Leucas lanata	1.5
Origanum vulgare	1.75
Galium sp.	0.25
Pinus roxburghii	0.25
Lespedeza stenocarpa	0.25
Artemisia vulgaris	0.75
Ureria picta	0.25
Rubus ellipticus	0.25
Pilea sp.	0.25
Verbascum thapsus	0.25

Table 71. Ground Cover per ha for Magra mixed plot

Category	% Ground Cover/ha
Bryophyte	0
Rocks	4.5
Bare Soil	6.75
Woody Debris	3.5
Pteridophyte	0.25
Bidens pilosa	0.5
Oplismenus sp. *(grass)*	1.5
Carex sp.	1.25
Eupatorium adenophorum	5.25
Erigeron sp.	8.25
Eriophorum comosum	19
Smilax spinosa	0.75
Vitis himalayana	2.25
Sterculia villosa	2.25
Hedra sp.	0.25
Rubia cordifolia	4
Pimpinella diversifolia	3.75
Dryopteris sp.	0.25

Table 71. Cont.

Category	% Ground Cover/ha
Origanum vulgare	0.5
Pinus roxburghii	0.25
Artemisia vulgaris	0.5
Commelina benghalensis	0.75
Cynoglossum sp.	0.5
Indigofera heterantha	2.25
Stellaria media	0.75
Uraria picta	0.75
Apluda sp.	0.75
Jasminum humile	0.5
Thalictrum sp.	0.25
Agrimonia sp.	1.25
Phyllanthus sp.	0.25
Reinwardtia indica	0.75

Table 72. Ground Cover per ha for Magra oak plot

Category	% Ground Cover/ha
Bryophyte	7.25
Rocks	0
Bare Soil	15.5
Woody Debris	6
Eriophorum comosum	7.5
Cyperus sp.	4.75
Erigeron sp.	7
Cornus macrophylla	0.25
Boenninghausenia biflora	2.25
Fern *(Pteris)*	0.25
Viola serpens	0.25
Rosa moschata	0.25
Eupatorium adenophorum	6
Agrimonia sp.	0.75
Oplismenus sp.	1.25
Apluda mutica	0.5

Table 72. Cont.

Category	% Ground Cover/ha
Smilax spinosa	0.5
Vitis himalayana	0.75
Pimpinella diversifolia	0.25
Desmodium sp.	0.25
Gerbera gossypina	0.25
Caryopteris grata	0.25
Oxalis corniculata	0.25
Verbascum sp.	0.25
Myrsine africana	0.25

Table 73. Summary of plants identified in the study plots.

Number	Species Name	Number	Species Name
1	*Acacia mollissima*	22	*Bidens pilosa*
2	*Abelia triflora*	23	*Blumea* sp.
3	*Ageratum conyzoides*	24	*Boenninghausenia biflora*
4	*Agrimonia pilosa*	25	*Bupleurum* sp.
5	*Ainsliaea aptera*	26	*Calathea sp.*
6	*Ajuga bracteosa*	27	*Carex* sp.
7	*Anaphalis roylei*	28	*Caryopteris grata*
8	*Anaphalis triplinervis*	29	*Caryopteris odorata*
9	*Apluda mutica*	30	*Citrus* sp.
10	*Arisaema tortuosum*	31	*Coccinia grandis*
11	*Artemisia annua*	32	*Colebrookea oppositifolia*
12	*Artemisia roxburghiana*	33	*Commelina benghalensis*
13	*Artemisia vulgaris*	34	*Coriaria nepalensis*
14	*Arundinella bengalensis*	35	*Cornus capitata*
15	*Arundinella nepalensis*	36	*Cornus macrophylla*
16	*Asparagus* sp.	37	*Cotoneaster bacillaris*
17	*Barleria cristata*	38	*Cotoneaster microphylla*
18	*Berberis aristata*	39	*Cotoneaster microphyllus*
19	*Berberis lycium*	40	*Cynodon dactylon*
20	*Bergenia ciliata*	41	*Cynoglossum* sp.
21	*Bergenia ligulata*	42	*Cyperus* sp.

Table 73. Cont.

Number	Species Name	Number	Species Name
43	*Daphne papyracea*	64	*Ficus scandens*
44	*Debregeasia hypoleuca*	65	*Fimbristylis dichotoma*
45	*Desmodium elegans*	66	*Flemingia macrophylla*
46	*Desmodium gangeticum*	67	*Flemingia bracteata*
47	*Desmodium multiflorum*	68	*Fragaria indica*
48	*Desmodium triflorum*	69	*Galium aparine*
49	*Desmostachya bipinnata*	70	*Galium rotundifolium*
50	*Dicliptera* sp.	71	*Galium triflorum*
51	*Dioscorea deltoidea*	72	*Geranium wallichianum*
52	*Dryopteris* sp.	73	*Gerbera gossypina*
53	*Elaeagnus* sp.	74	*Gnaphalium* sp.
54	*Elsholtzia frutescens*	75	*Hedera nepalensis*
55	*Elucine indica*	76	*Heteropogon contortus*
56	*Erigeron karvanskianus*	77	*Hypericum oblongifolium*
57	*Erigeron* sp.	78	*Ilex dipyrena*
58	*Eriophorum comosum*	79	*Indigofera heterantha*
59	*Eupatorium adenophorum*	80	*Jasminum humile*
60	*Ureria picta*	81	*Justicia* sp.
61	*Evolvulus alsinoides*	82	*Lantana camara*
62	*Ficus nemoralis*	83	*Leptodermis lanceolata*
63	*Ficus racemosa*	84	*Lespedeza gerardiana*

Table 73. Cont.

Number	Species Name	Number	Species Name
85	*Lespedeza juncea*	106	*Pouzolzia* sp.
86	*Lespedeza stenocarpa*	107	*Prunus cerasoides*
87	*Leucas lanata*	108	*Pyracantha crenulata*
88	*Lindera pulcherrima*	109	*Prunus cerasoides*
89	*Litsea umbrosa*	110	*Pyrus pashia*
90	*Lonicera quinquelocularis*	111	*Quercus floribunda*
91	*Lyonia ovalifolia*	112	*Quercus leucotrichophora*
92	*Medicago* sp.	113	*Randia tetrasperma*
93	*Micromeria biflora*	114	*Reinwardtia indica*
94	*Myrica esculenta*	115	*Rhamnus* sp.
95	*Myrsine africana*	116	*Rhododendron* sp.
96	*Myrsine semiserrata*	117	*Rhus parviflora*
97	*Oplismenus compositus*	118	*Rhus wallichii*
98	*Origanum vulgare*	119	*Rosa moschata*
99	*Oxalis corniculata*	120	*Roscoea purpurea*
100	*Phyllanthus* sp.	121	*Rubia cordifolia*
101	*Pilea scripta*	122	*Rubus ellipticus*
102	*Pimpinella diversifolia*	123	*Rubus niveus*
103	*Pinus roxburghii*	124	*Sagittaria* sp.
104	*Polygala* sp.	125	*Salvia lanata*
105	*Potentilla microphylla*	126	*Sarcococca saligna*

Table 73. Cont.

Number	Species Name	Number	Species Name
127	*Scutellaria scandens*	148	*Valeriana jatamansi*
128	*Senecio nudicaulis*	149	*Valeriana wallichii*
129	*Sterculia villosa*	150	*Verbascum thapsus*
130	*Silene* sp.	151	*Veronica cineraria*
131	*Cynoglossum* sp.	152	*Veronica* sp.
132	*Smilax aspera*	153	*Viburnum coriaceum*
133	*Smilax spinosa*	154	*Viburnum cotinifolium*
134	*Solanum nigrum*	155	*Viburnum cylindricum*
135	*Solanum torvum*	156	*Viburnum mullaha*
136	*Spiraea canescens*	157	*Viola canescens*
137	*Stachys* sp.	158	*Viola serpens*
138	*Stellaria media*	159	*Vitis himalayana*
139	*Stellaria* sp.	160	*Wikstroemia canescens*
140	*Strobilanthes atropurpureus*		
141	*Symplocos chinensis*		
142	*Taraxacum officinale*		
143	*Thalictrum foliolosum*		
144	*Thalictrum* sp.		
145	*Themeda anathera*		
146	*Toona serrata*		
147	*Uraria picta*		

Table 74. COFECHA Descriptive Statistics: Hulanakhal Earlywood.

Seq	Series	Interval		Years	Corr. With Master
1	HKP01B	1952	2011	60	0.694
2	HKP02A	1958	2011	54	0.745
3	HKP02B	1950	2011	62	0.574
4	HKP06B	1945	2011	67	0.701
5	HKP07A	1935	2011	77	0.772
6	HKP07B	1930	2011	82	0.803
7	HKP08A	1903	2011	109	0.629
8	HKP08B	1905	2008	104	0.699
9	HKP09A	1939	2011	73	0.718
10	HKP09B	1940	2011	72	0.744
11	HKP10A	1943	2011	69	0.654
12	HKP10B	1939	2011	73	0.685
13	HKP11A	1956	2011	56	0.686
14	HKP11B	1935	2011	77	0.763
15	HKP12A	1892	2011	120	0.626
16	HKP12B	1901	2011	111	0.656
17	HKP14B	1950	2011	62	0.592
18	HKP15A	1923	2003	81	0.607
19	HKP15B	1933	2011	79	0.691
20	HKP16B	1944	2011	68	0.653
21	HKP19A	1948	2011	64	0.599
22	HKP19B	1954	2011	58	0.578
23	HKP20A	1938	2011	74	0.494
24	HKP20B	1938	2011	74	0.503
25	HKP21A	1927	2011	85	0.52

Table 74. Cont.

Seq	Series	Interval		Years	Corr. With Master
26	HKP21B	1938	2011	74	0.544
27	HKP22A	1938	2011	74	0.688
28	HKP22B	1933	2011	79	0.753
29	HKP23A	1921	2011	91	0.646
30	HKP23B	1927	2011	85	0.65
31	HKP24A	1948	2011	64	0.641
32	HKP24B	1958	2011	54	0.58
33	HKP25A	1929	2011	83	0.759
34	HKP25B	1926	2011	86	0.758
35	HKP28A	1952	2011	60	0.673
36	HKP28B	1918	2011	94	0.633
37	HKP29A	1903	1998	96	0.701
38	HKP29B	1913	2011	99	0.764
39	HKP30A	1898	2011	114	0.695
40	HKP30A"	1898	1943	46	0.816
41	HKP30B	1901	2011	111	0.748
42	HKP 30B"	1901	1955	55	0.683
	Total or mean			3276	0.671

Table 75. COFECHA Descriptive Statistics: Hulanakhal Latewood

Seq	Series	Interval		Years	Corr With Master
1	HKP01B	1952	2011	60	0.59
2	HKP02A	1958	2011	54	0.793
3	HKP02B	1950	2011	62	0.615
4	HKP06B	1945	2011	67	0.631
5	HKP07A	1935	2011	77	0.739
6	HKP07B	1930	2011	82	0.701
7	HKP08A	1903	2011	109	0.404
8	HKP08B	1905	2008	104	0.443
9	HKP09A	1939	2011	73	0.597
10	HKP09B	1940	2011	72	0.7
11	HKP10A	1943	2011	69	0.589
12	HKP10B	1939	2011	73	0.406
13	HKP11A	1956	2011	56	0.64
14	HKP11B	1935	2011	77	0.681
15	HKP12A	1892	2011	120	0.429
16	HKP12B	1901	2011	111	0.491
17	HKP14B	1950	2011	62	0.425
18	HKP15A	1923	2003	81	0.476
19	HKP15B	1933	2011	79	0.501
20	HKP16B	1944	2011	68	0.668
21	HKP19A	1948	2011	64	0.572
22	HKP19B	1954	2011	58	0.579
23	HKP20A	1938	2011	74	0.467
24	HKP20B	1938	2011	74	0.627
25	HKP21A	1927	2011	85	0.321

Table 75. Cont.

Seq	Series	Interval		Years	Corr. With Master
26	HKP21B	1938	2011	74	0.434
27	HKP22A	1938	2011	74	0.708
28	HKP22B	1933	2011	79	0.57
29	HKP23A	1921	2011	91	0.457
30	HKP23B	1927	2011	85	0.549
31	HKP24A	1948	2011	64	0.694
32	HKP24B	1958	2011	54	0.574
33	HKP25A	1929	2011	83	0.595
34	HKP25B	1926	2011	86	0.58
35	HKP28A	1952	2011	60	0.694
36	HKP28B	1918	2011	94	0.455
37	HKP29A	1903	1998	96	0.567
38	HKP29B	1913	2011	99	0.607
39	HKP30A	1898	2011	114	0.581
40	HKP30A"	1898	1943	46	0.631
41	HKP30B	1901	2011	111	0.626
42	HKP30B"	1901	1955	55	0.601
	Total or mean			3276	0.562

Table 76. COFECHA Descriptive Statistics: Bhaktapur Earlywood .

Seq	Series	Interval		Years	Corr. With Master
1	BAT101A	1900	1996	97	0.447
2	BAT101B	1885	1995	111	0.441
3	BAT103A	1889	1996	108	0.488
4	BAT103B	1894	1996	103	0.349
5	BAT104A	1883	1996	114	0.473
6	BAT104B	1889	1996	108	0.485
7	BAT205B	1930	1996	67	0.255
8	BAT206A	1882	1996	115	0.616
9	BAT206B	1893	1996	104	0.675
10	BAT210A	1930	1996	67	0.546
11	BAT210B	1950	1995	46	0.232
12	BAT211B	1923	1996	74	0.743
13	BAT212A	1920	1995	76	0.276
	Total or mean			1190	0.478

Table 77. COFECHA Descriptive Statistics: Bhaktapur Latewood.

Seq	Series	Interval		Years	Corr. With Master
1	BAT101A	1900	1996	97	0.515
2	BAT101B	1885	1995	111	0.584
3	BAT103A	1889	1996	108	0.475
4	BAT103B	1894	1996	103	0.426
5	BAT104A	1883	1996	114	0.463
6	BAT104B	1889	1996	108	0.600
7	BAT205B	1930	1996	67	0.463
8	BAT206A	1882	1996	115	0.606
9	BAT206B	1893	1996	104	0.656
10	BAT210A	1930	1996	67	0.535
11	BAT210B	1950	1995	46	0.437
12	BAT211B	1923	1996	74	0.679
13	BAT212A	1920	1995	76	0.486
	Total or mean			1190	0.538

Table 78.COFECHA Descriptive Statistics: Kalipang Earlywood.

Seq	Series	Interval		Years	Corr. With Master
1	KLP01A	1717	1970	254	0.564
2	KLP01B	1715	1975	261	0.574
3	KLP02A	1689	2003	315	0.372
4	KLP02B	1730	2002	273	0.345
5	KLP03A	1681	1920	240	0.629
6	KLP03B	1674	1930	257	0.671
7	KLP04A	1790	1920	131	0.573
8	KLP04B	1830	2001	172	0.475
9	KLP05A	1710	1900	191	0.639
10	KLP05B	1690	1900	211	0.647
11	KLP06A	1780	1940	161	0.542
12	KLP06B	1780	1960	181	0.551
13	KLP07A	1724	1992	269	0.641
14	KLP07B	1727	1990	264	0.678
15	KLP09A	1710	1885	176	0.689
16	KLP09B	1722	1885	164	0.681
17	KLP10A	1744	1870	127	0.524
18	KLP11A	1666	1991	326	0.65
19	KLP11B	1661	1981	321	0.598
20	KLP12A	1715	2003	289	0.649
21	KLP12B	1725	2003	279	0.556
22	KLP13A	1700	1890	191	0.551
23	KLP13B	1686	1890	205	0.598
24	KLP14A	1781	2003	223	0.64
25	KLP14B	1776	2003	228	0.639

Table 78. Cont.

Seq	Series	Interval		Years	Corr. With Master
26	KLP15A	1774	1991	218	0.608
27	KLP15B	1786	1994	209	0.66
28	KLP16A	1801	1962	162	0.522
29	KLP16B	1788	2003	216	0.673
30	KLP17A	1800	1994	195	0.651
31	KLP17B	1783	2001	219	0.688
32	KLP19A	1711	1930	220	0.681
33	KLP19B	1723	1930	208	0.692
34	KLP21A	1713	1880	168	0.632
35	KLP21B	1712	1880	169	0.614
36	KLP23A	1739	1927	189	0.749
37	KLP23B	1738	1917	180	0.792
38	KLP27A	1650	1900	251	0.409
39	KLP27B	1668	1931	264	0.514
40	KLP29A	1790	2003	214	0.573
41	KLP29B	1776	2003	228	0.584
42	KLP31A	1752	1995	244	0.582
43	KLP31B	1768	1992	225	0.566
e	KLP33A	1864	2003	140	0.598
45	KLP33B	1866	2003	138	0.641
46	KLP35A	1748	1993	246	0.684
47	KLP35B	1747	1993	247	0.707
	Total or mean			10259	0.603

Table 79. COFECHA Descriptive Statistics: Kalipang Latewood.

Seq	Series	Interval		Years	Corr. With Master
1	KLP01A	1717	1970	254	0.452
2	KLP01B	1715	1975	261	0.47
3	KLP02A	1689	2003	315	0.257
4	KLP02B	1726	2002	277	0.299
5	KLP03A	1681	1879	199	0.388
6	KLP03B	1674	1930	257	0.455
7	KLP04A	1790	1920	131	0.291
8	KLP04B	1830	1923	94	0.384
9	KLP05A	1697	1900	204	0.54
10	KLP05B	1680	1900	221	0.496
11	KLP06A	1760	1940	181	0.377
12	KLP06B	1757	1960	204	0.393
13	KLP07A	1724	1992	269	0.517
14	KLP07B	1727	1990	264	0.498
15	KLP09A	1710	1885	176	0.427
16	KLP09B	1720	1885	166	0.495
17	KLP10A	1744	1870	127	0.224
18	KLP11A	1666	1991	326	0.469
19	KLP11B	1661	1981	321	0.42
20	KLP12A	1715	2003	289	0.322
21	KLP12B	1725	2003	279	0.324
22	KLP13A	1684	1890	207	0.463
23	KLP13B	1686	1890	205	0.456
24	KLP14A	1781	2003	223	0.363
25	KLP14B	1776	2003	228	0.346

Table 79. Cont.

Seq	Series	Interval		Years	Corr. with Master
26	KLP15A	1774	1991	218	0.578
27	KLP15B	1786	1994	209	0.563
28	KLP16A	1801	1962	162	0.352
29	KLP16B	1788	2003	216	0.419
30	KLP17A	1800	1994	195	0.663
31	KLP17B	1783	2001	219	0.548
32	KLP19A	1711	1889	179	0.599
33	KLP19B	1723	1930	208	0.704
34	KLP21A	1713	1880	168	0.483
35	KLP21B	1712	1880	169	0.456
36	KLP23A	1739	1889	151	0.571
37	KLP23B	1738	1889	152	0.458
38	KLP27A	1650	1900	251	0.462
39	KLP27B	1668	1931	264	0.421
40	KLP29A	1790	2003	214	0.34
41	KLP29B	1776	2003	228	0.334
42	KLP31A	1752	1995	244	0.502
43	KLP31B	1768	1992	225	0.475
44	KLP33A	1864	2003	140	0.428
45	KLP33B	1866	2003	138	0.447
46	KLP35A	1748	1993	246	0.64
47	KLP35B	1747	1992	246	0.569
	Total or mean			10120	0.449

Table 80. Soil analysis for different parameters for all 15 (0.1 ha) plots.

Site Name	pH Value	Organic-C (g/Kg) soil	Nitrogen (kg/ha)	Phosphorous (kg/ha)	Potassium (kg/ha)	Magnesium (meq/100 g)	Calcium (meq/100 g)
Magra Oak/Banj	6.1	9.4	**591**	**102**	**1075**	**3.4**	**2.2**
Magra Pine/Chir	6.7	5.2	354	**28**	**426**	**3.4**	**9.8**
Magra Mixed	6.2	6.6	494	**40**	**940**	**3.5**	**10.8**
Jakholi Oak/Banj	4.1	*4.3*	**806**	**61**	**893**	**1.8**	**3**
Jakholi Pine/Chir	4.7	*3.1*	460	17	**512**	**1.8**	**5**
Jakholi Mixed	4.5	*2.8*	339	12	**660**	**2**	**3.8**
B.T Oak/Banj	5.5	5.7	**1061**	77	**724**	**2.8**	**9.9**
B.T. Pine/Chir	5.4	*3.2*	280	10	**610**	**2.1**	**9.1**
B.T. Mixed	6	*3.6*	295	18	**680**	**2.2**	**8.7**
Chamba Oak/Banj	4.5	*3.1*	*250*	16	**483**	**2**	**5**
Chamba Pine/Chir	5.3	*3.6*	355	11	**606**	**2.1**	**9**
Chamba Mixed	4.8	*2.1*	*240*	*5*	**667**	**1.6**	**4.7**

Table 80. Cont.

Site Name	pH Value	Organic-C (g/Kg) soil	Nitrogen (kg/ha)	Phosphorous (kg/ha)	Potassium (kg/ha)	Magnesium (meq/100 g)	Calcium (meq/100 g)
Ghansali Oak/Banj	4.5	*3.7*	462	*4*	**323**	**1.6**	**4.1**
Ghansali Pine/Chir	4.2	*1.4*	*127*	*3*	**283**	*0.9*	*1.3*
Ghansali Mixed	5.1	*0.1*	*176*	*2*	**292**	*0.7*	**2**

Table 81. Soil nutrient value range as provided by the soil testing lab.

Organic Carbon Medium Range/Threshold Value (g/kg soil)	Nitrogen Medium Range/Threshold Value (kg/ha)	Phosphorous Medium Range/Threshold Value (kg/ha)	Potassium Medium Range/Threshold Value (kg/ha)	Magnesium Medium Range/Threshold Value (meq/100g)	Calcium Medium Range/Threshold Value (meq/100g)
5-10	280-560	10-25	118-280	1	1.5

Italicized = Low (or Deficient in case of Magnesium and Calcium)

Normal font = Medium

Bold = High (or Sufficient in case of Magnesium and Calcium)