CHARACTERISING SPATIAL VARIABILITY IN SOIL MACROFAUNA IN MID-ALTITUDE VILLAGE LANDSCAPE IN GARHWAL HIMALAYA

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CERTIFICATE

The research work embodied in this dissertation entitled "Characterising spatial variability in soil macrofauna in mid-altitude village landscape in Garhwal Himalaya" has been carried out at the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi – 110067. This work is original and has not been submitted in part or full for any other degree or diploma of any university.

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1. Introduction

Soil is a habitat for huge variety of organisms. The processes occurring in the top few centi meters of earth's surface are the basis of all life on dry land. The ecologists have traditionally portrayed the inhabitants of soil as a black box labeled "decomposers" - essentially a single trophic level through which all the aboveground material, with its multiple trophic levels is ultimately recycled. Digging deeper, it turns out the soil food web is every bit as complex as the aboveground web, with intricate connections to its aerial counterpart.

Macro-invertebrates occupy prominent place in the community of soil organisms and play a key role in different processes that determine soil fertility. They regulate microbial population responsible for mineralization and humification and consequently influence organic matter recycling and release of nutrients. They contribute to the formation of stable aggregates that may protect a part of soil organic matter from rapid mineralization and therefore constitute a plant nutrient reserve. Soil macrofauna are regarded as secondary decomposers contributing to soil physical properties viz., structure, stability, organic matter distribution, water infiltration and retention (Lavelle et al., 1997).

1.1 Soil Organisms

Soil organisms are conveniently grouped into three categories based on size of the organisms. The macrofauna include termites, earthworms, and large arthropods. They have the ability to dig the soil and are some time called 'ecosystem engineers' because of their impact on soil structure (Kladivko, 2001). The mesofauna include organisms larger than microfauna but smaller than macrofauna (average size < 2 mm) and include organisms such as mites (acarids), springtails (collembolans), and the small oligochaeta and the enchytraeidae. The microfauna are small (< 0.2 mm body width), live in the water filled pore space, and are comprised mainly of protozoa and nematodes. They feed on bacteria and fungi, leading to nutrient release from microbial biomass. Microfauna can affect the nutrient mineralization directly, by excreting mineral nutrients and indirectly by causing shifts in the microbial community structure and growth rates. Grazing by nematodes and protozoa can increase microbial turnover by stimulating growth of surviving microbial populations by reducing microbial competition and increasing nutrient availability. These trophic interactions are influenced by soil physical and chemical properties (Savin *et al.,* 2001).

The macrofauna can be further divided into three groups which play different roles in ecosystems (Bouche, 1977): the epigeics, the anecics and the endogeics.

The epigeics live and feed in surface litter. They include saprophagous arthropods and small pigmented earthworms, as well as predators of these species (chilopods, ants and some coleopterans). They progressively fragment the litter and participating in decomposition.

Anecics feed on surface litter but build subterranean burrows and nests that provide shelter. This group consists of some large pigmented earthworms and the vast majority of the termite species. They remove litter from the litter system and transport it to different environments such as the subsoil or a termite nest, thus changing dramatically the kinetics of decomposition and the spatial distribution of its products.

The endogeics live in the soil, consisting mainly of termites and unpigmented earthworms, they are geophagous and feed on soil organic matter and live on dead roots. Endogeics produce casts and faecal pellets which are the component elements of macroaggregate soil structures. They dig galleries, nests and chambers and eventually egest soil at the surface as earthworm casts, termite sheetings or epigeic nests of ants or termites.

1.1.1 Diplopoda

Tropical millipedes are primarily epigeic during rainy season when they are often observed on the surface in large numbers.

Millipedes are predominantly woodland species and are usually found in damp places under leaves, in moss, under stones or boards, in rotting wood or in the soil.

Millipedes are mostly herbivorous and feed on plant litter in varying stages of decomposition.

In general, it seems that many millipedes eat large amounts of leaf litter of little nutritional value and excrete most of it relatively unchanged chemically but greatly fragmented and so more readily available to microorganisms.

1.1.2 Chilopoda

Centipedes usullay occur in a protected situation such as in the soil, under bark or in rotten logs. They are very active, fast running animals and are predacious; they feed on insects, spiders and other small animals. Some geophilomorph centipede will occasionally feed on the plant tissue.

Geophilomorph centipedes are able to burrow themselves several inches deep in the soil. Geophilomorph centipedes are part of the true hypogeal fauna. Lithobiomorph centipedes are unable to burrow properly and tend to be restricted sheltered niches on the soil surface, beneath stones, bark, etc., or to a porous litter layer through which they can push their way.

1.1.3 Orthoptera

This order contains a rather varied assemblage of insects. Most of them are plant feeders and some of them are important pests of cultivated plants; a few are predacious, a few are scavengers, and a few are more or less omnivorous. 97 species of major orthopteroid groups namely, acridoidea, grylloidea, tetrigoidea and tridectyloidea have been chronicled from Garhwal and Kumaon hills (Tandon and Shishodia, 1991). Mole cricket is regarded as the true soil animals. They construct long burrows at a depth of 15 to 20 cm and mix aerate the soil by their activity. Their food chiefly consists of root although insects are also taken. They consume very large amounts of plants and add the indigestible residues to soil.

1.1.4 Dermaptera

Earwigs are normal inhabitants of ground litter. These are largely nocturnal in habit and hide during the day in cracks, in crevices, under bark and in debris. They feed mainly on dead and decaying vegetable matter, but some occasionally feed on living plants and a few are predacious. Preliminary study by Srivastava (1991) reveals the presence of 43 species from Garhwal and Kumaon hills.

1.1.5 Hemiptera

Hemiptera are large and widely distributed group of insects. Most species are terrestrial, but many are aquatic. Many feed on plant juice and some of these are serious pests of cultivated plants; others are predacious, and some of these are very beneficial to man. Arora and Julka (1993) reported about 250 species of bugs, aphids, scale insects, etc., from western and north-western Himalayas.

1.1.6 Coleoptera

The order coleoptera is the largest order of insects and contains about 40% of known species in the class hexapoda. Mouth parts in this order is chewing type. Beetle may be found in almost every type of habitat in which any insect is found and they feed on all sorts of plant and animal materials. Many are phytophagous, many are predacious, some are scavengers, other feed on mold or fungi, and a very few are parasitic.

Biswas (1991) reported 106 species of beetles from Garhwal and Kumaon hills which are chiefly based on the collection from district Dehradun. Arora and Julka (1993) reported about 690 species of coleoptera from north-west Himalaya. Important factor affecting the distribution is moisture. Beetle adult generally found in top 10 cm of soil layer and below this they decrease greatly in numbers. Larvae on the other hand, occur quite normally in deeper soil layers.

Coleoptera larvae live in soil and are predominantly phytophagous. Some larvae feed on the roots of plants such as sugar cane and rice and are crop pests. Some are found in plant refuse seem to be mainly saprophagous.

1.1.7 Termites

Termites are small to medium insects that lives in social groups and have highly developed caste system. Termites are major decomposers in most terrestrial ecosystems, responsible for mineralization up to 30% of the primary production (mostly as CO_2) in some systems and breakdown of up to 60% of litter (Brian, 1978). Subterranean termites enhance microporosity and infiltration with beneficial effects on soil water storage and primary productivity. They digest cellulose and lignin in an efficient manner (60-93 %; Wood, 1996). Termites harbour flagellates in their intestine that secretes cellulase and helps in digestion of cellulose in the food material. Most termite communities are a mosaic of various functional groups including soil feeding humivorous, wood feeding xylophagous, fungus growers or harvesters (Lavelle, 1997).

Verma (1991) compiled the list of 44 species of termites from Garhwal and Kumaon hills. The termites of the temperate region don't erect aboveground nests, but live in self made burrows in the earth.

1.1.8 Earthworms

Earthworms are bioindicators of soil health. They are unprotected body can detect the the adversities in their immediate environment. Monitoring of earthworm diversity and activity could enable detection of early stages of loss of ecosystem function and land degradation. Earthworms further catalyze the decomposition process by fragmenting organic residues and increasing the surface area expose to microflora.

1.1.9 Hymenoptera

Ant species diversity declines with increasing latitude, altitude and aridity. Soil ants (including mound builders) are representatives of predators, herbivores (granivores) and bioturbatours, bringing about important changes in the physical and chemical properties of soils, as well as dispersing plant propagules. Networks of galleries and chambers increase the porosity of the soil, increasing drainage and soil aeration and reducing bulk density.

1.1.10 Diptera

The diptera larvae associated with soil are saprophagous, decomposing plant organic material. Some occur in moist of semiaquatic habitats, where decaying organic matter is plentiful. Some of the diptera larvae are phytophagous and feed gregariously at the roots of grasses and aerable crops and from time to time have been reported as damaging crops. Larvae of some species feed mainly on fungi, while others are scavengers and decompose plant and animal material; others feed on faeces of insect larva, nematodes and earthworms, where as few are parasitic on other insects and arthropods.

1.1.11 Lepidoptera

Lepidoptera comprises butterflies and moths. Most of the larval stages are herbivorous and these cause extensive damage to their hosts, including plants of economic importance like agricultural crops, plantations, forests, stored grains; and feed as pest borers, defoliators, etc. Because of total dependence of their larval stage on plant food, their population in nature is greatly influenced by local conditions, including severe ecological degradation due to heavy deforestation, habitat destruction, forest fires and other climatic conditions. As many as 325 species of butterflies from Garhwal and nearly 350 species from Kumaon hills has been recorded (Arora, 1991).

1.2 Land use – land cover changes in Himalaya

Semwal et al. (2004) observed agricultural extensification in Central Himalaya during 1963-93. During this period agricultural land use increased by 30 percent at the cost of loss of 5% of forest land. They reported complete or partial replacement of traditional crops, yielding fodders by potato lacking any fodder values. These leads to depletion of forest resources.

Wakeel et al. (2005) studied the spatial and temporal patterns of land use/land cover change in a micro-watershed in central Himalaya, India during 1967-1997 based on the interpretation of satellite data and using Geographic Information System (GIS). In 30 years agricultural expansion at the cost of loss of forest cover was most prominent change in the forest managed by the people. Increased food requirements were largely met through intensification of agriculture with introduction of irrigation facilities. The irrigated land area increased almost 3 times during the study period. In the government reserve forest, there was no agricultural expansion but a constant thinning of the forest (i.e., conversion of dense forest to degraded/open forest) was observed within as well as outside the area governed by the forest department.

1.3 Agroforestry Systems

Ralhan et al., (1991) studied structure and function of agroforestry system in the Pithoragarh district of central Himalaya. They found most of the village area was deforested. The villagers raised fodder and firewood trees around their crop fields, but they depend heavily on state government forest to meet the requirements of firewood, fodder and bedding leaves cattle. The organic compost derived from forest, accounted for over 90% of the total energy input to the crop fields in all the villages. Crop field output-input energy ratios were well below unity (0.26-0.68) in different villages. For raising each energy unit of agronomic yield (grain, tuber etc.) from the agro-ecosystem, 2-9 energy units were required from the forest. In rainfed conditions, the ratio of forest biomass unit consumed to support a unit of agriculture and agronomic yield is reported to be about 10-12.

Maikhuri et al. (2001) revealed that there was a significant decline in the cultivated area under many traditional crops in the Alaknanda catchments of central Himalaya over a period of two decade.

Maikhuri et al. (1997) studied on agroforestry approach for rehabilitation of degraded village community lands and tested in a mid altitude village in Garhwal Himalaya. The approach involved supplemental irrigation and plantation of multipurpose trees and economically important crops preferred by the local communities. This enabled higher crop yields with substantially lower organic manure and seed inputs compared to rainfed non-irrigated system. The monetary output:input ratio of crop component in the irrigated system was 1.97 as compared to 0.86 in non-irrigated system.

Rawat et al. (2006) studied on *Salix fragilis* a multipurpose tree species grown extensively under the indigenous agroforestry system in the cold desert of Lahaul valley located in the north western Himalaya, India. They found that these trees are under severe pest attack and other infections. These made its survival in the area questionable. This deciduous multipurpose tree species provides vegetation covered to the barren landscape of Lahaul and is a significant contributor fuel and fodder to the region. According to their observations only 30± 20.1% trees are healthy: 55.2± 16.1% of the willows have dried up and 14.8 ± 6.1% were in dry condition.

Quazi et al.(2003) observed that of banj oak originated after abandonment of agricultural land which is contradictory to the view that Disturbed sites that create large canopy openings and exposed topsoil were reported to promote stands of chir pine, (*Pinus roxburghii* Sarg.). Banj oak density was found to be higher than chir pine on terraces under both high and low post-abandonment disturbance for the chronosequence. Banj oak was also found to predominate on the terrace risers. . Terraced lands thus act as a nursery for the subsequent release and development of future stands dominated by banj oak.

1.4 Characterization of Forest Ecosystems

Thadani and Ashton (1995) studied the regeneration of Banj oak (*Q. leucotrichophora*) in forests of Central Himalaya. The study of banj forests was carried out in three areas of the Central Himalaya in forests under different tenurial and disturbance regimes. They found in sanctuary forests (state preserves), which were well protected from grazing and lopping, the seedling number averaged only 510 seedlings/ha. The high tree basal area (36 m^2/ha) and dense canopy of these forests does not promote the satisfactory establishment of oak in the understory. High grazing pressure and often severe lopping result in a open canopy and low seedling number in community forests. Moderate disturbance appears to benefit regeneration in private and reserve forests (state forests), where over 2000 seedlings/ha were recorded.

Semwal et al. (2003) studied the leaf litter decomposition and nutrient release patterns of six multi-purpose tree species of Central Himalayas. They showed that a diverse multi-purpose tree communities provides not only diverse products but may also render stable nutrient cycling. *A. lebbek, A. nepalensis, D. sissoo* and *F. glomerata* litter on the account of their fast decomposition seems to be more appropriate for rapid recovery of soil fertility in degraded lands.

Dubey et al. (2003) recorded an upward shift of pine forest in central Himalaya. The high rate of upward shift of Himalayan pine observed (19 m/10 yrs on south and 14 m/10 yrs on north slope), reflects its sensitivity to climatic warming. The observed rate of upward shift of pine in the Himalayan region is higher in comparison to other species recorded in Alps and elsewhere, where the maximum upward migration has been recorded to be around 4 m/10 yrs. Higher rate of colonization on south slopes in comparison to north reflects that the pine populations on south slopes are more vulnerable to climate change as compared to those on north slopes.

Rawal et al. (2003) observed relative high contribution of *Myrica* seedlings and saplings in chir pine forests. This was indicative that this habitat provides a satisfactory regeneration niche. Also, seeds obtained from this habitat showed higher germination response. *M. esculenta* finds a satisfactory regeneration niche in *Pinus roxburghii* forests, and provides options for putting these hitherto unutilized habitats for ecological and economic benefits in the region

1.5 Distribution of soil macrofauna

Lavelle et al. (1994) studied the effects of vegetation type, biogeography and land use practices on soil macrofauna community from 29 sites. They found earthworms were most dominant in Savanna and pasture followed by fallows and tree plantations and were least abundant in the forests. High population of litter dwelling arthropods, coleopterans and endogeic larvae were recorded in sites with high rate of litter accumulation as a consequence of low earthworm and termite activities. Termitosphere and ant effects were more prominent in forests of Kenya and Peruvian Amazonia, from low input cropping systems derived from those forests, the dry Savannas sites such as Morondera in Zimbabwe and low external input cropping systems in Mexico and Martinique.

Barros et al. (2002) studied the impacts of land use practices on soil macrofauna communities in Western Brazilian Amazonia. Low densities of macroinvertebrates recorded in forest (884 ind./m^2) and in pastures (841 ind./m^2) and higher densities were found in fallow, agroforestry system and annual crops (1737 – 1761 ind./m^2). Earthworms were dominant in pasture (155 ind./m^2 and 56.2 g/m^2 on average), where as termites were abundant in annual crops and fallows (with respective densities of 1287 and 816 ind./m^2 and biomasses of 2.32 and 1.38 g/m^2). Diversity decreased gradually with intensification of land use in the system. Forest had the higher density (2.22) followed by fallow (2.14), Agroforestry (1.92), pasture (1.73) and finally by annual crop system. Termite:earthworm ratios were very low in pastures (0.2), had similar values in the forest (7.9) and the Agroforestry system (8.8), which is much lower than fallows (20.4) and highest in annual crops (21.4).

Rossi and Blanchart (2005) surveyed the soil macrofauna communities along the disturbance gradient in Western Ghats, India. The sampling sites included primary forest, weakly disturbed forest, highly disturbed forest, plantation and pastures. They showed that both land management and temporal variability induced significant changes in the soil macrofauna. They found mean density of macrofauna much higher in forest sites (ranging from 2416 to 3061 ind./m^2) than other sites (pasture and plantation: 1333 to 1654 ind./m^2). Earthworms mainly exhibit temporal variability with more than 62% of variance being explained by the date effects. Maximum density of earthworms was recorded in October at the end of the rainy season. Groups like termites and ants reached their maximum density during the dry season. They found that some groups like chilopoda, isoptera, coleoptera, diplopoda, dermaptera and homoptera mainly affected by land use differences than temporal variability. The densities of groups like diptera larva, enchytraeidae, coleoptera larva, isopoda, hemiptera, oligocaeta and Lepidoptera were changed markedly with time.

Tropical forests host higher soil macrofauna densities than cultivated lands, for e.g., in various tropical forest plots in Mexico, Lavelle and Kohlman (1984) reported densities ranging from 888 to 3011 ind./m^2, where as in tropical forest in Cote d'Ivoire, Gilot et al. (1995) reported 5747 ind./m^2. however the global densities of soil macrofauna tends to decrease to low levels in crop lands; Decaens et al. (1994) reported densities from 429 to 592 ind./m^2 in high input crop in Carimagua (Columbia) and Lavelle and Pashanasi (1989) reported a density of 730 ind./m^2 in a similar plot in Peru.

Decaens et al. (2004) studied the macrofauna communities in permanent pastures derived from tropical forest and Savanna. They assessed the impacts of land use conversion on the soil microinvertebrates. Macrofauna communities of the native Savanna had a biomass of 15.3 g/m^2, mostly dominated by termites (47%) and earthworms (31%). The conversion to pastures maintains macrofauna diversity and composition but the biomass increased. The forest had a total macroinvertebrates biomass of 53.3 g/m^2 mostly represented by earthworms (more than 80% of the biomass). The conversion of forest in to intensive pastures resulted in dramatic effects on native macroinvertebrate communities. There was total disappearance of native species of earthworms and build up of large populations of exotic and endogeic species. There was decrease in macrofaunal diversity and biomass, there was also decrease in species composition. Conversion had the dramatic effects on microclimate, organic matter input and litter availability, hence decrease macrofauna diversity and biomass and changes the species composition.

Thomas et al. (2004) assessed the biodiversity of soil macrofauna along the chronosequence abandoned rice paddy fields, including situations of 2, 4, 7 and 15 years, since the last rice harvest, compared to a control without agricultural disturbances. The density of the soil macrofauna was maximum in the 2 year abandoned rice field 4360 ind./m^2 and minimum in natural grassland (397.3 ind./m^2). The highest species richness was observed in natural grassland and in 2 year fallow with 53 and 59 species respectively. Species diversity was found maximum in natural grassland (1.98), minimum in 2 year fallow (1.01) and increased progressively through at the chronosequence.

Soil macrofauna quickly recolonised the ex-rice fields after abandonment of cultivation. After 2 years, the faunal density had recovered up to 4360 ind./m^2 probably they originate from neighbouring fallow plots. The species in newly abandoned rice fields differ from the natural grassland showing that most of the successful colonizers did not come from natural grassland sites.

Sinha et al. (2003) found highest density of earthworms under pine forest and species richness was greatest under the broad-leaved forest. Forest ecosystem had a mixed population of endemic and exotic species, where as in agroecosystems endemics dominated. Epigeic species were the dominant functional group under broad-leaved forest and pine-broad-leaved mixed forests, whilst endogeic species were dominant under pine forest. Irrigated agroecosystem supported only endogeics, where as endogeic and epi-anecic species were observed in rainfed agroecosystem. This suggest that distribution of functional groups is determined by the land use practices.

Bhadauria et al. (2000) studied the impact of deforestation and degradation of natural forest sites. Earthworm communities were studied in the climax forest, sub-climax mixed forest, regenerating open grassland and 6 and 40 year old pine forests sites with varying degree of disturbances in monthly interval. Due to the process of deforestation and degradation, a general decline in the density of endemic species and the dominance by exotics were observed. Maximum number of species were recorded in 40-year old pine forest. The mean density, biomass values of earthworms in 40-year old pine forest were recorded (395 ind./m^2 and 7.10 g/m^2), in climax oak forest, the density and biomass were found to be 189 ind./m^2 and 6.25 g/m^2. The destruction of natural forests leads to modification and alteration of soil conditions, which in turn results in the loss of some endemic species and the appearance of other exotic/endemic species.

Bhadauria et al. (1997) studied the population dynamics of earthworms during crop rotation under rainfed agriculture in Central Himalaya, India. They observed the density and seasonal distribution patterns of earthworm species in relation to crop rotation. Maximum earthworm density (200 ind./m^2) was recorded in late rainy season in rice crop mixture and in *Eleusine coracana* crop mixture (335 ind./m^2) sown following the harvest of winter wheat crop. Ploughing, harrowing and cult-discing the soils in the agricultural systems during crop rotation found to have adverse effect on earthworm species population.

1.6 Soil macrofauna studies in the Himalayan region

There is a steady shift from traditional agroecosystems which maintain and protect biological diversity to modern agroecosystems which are based on intensive cropping (eg., monocropping, plantations etc), and have evolved basically to increase yield and economic returns with considerable loss of biological diversity as a result (Maikhuri et al., 1996; Palni et al., 1998). The area under oak (*Avena sativa*) buck wheat (*Fagopyrum* sps), naked bean (*Hardeum himalayans*), and legumes like cow pea, mat bean, adjuki bean (*Vigna* sps) and horse gram (*Macrotyloma uniflorum*) has declined by 72-95%. The crops mostly replaced by cash crops like potato, soya bean, kidney bean, pigeon bean, mustard and amaranthus.

The land use modifications have been witnessed in terms of both extensification and intensification for last 2-3 decades in Garhwal Himalaya (Wakeel et al. 2005; Semwal et al. 2004).

Studies available on soil in the Himalayan region have majorly focused litter decomposition and nutrient dynamics (Semwal et al., 2003; Mehra et al., 1985; Pandey and Singh, 1981; Singh et al., 1984b; Sharma et al., 1994; Rawat and Singh, 1989). Attempts however have also been made to study soil biota, but there are largely confined to arbuscular mycorrhizal fungi (Chaurasia et al., 2005) and earthworms despite the known prospects of other taxonomic/functional groups of soil organisms.

In Himalayan region, many studies on diversity and density of earthworms are available (Mishra and Ramakrishnan, 1988; Bhadauria and Ramakrishnan, 1989, 1991, 1996; Bhadauria et al., 1997, 2000; Tewari and Mishra, 1995). Similar studies from Garhwal Himalayas are limited and ecosystem specific, restricted to sub-temperate forest ecosystems (Bhadauria et al., 2000), or to Rainfed agroecosystem types (Bhadauria et al., 1997) and the impact of ecosystem type, quality of organic inputs and water management on diversity and abundance of earthworms (Sinha et al., 2003). The present study aims to study the abundance of different groups of soil macroinvertebrates in different land uses with the following objectives.

Objectives

1. To characterize spatial variability in soil macrofauna in mid-altitude village landscape in Garhwal Himalaya
2. To characterize aboveground vegetation in terms of density, frequency and basal area.

2. Materials and Methods

2.1 Study Area

Himalayan mountain system covering eight developing countries of south-Asia including Afganisthan, Bangladesh, Bhutan, China, India, Myanmar, Nepal and Pakistan. The study site located in Garhwal region of central Himalayas, which is situated between 29^0 31^1 to 31^0 26^1 N and 77^0 35^1 to 80^0 6^1 E and covers an area of about 30090 km^2. the study was carried out in Kudi village (1400 m above mean sea level) in district of Rudraprayag, Garhwal in the state of Uttaranchal. The monthly mean minimum and maximum temperature vary in the range of 6 – 21^0 C and 18 – 35^0C respectively. About 80% of annual rainfall (1700 mm) is derived during July to September. The soil is derived from feldspathic, quartz schists, quartz muscovite schists and quartz chlorite schists and can be classified as Dystic cambisol according to FAO system.

The total area of the village was 120.982 ha, among this rainfed agricultural land constitute 67.02 ha and 0.123 ha lands were agricultural. Forest and abandoned agricultural land constitute 48.58 ha.

2.2 Land use – land cover types

Himalayan village is an ecosystem which function as a independent unit of economic activity and is comprised of agroecosystem, livestock and forest system and market support.

The landscape is differentiated into seven land uses, which are (a) rainfed agricultural land, (b) irrigated agricultural land, (c) abandoned agricultural land, (d) reserve pine forest (e) community pine forest, (f) reserve mixed forest, and (g). community mixed forest,

2.2.1 Rainfed agricultural land

Central Himalayas has the long heritage of subsistence economy with agriculture being core component, in which over 80% of people are involved. Rainfed agriculture on the terraced slopes are with scattered multipurpose tree. Agroforestry land use covering 20% of the total geographical areas of Indian Himalaya, is distributed as patches in the matrix of forest covering 52% area. In the rainfed agricultural land, density of agroforestry trees were 227.3

individuals/ha. Traditionally massive amount of leaf litter collected from nearby oak and pine forest is allowed to decompose along with livestock excreta and the farmyard manure is transferred to crop fields.

Rice (*Oryza sativa* L.), Barnyard millet (*Echinochloa frumentacea* L.), Foxtail millet (*Setaria etalica* (L), *P. beauv* and finger millet (*Eleusine coracana* (L.) are the dominant crops of the warm rainy season, while wheat (*Triticum aestivum* L), mustard (*Brassica campestris* L.) and Lentil (*Lens esculenta*) are grown during winter season. In rainy season, one cereal or millet crop was always mixed with a pulse (grain legume). Only one crop species was sown during winter season. From rain fed agriculture generally three crops are taken every two years.

2.2.2 Irrigated agricultural land

Irrigation is practiced on very small scale, particularly on both side of the stream. Here two crops are harvested in a year. Rice (*Oryza sativa* L.) being the major crop of the summer season and wheat (*Triticum aestivum* L.)of winter season. No fallowing is done in irrigated agricultural land. Reduction in crop yields due to trees in the agricultural land is the main reason why people don't prefer agroforestry trees in irrigated agricultural land.

2.2.3 Abandoned agricultural land

Some of the agricultural lands were abandoned due to uneconomic production from inconveniently located agricultural plots. Since food grain production is not enough to meet the requirement of the people, large scale migration for off farm employment result in abandonment of agricultural land. These abandoned agricultural lands are used as grazing lands in some cases.

2.2.4 Reserve Pine Forest

It is under the control of Forest Department. The tree density is very low in reserved pine forest. It is very old and mature pine forest as shown by the density and basal area. Forest fire is common and occur once in a year in the dry season. Understory vegetation is absent in reserve pine forest. Frequent forest fire deplete the soil moisture and degrade the soil quality.

2.2.5 Community Pine Forest

Pine forest is a major forest type in Garhwal Himalaya. Pine forest dominate between 1000 to 2200 m amsl. Pure patches of *Pinus roxburghii* dominate up to 1700 m elevation. It also occurs as pine-oak mixed crop in patches up to 2000 m. Pine is light demanding, fires adapted but fire promoting species. Pine forest naturally occur in the driest and rockiest slopes and can spread greatly under influence of cutting and burning. The pine at places are intruding into oak and oak-mixed areas. It has greatly nutrient conserving ability and can create nitrogen deficiency in the soil.

The community pine forest is pine-broadleaved mixed forest. *Pinus roxburghii* is the dominant species and *Myrica esculenta, Pyrus pashia* and *Rhododendron arboreum* are the main understory vegetation. Forest fire in community pine forest is not common, pine leaves are unpalatable and used for bedding of cattle. Pines are important for its resin and timber.

2.2.6 Reserve mixed forest

Currently 92% of central Himalayan forests are reserve/protected/civil forests managed by government. This forest was earlier under the control of King of Tehri, after independence, it came under the control of Forest Department. This forest is dominated by *Q. leucotrichophora* and *R. arboreum*. Rhododendron flower is used as minor forest product for extraction of juice which have medicinal value. Agriculture in the central Himalaya are largely forest based and huge amount of leaves extracted daily. According one estimate, 6 ha of good quality forest is required to support 1 ha agricultural land on sustainable basis.

2.2.7 Community Mixed Forest

Community mixed forests were carved out of the reserve and protected forest by 1940. Whose management was entrusted to the village communities. Currently 7% of the Himalayan forests are community forests. Community mixed forest is dominated by *Q. leucotrichophora* and *Q. glauca*. *Q. leucotrichophora* is an evergreen broadleaved trees, covers extensive areas in central Himalayas at 1500 to 2300 m altitudinal range. *Q. leucotrichophora* is the principal source of fuel supply as well as main fodder tree in this region. This forest is also considered best for soil and water conservation and soil fertility enhancement. *Q. glauca* produce best quality timber.

2.3 Sampling

Samples were collected in March-April from each of seven land use – land cover types. Sampling quadrats were chosen along random transects running across elevation gradient. Quadrats of 10m × 10 m were laid down and quadrats were separated by a distance of 30 - 50 m. In each quadrat regenerating tree and mature tree were counted and circumference at breast height (CBH) were measured for all individuals with CBH >10 cm and species were identified (Gaur, 1999). Woody individuals having CBH <30 cm were classified as regenerating trees and CBH ≥30 cm were classified as mature trees.

In each quadrat one sampling area of 30 cm × 30 cm were demarcated and litter was collected and its soil fauna hand sorted. A trench was then dug to a depth of 30 cm around the 30 cm × 30 cm area to get a soil monolith. Soil monoliths were divided into three layers (0-10, 10-20 and 20-30 cm) and macrofauna were handsorted separately from each layer. Soil fauna from the litter was added with the 0-10 cm soil fauna. All individuals were preserved in 4% formaldehyde (Anderson and Ingram, 1989). Specimens were later identified in the laboratory (Borror et al., 1981) and counted. Soil organisms were separated into 14 broad taxonomical groups. Soil samples were also collected separately from each layer of the monolith, but due to time constraints it had not been analyzed.

2.4 Tree community structure in different land uses in village landscape

Frequency and relative frequency of tree species: Frequency is refers to the occurrence of a speices in a sample is an improvement over a mere listing of species. It is a measure of distribution uniformly, not abundance. Frequency is expressed as a percentage.

$$\text{Frequency} = \frac{\text{Number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Frequency of the species}}{\text{Total frequency of all the species}} \times 100$$

2.5 Density and relative density of tree species

Density represents numerical strength of a species in the community. The number of individuals of the species in any unit area is its density. Density gives an idea of degree of competition (Sharma, 2000).

$$\text{Density} = \frac{\text{Total number of individuals of the tree species in all the sampling units}}{\text{Total number of sampling units studied}}$$

The results were multiplied with 100 to convert the data into number of individuals per ha.

$$\text{Relative density} = \frac{\text{Density of a speices}}{\text{Total density of all the species}} \times 100$$

Basal area and relative basal area of tree species: basal area refers to the ground actually penetrated by the stems. It is one of the chief characteristics to determine dominance.

$$\text{Basal area} = \frac{(\text{Circumference at breast height})^2}{4\pi}$$

$$\text{Relative basal area} = \frac{\text{Basal area of the species}}{\text{Total basal area of all the species}} \times 100$$

3. Results

3.1 Macrofauna

Highest macrofaunal density was found in abandoned agricultural land (937.6 ind/m^2), isoptera accounted for 67.5% of the total population. Lowest density of macrofaunal population was found in community mixed forest (131.9 individuals m^{-2}), where most of fauna were present in the surface layer of 0-10 cm soil depth. Coleoptera and Hymenoptera, orthoptera, aranae and diptera larvae were found in all seven land uses. Community pine forest had a lowest faunal density (143.6 individuals m^{-2}) than reserved pine forest (419.8 individuals m^{-2}). Similarly community mixed forest had a lower faunal density (131.9 individuals m^{-2}) than reserved mixed forest (214.3 individuals m^{-2}).

3.1.1 Earthworms

Earthworms were recorded in all land uses except irrigated agricultural land. The highest density of earthworms were recorded in rainfed agricultural land (29.2 individuals m^{-2}) followed by reserved pine forest with density (25.5 individuals m^{-2}). Lowest density of earthworms were found in community mixed forest of 0. 8 individuals m^{-2}. 57% of the total earthworm population in rainfed agricultural land was found in 20-30 cm soil depth. In reserve mixed forest and community pine forest, top 10 cm of soil layer accounted for 80% and 66% of the total earthworm population respectively. In 10-20 cm soil layer of reserve pine forest, 52% of the total earthworm populations were found.

3.1.2 Diplopoda

Diplopoda was found only in community mixed forest with density (1.6 individuals m^{-2}) in 0-10 cm soil layer.

3.1.3 Chilopoda

These were prominent in mixed forests. Chilopoda were found in all land uses except irrigated agricultural land. Highest density of chilopoda was found in reserve mixed forest (10 individuals m^{-2}) followed by community mixed forest (5.6 individuals m^{-2}), rainfed agricultural land (4.7 individuals m^{-2}) and reserve pine forest (4.4 individuals m^{-2}). In reserve pine forest, reserve mixed forest and community pine forest, most of the chilopoda were recorded in the upper 10 cm soil layer. In community mixed forest, 71% of the chilopoda were found in 10-20 cm soil layer. All chilopoda in abandoned agricultural land were recorded in 10-20 cm soil depth and in rainfed agricultural land, they were found only in 20-30 cm soil layer.

3.1.4 Spider

They were present in all the land uses, mostly in surface soil layer. Highest density of spiders were found in irrigated agricultural land (15.6 individuals m^{-2}) followed by abandoned agricultural land (8.9 individuals m^{-2}), community pine forest (8.7 individuals m^{-2}), lowest density was recorded in rainfed agricultural land.

3.1.5 Orthoptera

These were also recorded in all the seven land uses. Highest density of orthoptera was found in irrigated agricultural land (33. 4 individuals m^{-2}), followed by reserve mixed forest (10 individuals m^{-2}), community mixed forest (9.5 individuals m^{-2}), abandoned agricultural land (8.9 individuals m^{-2})). In abandoned agricultural land nearly 25% of the orthoptera were found in 20-30 cm soil depth, 15% of the total orhtoptera found in rainfed agricultural land, 20% were found in 10-20 cm of soil layer in irrigated agricultural land.

3.1.6 Dermaptera

They were found mostly in mixed broadleaved forest. Both reserve mixed forest and community mixed forest accounted for 97.5% of the total dermaptera population of all the land uses. Highest density of dermaptera was found in reserve mixed forest (16.6 individuals m^{-2}) and community mixed forest 15.1 individuals m^{-2}).

3.1.7 Isoptera

Highest density of isoptera were recorded in abandoned agricultural land (633 individuals m^{-2}) followed by reserve pine forest (130 individuals m^{-2}) and community pine forest (77.8 individuals m^{-2}) and were found absent in irrigated agricultural land. Isoptera were represented nearly 70% of total fauna in abandoned agricultural land, 44% accounted in 20-30 cm soil layer. Nearly 60% of termites populations in rainfed agricultural land found in 20-

30 cm soil layer. In reserved pine forest and community pine forest, 59.8% of termites were abundant in 0-10 cm soil layer. In community mixed forest (10-20 cm) and reserved mixed forest (20-30 cm), termites were absent in 0-10 cm soil layer.

3.1.8 Hemiptera

Density of hemiptera were highest in irrigated agricultural land, reserve pine forest (8.9 individuals m^{-2}). In irrigated agricultural land, abandoned agricultural land and reserve mixed forest, hemiptera was found in 0-10 cm soil layer. In reserve pine forest, 63% of hemiptera were found in 10-20 cm soil layer and 24.7% found in 20-30 soil layer. They were absent in community mixed forest and community pine forest.

3.1.9 Coleoptera

Coleoptera was found in all the land uses. Coleoptera larvae was prominent in irrigated agricultural land, where as coleoptera adults were prominent in abandoned agricultural land. Highest density of coleopteran (including larvae) was in irrigated agricultural land (173.3 individuals m^{-2}) followed by abandoned agricultural land (146.3 individuals m^{-2}), reserved pine forest (96.7 individuals m^{-2}), reserved mixed forest (94.3 individuals m^{-2}), community mixed forest (60.9) and lowest was observed in community pine forest (22.2 individuals m^{-2}). 36% of coleoptera adults were found in 20-30 cm soil layer of abandoned agricultural land and 88% of coleoptera larvae in irrigated agricultural land were recorded in 0-10 cm soil layer.

3.1.10 Lepidoptera Larvae

Highest density of Lepidoptera larvae found in irrigated agricultural land (17.8 individuals m^{-2}) followed by community mixed forest (7.2 individuals m^{-2}) and in irrigated agricultural land they were found in 0-10 cm soil layer.

3.1.11 Diptera Larve

The highest density of diptera larva found in irrigated agricultural land (93.3 individuals m^{-2}) followed by reserve mixed forest (15.5 individuals m^{-2}), community pine forest (12.7 individuals m^{-2}). 95% of diptera larvae found in irrigated agricultural land occurred in 0-10 cm soil layer. In community pine forest, reserved mixed forest and rainfed agricultural land, diptera larvae found in all the three depths.

3.1.12 Hymenoptera

Hymenoptera were recorded in all the land uses. Highest density of hymenoptera found in reserve pine forest (129.9 individuals m^{-2}) followed by abandoned agricultural land (106.7 individuals m^{-2}), rainfed agricultural land (56 individuals m^{-2}). In rainfed agricultural land hymenoptera were found in 10-20 cm soil layer. In reserve pine forest 57% of hymenoptera observed in 20-30 cm soil layer.

3.2 Distribution of Macrofauna Across Different Land Uses

3.2.1 Rainfed Agricultural Land

Total macrofaunal density in rainfed agricultural land is 214.7 (individuals m^{-2}), major contribution were made by coleoptrea (including larvae), hymenoptera and isoptera were 28.5%, 26% and 19% respectively. The density of earthworms was highest in rainfed agricultural land as compared to other land uses (29.2 individuals m^{-2}).

3.2.2 Irrigated Agricultural Land

Total density of macrofauna in irrigated agricultural land was found to be 351.2 (individuals m^{-2}). The high density was contributed by coleoptera (including larvae), which accounted for 49.5% (173.3 individuals m^{-2}) of the total fauna followed by Diptera larva (26.56%).

3.2.3 Abandoned Agricultural Land

The high density of total fauna was found in abandoned agricultural land (937.6 individuals m^{-2}) compared to other land uses. Isoptera was the major contributing group representing 67.5% of the total fauna. Isoptera, coleoptera and diptera accounted to 95% of the total fauna.

3.2.4 Reserve Pine Forest

Faunal density of reserved pine forest was found to be 419.8 (individuals m^{-2}). Isoptera (130 individuals m^{-2}) and hymenoptera (129.9 individuals m^{-2}) contributed more than 60% of the total density. Coleoptera (adults – 7.8 individuals m^{-2} and larvae – 88.9 individuals m^{-2}) was accounted 23% of the total fauna.

3.2.5 Community Pine Forest

Total macrofauna density in community pine forest was 143.6 individuals m^{-2}. Isoptera was the most dominant group with density of 77.8 (individuals m^{-2}) followed by coeoptera with density of 22.2 (individuals m^{-2}). Isoptera (54.1%) and coleopteran (15.4%) together contribute to 70% of the total fauna.

3.2.6 Reserve Mixed Forest

The density of macrofauna in reserved mixed forest (214.3 individuals m^{-2}) was similar to abandoned agricultural land (214.7 individuals m^{-2}). Coleoptera (including larvae) was most dominant (94.5 individuals m^{-2}) and accounted 44% of the total fauna followed by hymenoptera (35.6 individuals m^{-2}).

3.2.7 Community Mixed Forest

The density of macrofauna in community mixed forest was found to be 131.9 (individuals m^{-2}). Coleoptera (including larvae) had highest density of 60.9 individuals m^{-2} and contribute 46% of the total macrofauna. This was followed by dermaptera with density of 15.1 individuals m^{-2}.

3.3 Vertical Distribution

Macrofaunal density was very high in upper 0-10 cm soil layer in community pine forest, irrigated agricultural land, which accounted for 92% and 90% of the total population respectively. In community mixed forest and reserve mixed forest, macrofaunal population was found to be 81% of the total population in top 10 cm soil layer. In reserve pine forest, 0-10 cm soil layer contributed half of the total population, where as 10-20 cm and 20-30 cm layers contributed 27% and 21% of the total population respectively.

In rainfed agricultural land, vertical distribution of the macrofauna was found to be uniform. The faunal density in 0-10 cm, 10-20 cm and 20-30 cm soil depths were found to be 89.5 (individuals m^{-2}), 71.3 (individuals m^{-2}) and 53.9 (individuals m^{-2}) respectively.

In abandoned agricultural land 48% of the total macrofauna was found in 0-10 cm soil layer, 10% in 10-20 cm soil layer and 36% in 20-30 cm soil layer. Isoptera were most abundant in 20-30 cm soil layer in abandoned agricultural land and accounted for 78% of the total macorfaunal population in that layer.

3.4 Tree Community Structure

3.4.1 Rainfed Agricultural Land

Multipurpose tree species *Celtis australis, Ficus auriculata, Ficus subincisa* and *Quercus leucotrichophora* were dominant in the rainfed agricultural land. These species together contributed 77.37% of the total population.

3.4.2 Abandoned Agricultural Land

Regenerating tree species contributed more than 73% of the total tree population. This high density of regenerating tree species in abandoned agricultural land showed the initial stage of forest development. *Q. leucotrichophora* alone contributed 59% of total tree population.

3.4.3 Irrigated Agricultural Land

Agroforestry trees were absent in irrigated agricultural land.

3.4.4 Reserve Pine Forest

It is a mature, climax and old forest. *Pinus roxburghii* is the only species present in this land use. 84% of the total tree population falls in the CBH class >150 cm. Regenerating tree species were absent in this land use.

3.4.5 Community Pine Forest

Community pine forest was a pine broad-leaved mixed forest consisting of *Lyonia ovalifolia, Myrica esculenta, Pinus roxburghii, Pyrus pashia* and *Rhododendron arboreum* dominated by pine. The density of the regenerating tree species were very high and was about 63.4% of the total tree population in this land use. *P. roxburghii* was found in all the CBH classes, while other tree species were absent in higher CBH classes.

3.4.6 Reserve Mixed Forest

Regenerating tree species accounted for 26.3% of total tree population. *Q. leucotrichophora* and *R. arboreum* were the prominent tree species and represented more than 72% of the total tree population in this land use.

3.4.7 Community Mixed Forest

Community mixed forest was dominated by *Q. glauca* and *Q. leucotrichophora*. Both tree species contributed 56.6% of the total tree population. Number of tree species in higher CBH classes (>90 cm) are very low. Regenerating tree species accounted for 48.7% of the total tree population. *M. esculenta* and *R. arboreum* contributed for more than 75% of the total regenerating tree species. Although *Quercus* sps. were dominant in the land use, regenerating *Q. glauca* and *Q. leucotrichophora* contribute for only 16.6% of the total regenerating tree species.

3.5 Density of Tree Species

Density of regenerating tree species were highest in community pine forest (1950 individuals m^{-2}) followed by community mixed forest (1484.7 individuals m^{-2}), reserve mixed forest (720 individuals m^{-2}). Regenerating tree species were absent in reserve pine forest. Community mixed forest had a higher density of regenerating tree species than reserved mixed forest.

Highest density of mature tree species were found in reserved mixed forest (2020 individuals m^{-2}) followed by community mixed forest (1561 individuals m^{-2}), community pine forest (1125 individuals m^{-2}). Density of mature trees in rainfed agricultural land was found to be higher than abandoned agricultural land but the density of regenerating tree species was higher in abandoned agricultural land.

3.6 Basal Area

Overall basal area was higher in reserve mixed forest (73.69 m^2/ha) followed by reserved pine forest (62.35 m^2/ha), community pine forest (43.97 m^2/ha), community mixed forest (35.5 m^2/ha). Lowest basal area was found in abandoned agricultural land (2.56 m^2/ha). In community pine forest, pine represented 87% of the total tree basal area. In reserve mixed forest, *R. arboreum* and *Q. leucotrichophora* contributed 39.7% and 34% of the total basal area respectively. In community mixed forest *Q. glauca* and *Q. leucotrichophora* represented 53.7% and 38% of the total basal area respectively.

Table 1: Uses and ecological features of tree species of different land uses in village landscape

Local name	Botanical name	Family	Uses and ecological features
Ainyar	*Lyonia ovalifolia*	Ericaceae	Wood used as fuel; young leaves poisonous to cattle; medicinal
Banj	*Quercus leucotrichophora*	Fagaceae	Wood used as construction, plough and bed sticks as well as fuel; leaves used fodder; fruits eaten by monkeys and bears; decomposed leaves used as organic manure; an important tree of social forestry
Bhimal	*Grewia optiva*	Tiliaceae	Bark fiber extensively used for ropes, nets, saps, brushes, brooms etc.; sticks after filling of the barks used to lit fire; leaves provide good fodder; fruits edible and medicinal; an important agroforestry tree
Burans	*Rhododendron arboreum*	Ericaceae	Wood used for fuel and charcoal; flowers eaten raw or made into sauce, jellies, jams and refreshing drinks, flowers useful as bee forage
Channchri	*Ficus subincisa*	Moraceae	Leaves and branches used as fodder; fruits edible
Kaphal	*Myrica esculenta*	Myricaceae	Fruits edible, raw or made into refreshing drinks; wood used as fuel and implements
Katmora	*Litsea monopetala*	Lauraceae	Leaves chiefly used for silkworm farming; occasionally as fodder
Kharik	*Celtis australis*	Ulmaceae	Fruits edible; leaves provide good fodder; wood used for making small article and important tree of agroforestry
Lodh	*Symplocos ramosissima*	Symplocaceae	Leaves used as fodder; flowers visited by bees for nectar and pollen
Mole	*Pyrus pashia*	Rosaceae	Leaves and twigs as fodder; ripe fruits edible; flowers used in apiculture; believed to check soil erosion in landslide zones
Pine	*Pinus roxburghii*	Pinaceae	Wood used for construction; resin in varnishes and turpentine; saw-dust with honey used in asthma and bronchitis
Toon	*Toona hexandra*	Meliaceae	Wood priced for construction purposes, furniture and other articles
Timla	*Ficus auriculata*	Moraceae	Leaves made into cup an plates, also provide good fodder for cattle and elephants; ripe fruits edible, unripe fruits made into vegetable

Table 1 continued.......

Local name	Botanical name	Family	Uses and ecological features
Harinj	*Quercus glauca*	Fagaceae	Wood used as fuel; rarely for agricultural implements; leaves as fodder
Syanru	*Debregeasia salicifolia*	Urticaceae	Plant provides good fodder; bark yields strong fibre for ropes & cordages; fruits edible; plaster made from bark for bone fracture
Ust	*Alnus nepalensis*	Betulaceae	Wood used for carpentry and construction; bark used in local medicine; fast growing tree used as soil binder
Panyyan	*Prunus cerasoides*	Rosaceae	Branches for walking sticks; leaves as fodder and ripe fruits edible; flowers useful source of bee forage; plant regarded as sacred used in several rituals of locals
Others (Philku)	Botanical name could not be identified		
Others (Tithriat)	Botanical name could not be identified		
Others (Malio)	Botanical name could not be identified		
Others (Mowa)	Botanical name could not be identified		
Others (Kirmor)	Botanical name could not be identified		

Table 2: Frequency of tree species in a mid-altitude village landscape (RA, Rainfed Agriculture; IA, Irrigated Agriculture; AA, Abandoned Agriculture; RPF, Reserve Pine Forest; CPF, Community Pine Forest; RMF, Reserve Mixed Forest; CMF, Community Mixed Forest).

Tree species	RA	IA	AA	RPF	CPF	RMF	CMF
Alnus nepalensis	0.0	0.0	0.0	0.0	0.0	40.0	0.0
Celtis australis	31.8	0.0	20.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	40.9	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	40.9	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	13.6	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	13.6	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	4.5	0.0	20.0	0.0	75.0	70.0	30.8
Myrica esculenta	0.0	0.0	20.0	0.0	100.0	60.0	46.2
Pinus roxburghii	0.0	0.0	0.0	100.0	100.0	0.0	0.0
Prunus cerasoides	9.1	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	4.5	0.0	20.0	0.0	83.3	30.0	15.4
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0	100.0
Quercus leucotrichophora	4.5	0.0	40.0	0.0	25.0	100.0	100.0
Rhododendron arboreum	0.0	0.0	20.0	0.0	91.7	90.0	46.2
Symplocos ramosissima	0.0	0.0	0.0	0.0	41.7	40.0	0.0
Toona hexandra	9.1	0.0	0.0	0.0	0.0	0.0	0.0
Others	13.6	0.0	40.0	0.0	33.3	20.0	23.1

Table 3: Relative frequency of tree species in a mid-altitude village landscape (RA, Rainfed Agriculture; IA, Irrigated Agriculture; AA, Abandoned Agriculture; RPF, Reserve Pine Forest; CPF, Community Pine Forest; RMF, Reserve Mixed Forest; CMF, Community Mixed Forest).

Tree species	RA	IA	AA	RPF	CPF	RMF	CMF
Alnus nepalensis	0.0	0.0	0.0	0.0	0.0	8.9	0.0
Celtis australis	16.7	0.0	11.1	0.0	0.0	0.0	0.0
Debregeasia salicifolia	2.4	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	21.4	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	21.4	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	2.4	0.0	11.1	0.0	13.6	15.6	8.5
Myrica esculenta	0.0	0.0	11.1	0.0	18.2	13.3	12.8
Pinus roxburghii	0.0	0.0	0.0	100.0	18.2	0.0	0.0
Prunus cerasoides	4.8	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	2.4	0.0	11.1	0.0	15.2	6.7	4.3
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0	27.7
Quercus leucotrichophora	2.4	0.0	22.2	0.0	4.5	22.2	27.7
Rhododendron arboreum	0.0	0.0	11.1	0.0	16.7	20.0	12.8
Symplocos ramosissima	0.0	0.0	0.0	0.0	7.6	8.9	0.0
Toona hexandra	4.8	0.0	0.0	0.0	0.0	0.0	0.0
Others	7.1	0.0	22.2	0.0	6.1	4.4	6.4

Table 4: Basal area of tree species (m^2/ha) in a mid-altitude village landscape (RA, Rainfed Agriculture; IA, Irrigated Agriculture; AA, Abandoned Agriculture; RPF, Reserve Pine Forest; CPF, Community Pine Forest; RMF, Reserve Mixed Forest; CMF, Community Mixed Forest).

Tree species	RA	IA	AA	RPF	CPF	RMF	CMF
Alnus nepalensis	0.00	0.00	0.00	0.00	0.00	8.04	0.00
Celtis australis	1.12	0.00	0.18	0.00	0.00	0.00	0.00
Debregeasia salicifolia	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Ficus auriculata	3.86	0.00	0.00	0.00	0.00	0.00	0.00
Ficus subincisa	0.56	0.00	0.00	0.00	0.00	0.00	0.00
Grewia optiva	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Litsea monopetala	0.46	0.00	0.00	0.00	0.00	0.00	0.00
Lyonia ovalifolia	0.00	0.00	0.02	0.00	0.00	6.87	0.00
Myrica esculenta	0.00	0.00	0.30	0.00	3.91	3.44	0.83
Pinus roxburghii	0.00	0.00	0.00	62.35	38.54	0.00	0.00
Prunus cerasoides	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Pyrus pashia	0.15	0.00	0.08	0.00	0.10	0.44	0.00
Quercus glauca	0.00	0.00	0.00	0.00	0.00	0.00	19.08
Quercus leucotrichophora	0.51	0.00	1.51	0.00	0.00	25.06	13.65
Rhododendron arboreum	0.00	0.00	0.21	0.00	1.22	29.27	1.93
Symplocos ramosissima	0.00	0.00	0.00	0.00	0.21	0.30	0.00
Toona hexandra	0.19	0.00	0.00	0.00	0.00	0.00	0.00
Others	0.54	0.00	0.27	0.00	0.00	0.27	0.00
Total	7.92	0.00	2.56	62.35	43.97	73.69	35.50

Table 5: Relative Basal area of tree species in a mid-altitude village landscape (RA, Rainfed Agriculture; IA, Irrigated Agriculture; AA, Abandoned Agriculture; RPF, Reserve Pine Forest; CPF, Community Pine Forest; RMF, Reserve Mixed Forest; CMF, Community Mixed Forest).

Tree species	RA	IA	AA	RPF	CPF	RMF	CMF
Alnus nepalensis	0.0	0.0	0.0	0.0	0.0	10.9	0.0
Celtis australis	14.1	0.0	7.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	48.7	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	2.5	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	5.8	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	0.0	0.0	0.8	0.0	0.0	9.3	0.0
Myrica esculenta	0.0	0.0	11.7	0.0	8.9	4.7	2.3
Pinus roxburghii	0.0	0.0	0.0	100.0	87.7	0.0	0.0
Prunus cerasoides	3.9	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	1.9	0.0	3.1	0.0	0.2	0.6	0.0
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0	53.7
Quercus leucotrichophora	6.4	0.0	59.0	0.0	0.0	34.0	38.5
Rhododendron arboreum	0.0	0.0	8.2	0.0	2.8	39.7	5.4
Symplocos ramosissima	0.0	0.0	0.0	0.0	0.5	0.4	0.0
Toona hexandra	2.4	0.0	0.0	0.0	0.0	0.0	0.0
Others	6.8	0.0	10.5	0.0	0.0	0.4	0.0

Table 6: Density (No. of individuals/ha) of regenerating tree species (CBH<30 cm) in a mid-altitude village landscape (RA, Rainfed Agriculture; IA, Irrigated Agriculture; AA, Abandoned Agriculture; RPF, Reserve Pine Forest; CPF, Community Pine Forest; RMF, Reserve Mixed Forest; CMF, Community Mixed Forest).

Tree species	RA	IA	AA	RPF	CPF	RMF	CMF
Alnus nepalensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Celtis australis	22.7	0.0	0.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	4.6	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	9.1	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	54.6	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	4.6	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	13.6	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	0.0	0.0	20.0	0.0	225.0	20.0	53.9
Myrica esculenta	0.0	0.0	20.0	0.0	441.7	130.0	415.4
Pinus roxburghii	0.0	0.0	0.0	0.0	341.7	0.0	0.0
Prunus cerasoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	0.0	0.0	40.0	0.0	391.7	0.0	38.5
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0	223.1
Quercus leucotrichophora	50.0	0.0	280.0	0.0	16.7	340.0	23.1
Rhododendron arboreum	0.0	0.0	40.0	0.0	358.3	120.0	707.7
Symplocos ramosissima	0.0	0.0	0.0	0.0	116.7	100.0	0.0
Toona hexandra	4.6	0.0	0.0	0.0	0.0	0.0	0.0
Others	9.1	0.0	100.0	0.0	58.3	10.0	23.1
Total	172.8	0.0	500.0	0.0	1950.0	720.0	1484.6

Table 7: Relative Density of regenerating tree species (CBH<30 cm) in a mid-altitude village landscape (RA, Rainfed Agriculture; IA, Irrigated Agriculture; AA, Abandoned Agriculture; RPF, Reserve Pine Forest; CPF, Community Pine Forest; RMF, Reserve Mixed Forest; CMF, Community Mixed Forest).

Tree species	RA	IA	AA	RPF	CPF	RMF	CMF
Alnus nepalensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Celtis australis	13.2	0.0	0.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	5.3	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	31.6	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	7.9	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	0.0	0.0	4.0	0.0	11.5	2.8	3.6
Myrica esculenta	0.0	0.0	4.0	0.0	22.6	18.1	28.0
Pinus roxburghii	0.0	0.0	0.0	0.0	17.5	0.0	0.0
Prunus cerasoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	0.0	0.0	8.0	0.0	20.1	0.0	2.6
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0	15.0
Quercus leucotrichophora	28.9	0.0	56.0	0.0	0.9	47.2	1.6
Rhododendron arboreum	0.0	0.0	8.0	0.0	18.4	16.7	47.7
Symplocos ramosissima	0.0	0.0	0.0	0.0	6.0	13.9	0.0
Toona hexandra	2.6	0.0	0.0	0.0	0.0	0.0	0.0
Others	5.3	0.0	20.0	0.0	3.0	1.4	1.6

Table 8: Density (No. of individuals/ha) of mature tree species (CBH≥30 cm) in a mid-altitude village landscape (RA, Rainfed Agriculture; IA, Irrigated Agriculture; AA, Abandoned Agriculture; RPF, Reserve Pine Forest; CPF, Community Pine Forest; RMF, Reserve Mixed Forest; CMF, Community Mixed Forest).

Tree species	RA	IA	AA	RPF	CPF	RMF	CMF
Alnus nepalensis	0.0	0	0.0	0.0	0.0	60.0	0.0
Celtis australis	4.6	0	20.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	13.6	0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	77.3	0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	27.3	0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	13.6	0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	4.6	0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	4.6	0	0.0	0.0	0.0	240.0	0.0
Myrica esculenta	31.8	0	20.0	0.0	266.7	150.0	30.8
Pinus roxburghii	0.0	0	0.0	250.0	750.0	0.0	0.0
Prunus cerasoides	0.0	0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	0.0	0	0.0	0.0	8.3	30.0	0.0
Quercus glauca	0.0	0	0.0	0.0	0.0	0.0	923.1
Quercus leucotrichophora	36.4	0	120.0	0.0	16.7	850.0	553.9
Rhododendron arboreum	0.0	0	0.0	0.0	83.3	670.0	53.9
Symplocos ramosissima	0.0	0	0.0	0.0	0.0	10.0	0.0
Toona hexandra	4.6	0	0.0	0.0	0.0	0.0	0.0
Others	9.1	0.00	20.0	0.0	0.0	10.0	0.0
Total	227.3	0.00	180.0	250.0	1125.0	2020.0	1561.6

Table 9: Relative Density of mature tree species (CBH≥30 cm) in a mid-altitude village landscape (RA, Rainfed Agriculture; IA, Irrigated Agriculture; AA, Abandoned Agriculture; RPF, Reserve Pine Forest; CPF, Community Pine Forest; RMF, Reserve Mixed Forest; CMF, Community Mixed Forest).

Tree species	RA	IA	AA	RPF	CPF	RMF	CMF
Alnus nepalensis	0.0	0.0	0.0	0.0	0.0	3.0	0.0
Celtis australis	2.0	0.0	11.1	0.0	0.0	0.0	0.0
Debregeasia salicifolia	6.0	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	34.0	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	12.0	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	6.0	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	2.0	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	2.0	0.0	0.0	0.0	0.0	11.9	0.0
Myrica esculenta	14.0	0.0	11.1	0.0	23.7	7.4	2.0
Pinus roxburghii	0.0	0.0	0.0	100.0	66.7	0.0	0.0
Prunus cerasoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	0.0	0.0	0.0	0.0	0.7	1.5	0.0
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0	59.1
Quercus leucotrichophora	16.0	0.0	66.7	0.0	1.5	42.1	35.5
Rhododendron arboreum	0.0	0.0	0.0	0.0	7.4	33.2	3.4
Symplocos ramosissima	0.0	0.0	0.0	0.0	0.0	0.5	0.0
Toona hexandra	2.0	0.0	0.0	0.0	0.0	0.0	0.0
Others	4.0	0.0	11.1	0.0	0.0	0.5	0.0

Table 10: Tree population structure (No. of individuals/ha) of rainfed agriculture in a mid-altitude village landscape.

Tree species	Girth Classes					
	<30 cm	30-60 cm	60-90 cm	90-120 cm	120-150 cm	>150 cm
Alnus nepaliensis	0.0	0.0	0.0	0.0	0.0	0.0
Celtis australis	22.7	13.6	18.2	0.0	0.0	0.0
Debregeasia salicifolia	4.5	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	9.1	27.3	22.7	18.2	9.1	0.0
Ficus subincisa	54.5	27.3	0.0	0.0	0.0	0.0
Grewia optiva	4.5	13.6	0.0	0.0	0.0	0.0
Litsea monopetala	13.6	0.0	0.0	4.5	0.0	0.0
Lyonia ovalifolia	0.0	4.5	0.0	0.0	0.0	0.0
Myrica esculenta	0.0	0.0	0.0	0.0	0.0	0.0
Pinus roxburghii	0.0	0.0	0.0	0.0	0.0	0.0
Prunus cerasoides	0.0	4.5	4.5	0.0	0.0	0.0
Pyrus pashia	0.0	0.0	4.5	0.0	0.0	0.0
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0
Quercus leucotrichophora	50.0	36.4	0.0	0.0	0.0	0.0
Rhododendron arboreum	0.0	0.0	0.0	0.0	0.0	0.0
Symplocos ramosissima	0.0	0.0	0.0	0.0	0.0	0.0
Toona hexandra	4.5	0.0	4.5	0.0	0.0	0.0
Others	9.1	0.0	4.5	9.1	0.0	0.0

Table 11: Tree population structure (No. of individuals/ha) of abandoned agriculture land in a mid-altitude village landscape.

Tree species	Girth Classes					
	<30 cm	30-60 cm	60-90 cm	90-120 cm	120-150 cm	>150 cm
Alnus nepaliensis	0.0	0.0	0.0	0.0	0.0	0.0
Celtis australis	0.0	20.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	20.0	0.0	0.0	0.0	0.0	0.0
Myrica esculenta	20.0	20.0	0.0	0.0	0.0	0.0
Pinus roxburghii	0.0	0.0	0.0	0.0	0.0	0.0
Prunus cerasoides	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	40.0	0.0	0.0	0.0	0.0	0.0
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0
Quercus leucotrichophora	280.0	120.0	0.0	0.0	0.0	0.0
Rhododendron arboreum	40.0	0.0	0.0	0.0	0.0	0.0
Symplocos ramosissima	0.0	0.0	0.0	0.0	0.0	0.0
Toona hexandra	0.0	0.0	0.0	0.0	0.0	0.0
Others	100.0	20.0	0.0	0.0	0.0	0.0

Table 12: Tree population structure (No. of individuals/ha) in reserved pine forest of a mid-altitude village landscape.

Tree species	Girth Classes					
	<30 cm	30-60 cm	60-90 cm	90-120 cm	120-150 cm	>150 cm
Alnus nepaliensis	0.0	0.0	0.0	0.0	0.0	0.0
Celtis australis	0.0	0.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	0.0	0.0	0.0	0.0	0.0	0.0
Myrica esculenta	0.0	0.0	0.0	0.0	0.0	0.0
Pinus roxburghii	0.0	0.0	10.0	0.0	30.0	210.0
Prunus cerasoides	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	0.0	0.0	0.0	0.0	0.0	0.0
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0
Quercus leucotrichophora	0.0	0.0	0.0	0.0	0.0	0.0
Rhododendron arboreum	0.0	0.0	0.0	0.0	0.0	0.0
Symplocos ramosissima	0.0	0.0	0.0	0.0	0.0	0.0
Toona hexandra	0.0	0.0	0.0	0.0	0.0	0.0
Others	0.0	0.0	0.0	0.0	0.0	0.0

Table 13: Tree population structure (No. of individuals/ha) in reserved mixed forest of a mid-altitude village landscape.

Tree species	Girth Classes					
	<30 cm	30-60 cm	60-90 cm	90-120 cm	120-150 cm	>150 cm
Alnus nepaliensis	0.0	0.0	20.0	30.0	0.0	10.0
Celtis australis	0.0	0.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	20.0	140.0	80.0	20.0	0.0	0.0
Myrica esculenta	130.0	140.0	0.0	0.0	10.0	0.0
Pinus roxburghii	0.0	0.0	0.0	0.0	0.0	0.0
Prunus cerasoides	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	0.0	30.0	0.0	0.0	0.0	0.0
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0
Quercus leucotrichophora	340.0	500.0	310.0	30.0	0.0	10.0
Rhododendron arboreum	120.0	260.0	330.0	50.0	20.0	10.0
Symplocos ramosissima	100.0	10.0	0.0	0.0	0.0	0.0
Toona hexandra	0.0	0.0	0.0	0.0	0.0	0.0
Others	10.0	10.0	0.0	0.0	0.0	0.0

Table 14: Tree population structure (No. of individuals/ha) in community pine forest of a mid-altitude village landscape.

Tree species	Girth Classes					
	<30 cm	30-60 cm	60-90 cm	90-120 cm	120-150 cm	>150 cm
Alnus nepaliensis	0.0	0.0	0.0	0.0	0.0	0.0
Celtis australis	0.0	0.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	225.0	0.0	0.0	0.0	0.0	0.0
Myrica esculenta	441.7	266.7	0.0	0.0	0.0	0.0
Pinus roxburghii	341.7	325.0	200.0	141.7	50.0	33.3
Prunus cerasoides	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	391.7	8.3	0.0	0.0	0.0	0.0
Quercus glauca	0.0	0.0	0.0	0.0	0.0	0.0
Quercus leucotrichophora	16.7	16.7	0.0	0.0	0.0	0.0
Rhododendron arboreum	358.3	83.3	0.0	0.0	0.0	0.0
Symplocos ramosissima	116.7	0.0	0.0	0.0	0.0	0.0
Toona hexandra	0.0	0.0	0.0	0.0	0.0	0.0
Others	58.3	0.0	0.0	0.0	0.0	0.0

Table 15: Tree population structure (No. of individuals/ha) in community mixed forest of a mid-altitude village landscape

Tree species	Girth Classes					
	<30 cm	30-60 cm	60-90 cm	90-120 cm	120-150 cm	>150 cm
Alnus nepaliensis	0.0	0.0	0.0	0.0	0.0	0.0
Celtis australis	0.0	0.0	0.0	0.0	0.0	0.0
Debregeasia salicifolia	0.0	0.0	0.0	0.0	0.0	0.0
Ficus auriculata	0.0	0.0	0.0	0.0	0.0	0.0
Ficus subincisa	0.0	0.0	0.0	0.0	0.0	0.0
Grewia optiva	0.0	0.0	0.0	0.0	0.0	0.0
Litsea monopetala	0.0	0.0	0.0	0.0	0.0	0.0
Lyonia ovalifolia	53.8	0.0	0.0	0.0	0.0	0.0
Myrica esculenta	415.4	30.8	0.0	0.0	0.0	0.0
Pinus roxburghii	0.0	0.0	0.0	0.0	0.0	0.0
Prunus cerasoides	0.0	0.0	0.0	0.0	0.0	0.0
Pyrus pashia	38.5	0.0	0.0	0.0	0.0	0.0
Quercus glauca	223.1	753.8	161.5	0.0	0.0	7.7
Quercus leucotrichophora	23.1	423.1	115.4	0.0	7.7	7.7
Rhododendron arboreum	707.7	23.1	30.8	0.0	0.0	0.0
Symplocos ramosissima	0.0	0.0	0.0	0.0	0.0	0.0
Toona hexandra	0.0	0.0	0.0	0.0	0.0	0.0
Others	23.1	0.0	0.0	0.0	0.0	0.0

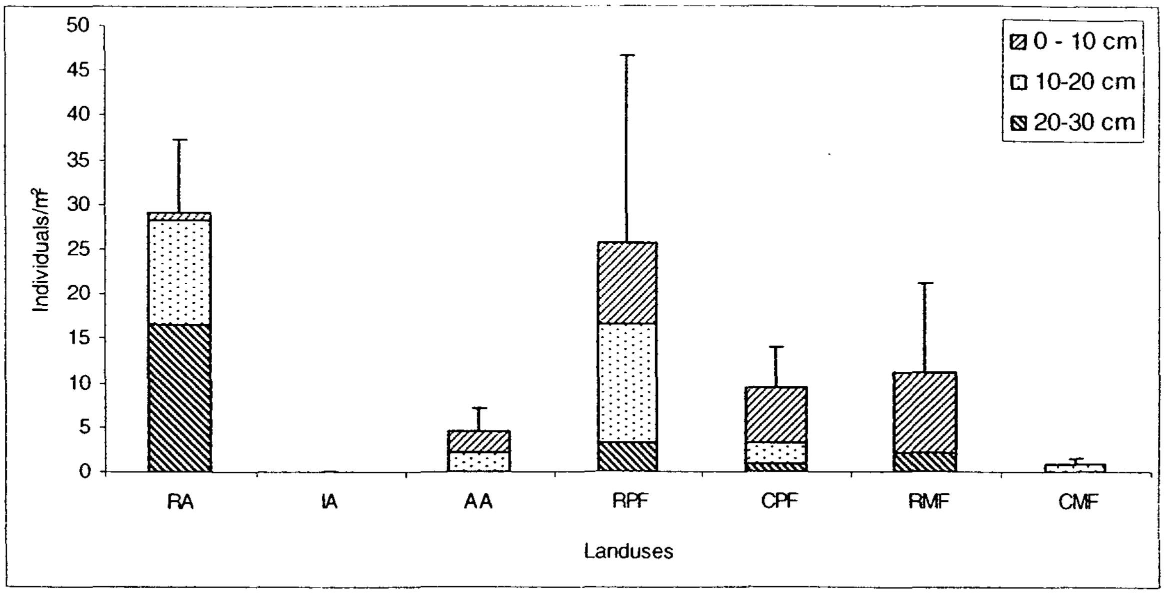

Fig. 1: Density of Earthworms (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

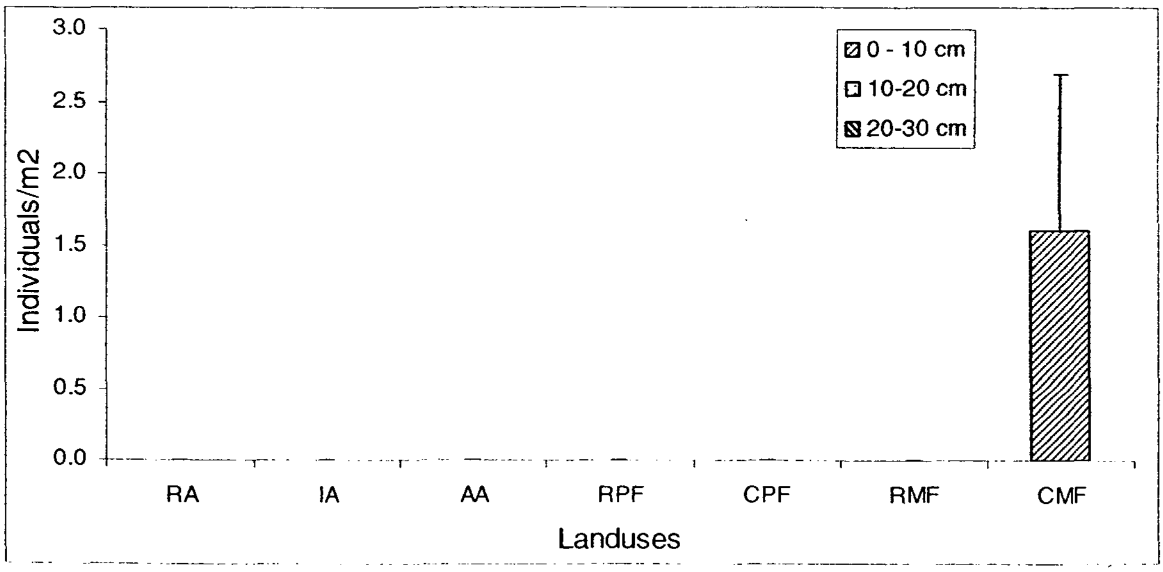

Fig. 2: Density of Diplopoda (Millepede) (individuals/m^2) in different land uses a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

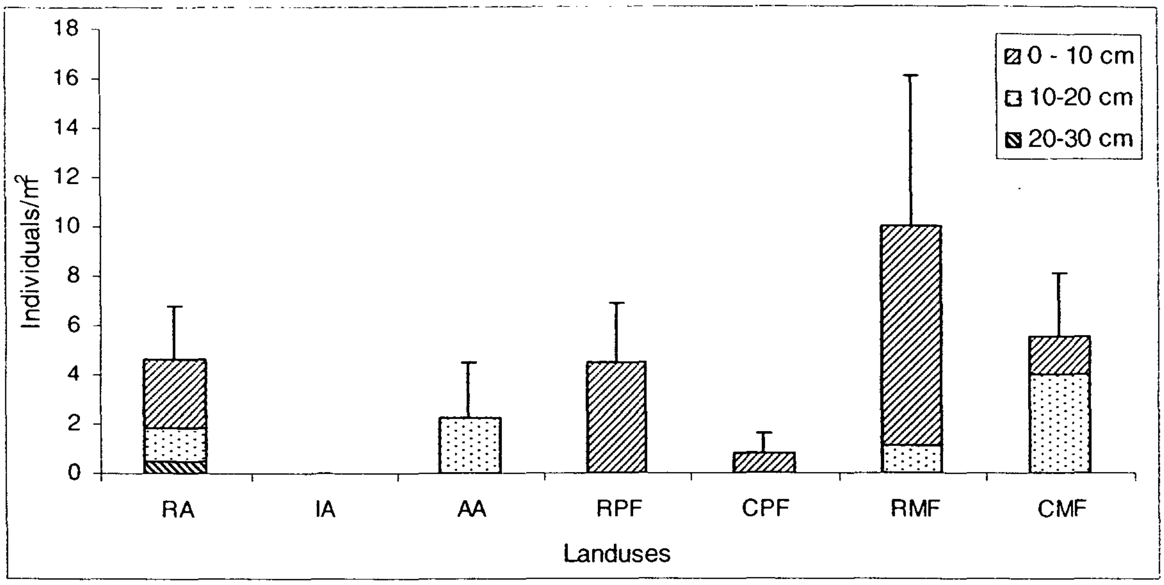

Fig. 3: Density of Chilopoda (Centipede) (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

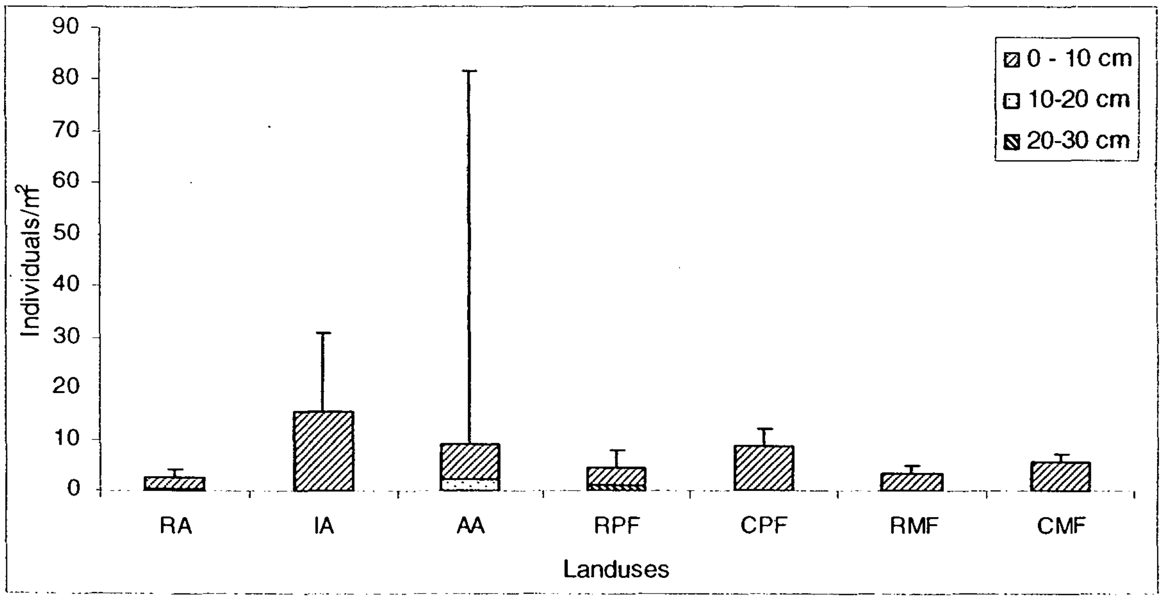

Fig. 4: Density of Aranae (Spider) (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

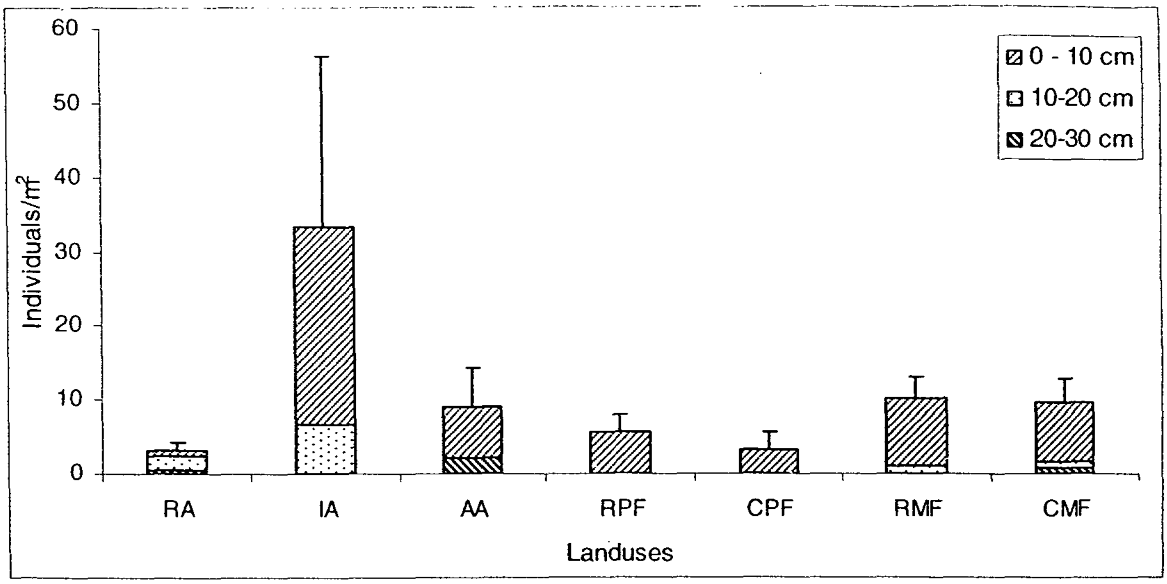

Fig. 5: Density of Orthoptera (individuals/m^2) in different land uses of a village landscape of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

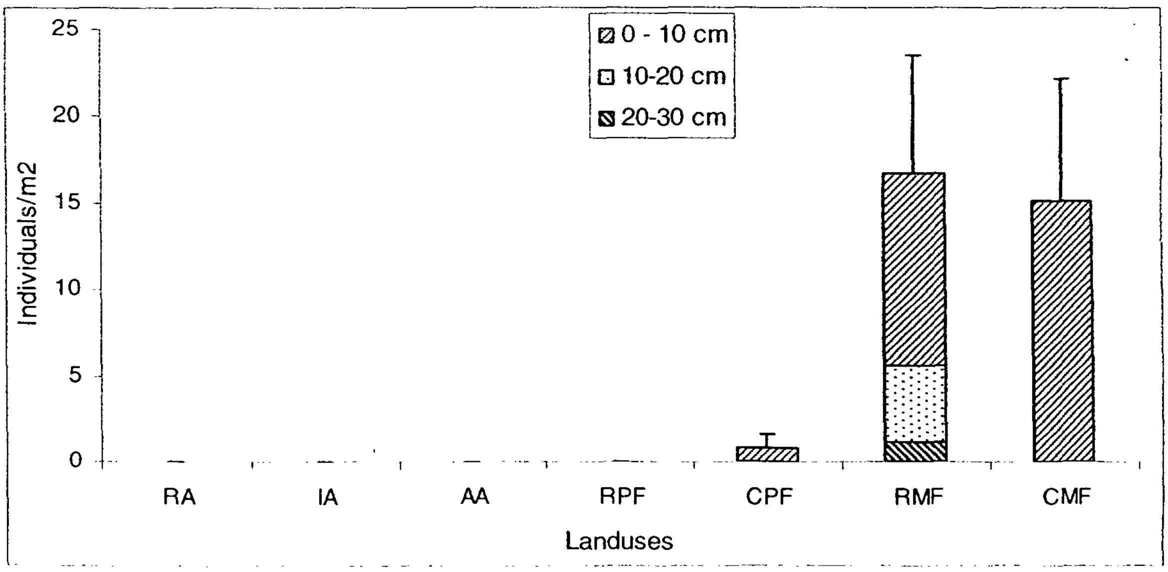

Fig. 6: Density of Dermaptera (Earwig) (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

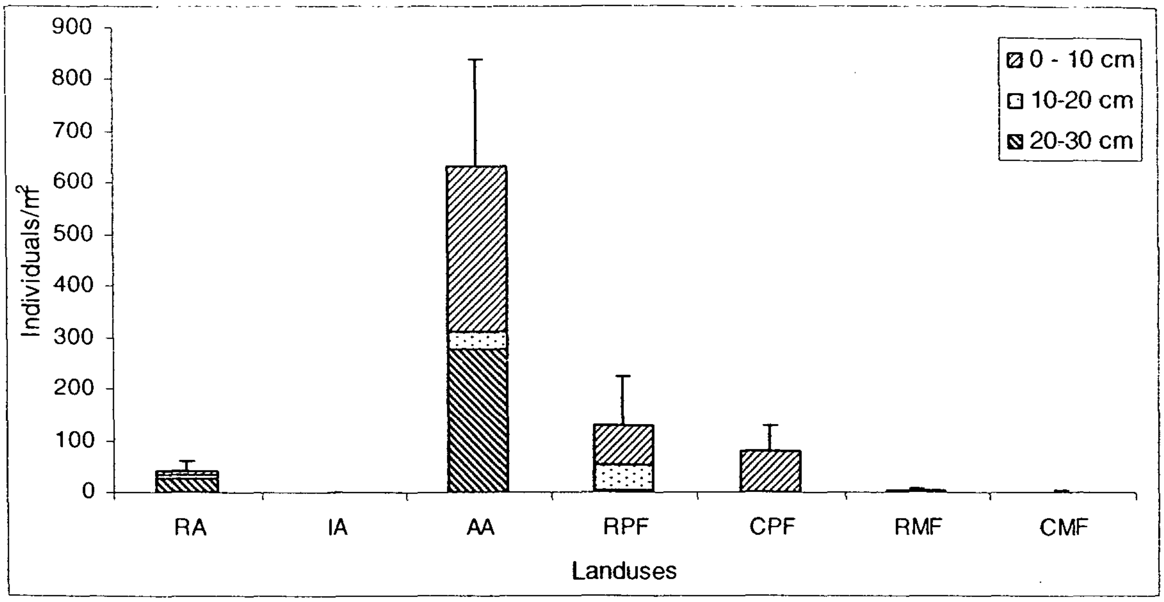

Fig. 7: Density of Isoptera (Termites) (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

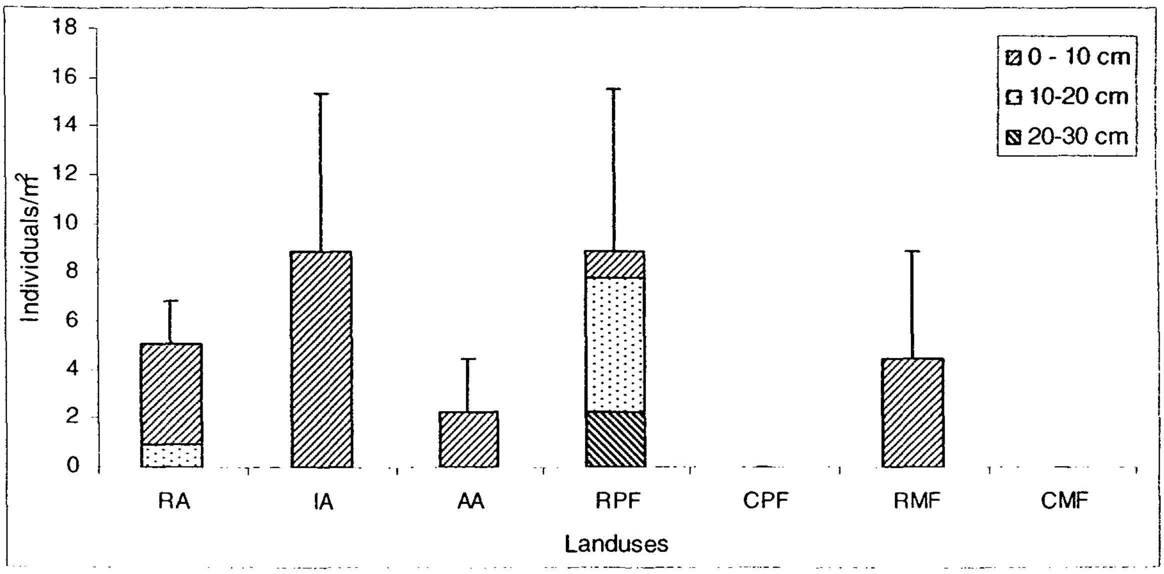

Fig. 8: Density of Hemiptera (Bugs) (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

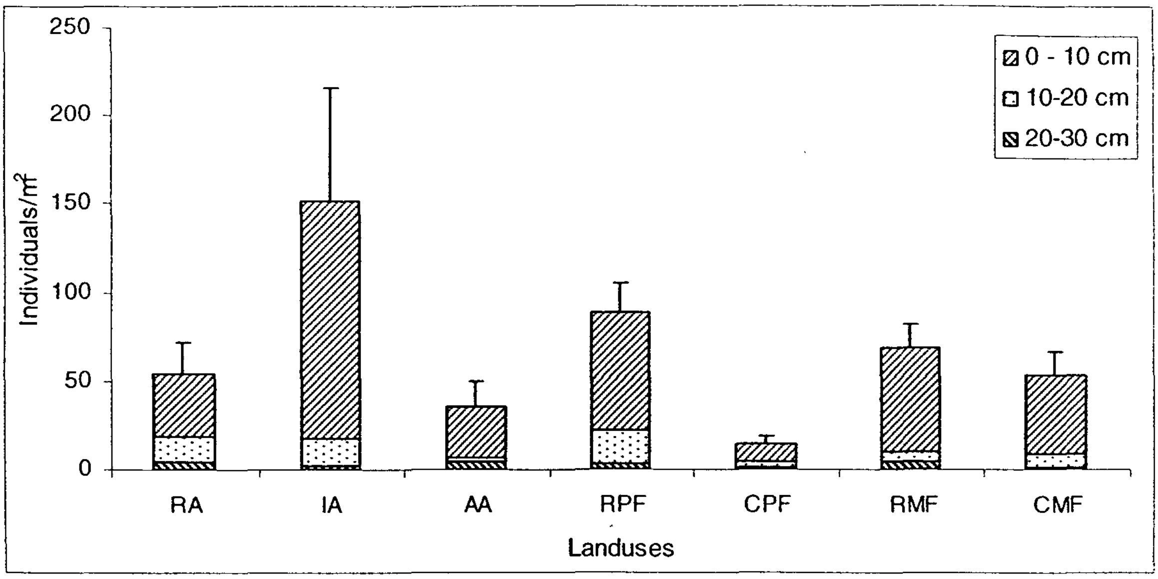

Fig.9: Density of Coleoptera Larvae (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

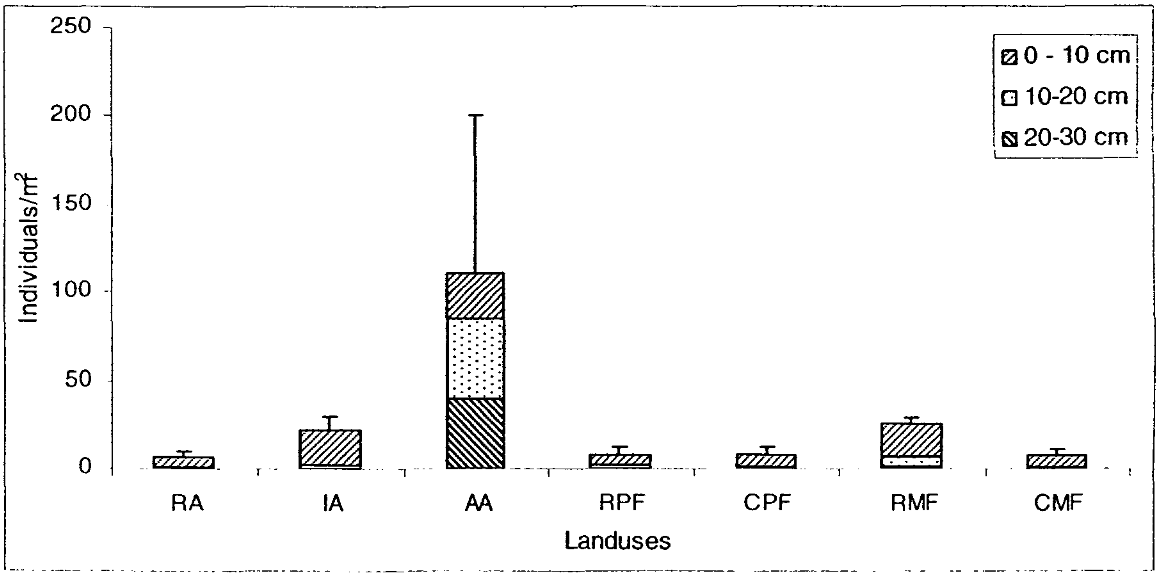

Fig.10: Density of Coleoptera Adults (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

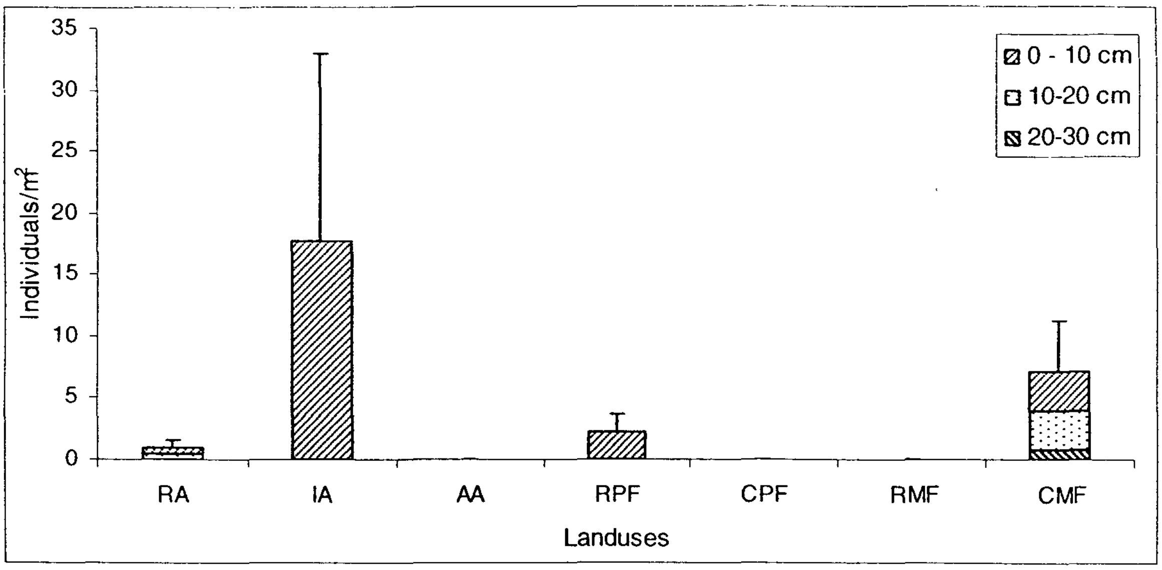

Fig.11: Density of Lepidoptera Larvae (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

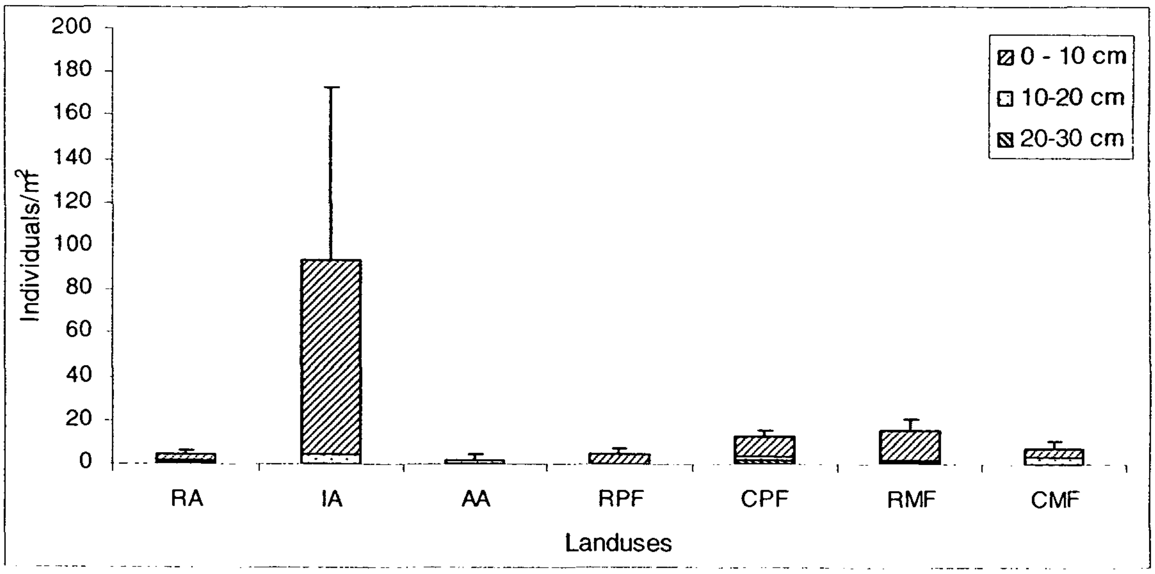

Fig.12: Density of Diptera Larvae (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

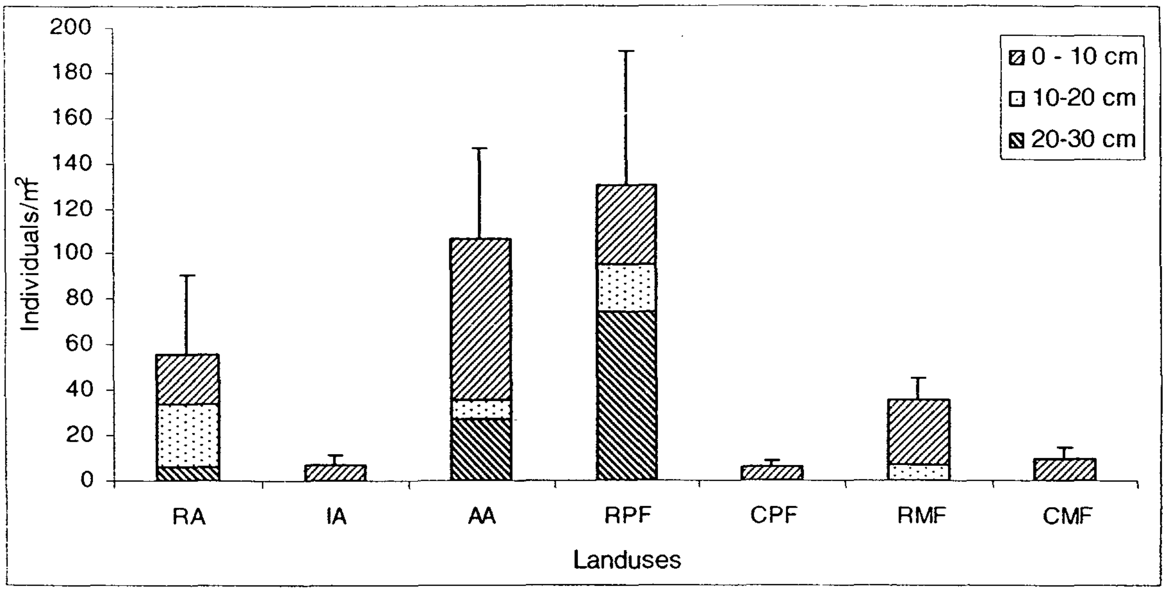

Fig.13: Density of Hymenoptera (Ants) (individuals/m^2) in different land uses of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

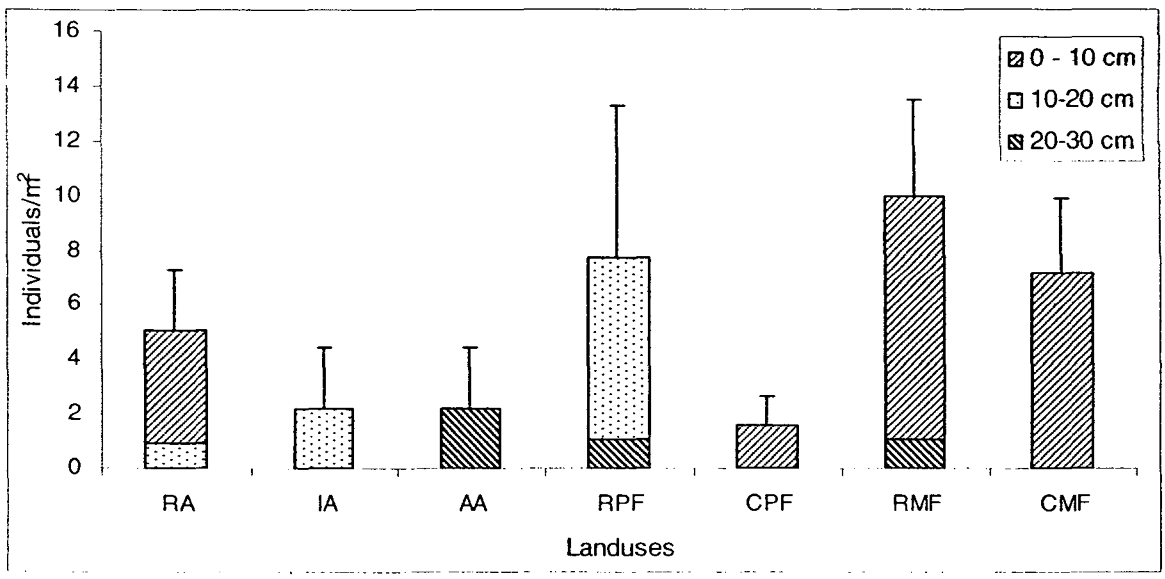

Fig.14: Density of others (individuals/m^2) in different land uses of a village landscape of a mid-altitude village landscape of Garhwal Himalayas (bars showing standard error; RA - Rainfed Agriculture; IA - Irrigated Agriculture; AA - Abandoned Agriculture; RPF - Reserve Pine Forest; RMF - Reserve Mixed Forest; CMF - Community Mixed Forest; CPF - Community Pine Forest).

4. Discussion

Mean density of overall soil fauna was highest in abandoned agricultural land (937 ind/ m^2), followed by reserve pine forest (419.8 ind/ m^2) and irrigated agricultural land (351.2 ind/ m^2). Lowest fauna density was recorded in mixed forests.

This trend of soil macro fauna density is similar to the study carried out by Barros et al. (2002) in Western Amazonia, who also found relatively low macro-fauna density in the forests (884 ind/ m^2) and high density in fallow, agro-forestry and annual crops with densities 1737 ind/ m^2, 1745 ind/ m^2, 1761 ind/ m^2 respectively. The mean densities of the soil macro fauna in the study are much lower than the values reported by Barros.

Different trends of macro fauna density were reported by Rossi and Blanchart (2005) in Western Ghat, who reported higher density of soil macro fauna in forest sites (ranging from 2415 individual / m^2 to 3061 individual / m^2) than pasture and plantation (1333 individual / m^2 to 1654 individual / m^2).

There are other studies which report higher densities of soil fauna in tropical forests. Lavelle and Kohlman (1984) found fauna densities ranging from 888 to 3011 individual / m^2 in tropical forest of Mexico, where as Gilot et al. (1995) reported 5747 individual / m^2 in the tropical forest of cote d' Ivoire.

In the present study mean fauna density in cropped land was greater than that of the forests (both Mixed broad-leaved and Pine forests), this is in contrast to the general view that the density of the soil macro-fauna tends to decrease towards low levels in the cropped land, as reported by Decaen et al. (1994) with density ranging from 429 to 592 individual / m^2 in high input cropland in Carimagua (Colombia). Lavelle and Pashanasi (1989) reported a density of 730 individual / m^2 in a similar plot in Peru.

In the present study density of the macro fauna in the abandoned agricultural land was highest among all land uses with density 937.6 individual/m^2. Contrary to this study Thomas et al. (2004) reported the density of 489.4 individual/m^2 in a 15 years abandoned rice field which is much lower than the present study. The reasons behind this difference may be the sampling time of this study which was done in the month of March-April (dry season). Termites are most abundant during dry season. In abandoned agricultural land termites population contribute 67.5 % of the total macrofauna. The field is abandoned since last 20 to 30 years. In some abandoned land organic manure is applied to promote the grass for feeding livestock which in turn might have enhanced soil fauna abundance.

4.1 Distribution of Major Soil Macro fauna Groups Across Land uses

4.1.1 Termites

Termites were the most dominant in all the land uses comprising 42% of the total fauna in rain fed agriculture, 67.5% in abandoned agricultural land and 31% in the Reserve pine forest and 54 percent in community pine forest. This is similar to study carried out by Rossi and Blanchart (2005) in Western Ghat who found maximum mean density of termites and ants in February (during dry season). Moreover the sampling in the present study was carried out in the month of March-April. Termites were most abundant in Rainfed agricultural land and Abandoned agricultural land. Thomas et al. (2004) recorded mean termite density of 216.1 individual / m^2 in 15 years abandoned rice field which is much smaller than the density recorded in Abandoned agricultural land of our study area. On the other hand Rossi and Blanchart (2005) recorded a termite density of 1816 individual / m^2 in the primary forest which is much higher than the density observed in our study.

Termites are mosaic of various functional groups including soil feeding humivorous, wood feeding xylophagous, fungus growers or harvesters (Lavelle et al. 1997). This might explain high termite density in agricultural land uses as our sampling was done after crop harvesting in March-April when traditional cultivation practices leave sufficient amount of crop residue in the field in form of a continuous litter cover which provides an extensive stock of food to termite populations.

4.1.2 Earthworms

Available studies on the soil macro fauna in the Himalayan region largely confined to earthworms despite the known prospect of other taxonomic and functional groups among soil organism. In our study earthworm density was highest in the Rainfed (29.2 ind/m^2) followed by Reserve pine forest (25.5 ind/m^2), Reserve mixed forest (11.1 ind./m^2), Community mixed forest (9.5 indi./m^2), Abandoned agricultural land (4.4 ind./m^2), Community pine forest (0.8 ind./m^2). Earthworms were absent in irrigated agricultural land.

Although high density of earthworms was recorded in rainfed agricultural land but it is comparable to that of Reserve pine forest. The lowest density was found in Pine dominated mixed forest (i.e., Community pine forest), this is in agreement with study carried out by Sinha et al. (2003) in Hariyali sacred landscape in Garhwal Himalaya, where he recorded highest density of earthworms in pine forest and lowest in pine broad-leaved mixed forest.

Among the forest land uses in the study site highest density of earthworms was recorded in Reserve pine forest, which agrees with the findings of Bhadauria et al. (2000) who recorded highest earthworm density in 40 year old pine forest with 395 individual/m^2 in Central Himalaya. Bhadauria and Ramakrishnan (1991) recorded that earthworm activity in pine stand increased with age of the stand and it reached maximum in sacred grove.

Low density of earthworm as compared to other groups may be due to sampling period (dry season) in our study. The earthworm group attains maximum density in October at the end of rainy season. Bhadauria and Ramakrishnan (1991) through their study in North-East India, have also recorded a maximum numbers of earthworms in the rainy or late rainy period (August-September). This is due to better soil moisture and temperature conditions.

Major determinants of earthworm community structure in an agro-ecosystem are the quantity and quality of organic manure added (Lavelle et al. 1994), the soil types (Fraser, 1994) and influence of disturbances (Werner and Dinbal, 1989). In the present study highest earthworm density found in the Rainfed agricultural land (29.2 individual / m^2). This is due to improved nutrient status of the soil because of ploughing back of roots of cereals and crop byproducts and through addition of organic manures before planting. This also has been observed by Edwards (1983) and Werner and Dindal (1989).

The density recorded in present study is lower than that recorded by Bhadauria et al. (1997) who found density of earthworms in three agricultural sites in Central Himalaya varied from 140 individual / m^2 to 335 individual / m^2. This difference may be due to different sampling periods.

Earthworm density in the Abandoned agricultural land was 4.4 individual / m^2 which is much lower than the study carried out by Thomas et al. (2004) in abandoned rice field (78.65 individual / m^2) in Northern Argentina.

In this study low termite and earthworm density were found in the forests, i.e., Reserve mixed forest and Community mixed forest. This is in agreement with Dangerfield (1990) and Villalobos and Lavelle (1990) who reported high population of litter dwelling arthropods, coleopterans and endogeic larvae where sufficient litter is available as consequence of low termite and earthworm activities.

4.2 Vertical Distribution of Soil Macro-fauna

Vertical distribution of macro fauna varied with type of land use depending on the abundance and quality of the surface litter.

In this study 81.4 % of macrofauna in Reserve mixed forest, 81.2% in Community mixed forest were found in 0-10 cm layer as compared to 83% fauna in top 0-10cm of the forest system reported by Barros et al. (2002).

As compared to forest systems higher proportions of soil fauna were found in deeper layers 10-20, 20-30cm in Rainfed agricultural land (42% in 0-10cm, 33% in 10-20cm and 25% in 20-30cm layer) and Abandoned agricultural land (50.9 % in 0-10cm, 10.6% in 10-20cm and 38.5% in 20-30cm layer). This distribution is supported by study carried by Barros et al. (2002) in Western Amazonia in Brazil. They also observed a similar trend.

4.3 Structure of vegetation community across different land uses

4.3.1 Rainfed and Irrigated agricultural land uses: Agroforestry system

Agroforestry is the main landuse in the study area which occupies majority of the rainfed agricultural land. It is an important traditional land use in the Himalayan region where the multiple trees valued primarily for fodder, fuel wood and fruits are either deliberately introduced or selectively protected in the cultivated land. Agroforestry practices control run off and soil erosion and offer the possibility of effective, low cost soil and water conservation. (Maikhuri et al 1997; Toky et al 1989; Ralhan et al, 1991; Nautiyal et al 1998).

Ficus auriculata was dominant species in agro forestry systems of the study site with density of 77.3 individual/ha. The density of agroforesry trees in the rainfed agricultural land was 227.3 individual / ha. This value is lower than those reported by Semwal and Maikhuri (1996) who recorded a density of 334-418 individuals of fodder trees per hectare on the agricultural fields of Dalimsain and Hathnur villages of central Himalaya. These meet the fodder requirements over the lean seasons. Singh (2002) recorded the density of agro forestry trees of 362 individual/ha. In traditional agriculture, the density of agroforestry trees varies from 182-419 trees/ha (Nautiyal et al. (1998). Semwal et al. (2002) recorded a much higher density of agroforestry tree of 1110 trees/ha.

The mean basal area of trees in agro ecosystems of study site was found to be 7.92 m^2/ha. which is much lower than that reported 26 m^2/ha by Singh (2002). Semwal et al. (2002) reported mean tree basal area in agricultural land as 9.2 m^2/ha. Lower density of agroforestry trees in our study site was due to presence of Reserve forest in the vicinity. Villagers chiefly procure fuel-wood and fodder from the Reserve forest and occasionally from the agroforestry trees (except for lean seasons) and therefore they grow limited number of agroforestry trees in their fields.

Absence of stumps in the agricultural land suggested that agroforestry trees were not cut but they were highly lopped for fodder. Agroforestry trees were absent in the irrigated agricultural land. Local people do not prefer trees in irrigated land to protect the crop from the shade effects.

4.3.2 Abandoned Agricultural Land

The dominant tree species in abandoned agricultural land was *Quercus leucotrichophora* with average density 120 individual/ha. Compared to total density of 180 individual/ha. high density of regenerating trees of *Quercus leucotrichophora* (280 individual/ha.) shows that it is in early successional stage for conversion into forest. It is generally assumed that disturbed site create large canopy openings and exposed top soils are widely reported to promote stamps of chir pine (*Pinus roxburghii*), however our result is contradictory to this and agrees with Quazi et al. (2003) who reported that stands of banj oak can also originate after agricultural abandonment in this region. Terraced lands thus act as a nursery for the subsequent release and development of future stands dominated by banj oak. Banj oak density was found to be higher than chir pine on terraces under both high and low post abandonment disturbance of chronosequences.

4.3.3 Community Mixed Forest

Currently 7% of central Himalayan forests are panchayat forests managed by the people. In the community forest of the study village *Q. glauca* and *Q leucotrichophora* were dominant with density 923 individual/ha. and 553 ind./ha. respectively. *Q. glauca* was confined to the community forest only. It was even absent in Reserve mixed forest nearby the village. Regenerating tree species density were high for *M. esculenta* (415 ind./ha) and *R. arboreum* (707 ind./ha). This may be due to shade tolerant features of *M. esculenta* and *R. arboreum.* Oak species are more sensitive to disturbances.

Tree density recorded by us (1561.6 individual/ha.) is much higher than that of Khan (2004) with density 558.3 individual/ha. in community broadleaved forest of central Himalaya. Total tree basal area in our site was 35.5 m^2/ha. higher than that reported by Khan (2004) 28.2 m^2/ha.

4.3.4 Reserve Mixed Forest

92% of central Himalayan forests are Reserved/protected/civil forest managed by the governments.In the Reserve mixed forest *Q leucotrichophora* and *R. arboreum* were the domiant and second domiant species respectively. The forest is located at the altitude of 1500 meters above sea level. Reserve mixed forest had the highest tree density among all land uses (2020 ind./ha). It had also highest basal area (73.69 m^2/ha).

4.3.5 Community Pine Forest

Community pine forest is a pine-broadleaved mixed forest, where pine is dominant 750 individual/ha. Mean tree density was found to be 1125 individual/m^2. Tree basal area was 43.97 m^2/ha. The values were much higher than that reported by Khan (2004) in pine forest where mean density were reported as 475 individuals/ha and total basal area as 19.8 m^2/ha. This high density was chiefly contributed by *M. esculenta* and *R. arboreum*. Community pine forest had the highest number of regenerating tree species.

4.3.6 Reserve Pine Forest

Reserve pine forest had the lowest tree density among all land uses. The forest was 50-60 years old mature forest. Mean tree density and mean basal area were 250 individual/ha. and 62.3 m^2/ha respectively. Only pine trees were present there. Regenerating trees were totally absent - probably the reason behind this may be frequent fire that catches forest annually. The Shallow rooted pine trees were more prone to felling by strong wind there. Despite lower ($1/6^{th}$) tree density in Reserve pine forest as compared to Community forest, Reserve pine forest has much higher basal area due to occurrence of more mature trees.

4.4 Natural regeneration of forest

Densities of regenerating trees were higher in community forests (both pine and broadleaved) as compared to Reserve mixed forest. In the Community pine forest *M. esculenta* had the highest number of regenerating trees contributing near by 25% of the total. This agrees with the view of Rawal et al. (2003) who reported *M. esculenta* finds a satisfactory regeneration niche in *Pinus roxburghii* forests, and provides options for putting these hitherto unutilized habitats for ecological and economic benefits in this region. Being a edible fruit, easy dispersal by *Rhesus Macaque*, Common langur and birds promotes high regeneration. The results of present study, however, do not agree with that of Thadani and Ashton (1995) who reported highest number of regenerating species in reserve forest than in the community forest.

Reserve mixed forest with highest tree density (2020 individual/ha.) and highest tree basal area (73.69 m^2/ha.) and dense canopy do not promote the satisfactory establishment of regenerating trees in the under story. Inadequate light in the understory might be the factor influencing regeneration establishment. Community mixed forest of the study village where lopping is done once or twice a year had a moderate level of disturbances. Better penetration of light due to moderate disturbances in the community mixed forest benefits regeneration. Community mixed forest in the study village is similar to one reported by Maithani (1994), which is closely monitored by the village panchayats and which in turn might have a better regeneration status.

Despite high density *Q. leucotrichophora* in community mixed forest density of regenerating banj were low as compared to others. Probable reasons may the lack of viable seeds due to insects or animal predation (Morquis et al. 1976), unfavorable microsites (Kittredge and Ashton, 1990) and grazing of siblings by domesticated animals (Piggot, 1983) or deer (Marquis et al. 1976; Tilgman, 1989; Kittredge and Ashton 1995). In the Himalaya low regeneration has been attributed to all the causes mentioned above (Singh and Singh, 1986). Other reasons for low regeneration may be high population densities of both human and cattle (Singh and Singh, 1992), Weevils infestations (Singh and Singh, 1986). *Dicranognathus nebulosus* and *Calandra glandium* were found to attack acorns (Kaushal and Kalia, 1989; Dwivedi and Mathur 1978).

Jeet Ram et al. (2006) found heavy infestation of oak trees by flowering parasite (*Taxillus Vestitus* (wall) Danser) in the forests of Uttaranchal Himalaya. High and heavy infestations were recorded in disturbed sites. High anthropogenic disturbance in the form of lopping of branches may be one of the reasons for infestation.

5. Conclusion

The important conclusions were drawn from this study carried out in a mid-altitude village landscape where the different ecosystems are intimately interconnected are

Since Reserve forest is available in the vicinity of village, peoples are not much dependent on agro forestry trees hence they grow lesser numbers of trees in their farm land,this reflects in lower density of agroforestry trees in the study site as compared to study by other people.

Preventing annual fire in Reserve pine forest can help in the regeneration of *M. esculenta* and *Rhododendron arboreum* as found in community pine forest. Conversion of pine forest to pine-broadleaved mixed forest will also be favoured by the local people, since broad-leaved mixed forest provide much more fodder and fuel wood than merely pine forest.

Mature tree density in community mixed forest was lower than reserve mixed forest, but the density of regenerating trees were higher. Highest tree density, basal area and dense canopy of reserve mixed forest does not promote satisfactory establishment of regenerating trees while in community mixed forest limited lopping act as intermediate level disturbance and its open canopy helps in regeneration.

Land abandonment promote the regeneration of banj oak in the present study. The results show that banj oak was the fast and better colonizers in the abandoned agricultural land than pine.

Termites were abundantly found in the agricultural land uses where they act as crop pests by feeding on the roots of crops and trees. Irrigation by traditional water management and clean cultivation may check their populations.

Highest density of diptera larvae were recorded in irrigated agricultural land due to moist habitat.

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