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Effect of altitude and disturbance on structure and species diversity of forest vegetation in a watershed of central Himalaya

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Abstract: The Phakot watershed of Central Himalaya harbours two forest types; *Anogeissus latifolia* subtropical dry deciduous forest (600 - 1200 m asl) and *Quercus leucotrichophora* moist temperate forest (1500 - 1900 m asl). We assessed the disturbance level in these forests and analyzed its effect on species composition and diversity. Three levels of disturbance (undisturbed, moderately disturbed and highly disturbed) were identified within both the forest types on the basis of canopy cover, tree density and light attenuation. The canopy cover and light attenuation were higher in the *Quercus leucotrichophora* forest as compared to the *Anogeissus latifolia* mixed forest. Asteraceae was the dominant family at all disturbance levels in both forest types. Tree density was higher in the *Anogeissus latifolia* mixed forest, while shrub and herb density was high in *Quercus leucotrichophora* forest as compared to the *Anogeissus latifolia* mixed forest. A sharp decline in tree density and basal area was recorded with increasing disturbance level in both the forests. Species richness (number of species per unit area) of trees, shrubs and herbs declined with disturbance, except for the highly disturbed *Anogeissus* forest which was more species rich than the undisturbed or moderately disturbed forest.

Resumen: Lacuenca Phakotde los Himalaya Centrales albergadostipos de bosque: bosquesub-tropical seco caducifolio de *Anogeissus latifolia* (600 - 1200 m s.n.m.) y bosque húmedo templado de *Quercus leucotrichophora* (1500-1900 m s.n.m.). Evaluamos el nivel de perturbación en estos bosques y analizamos su efecto en la composición y diversidad de especies. Se identificaron tres niveles de perturbación(no perturbado, moderadamente perturbado, y muy perturbado) en ambos tipos de bosquecon base en su cobertura del dosel, densidad de árboles y atenuación de luz. Lacobertura del dosel y la atenuación de luz fueron más altos en el bosquede *Quercus leucotrichophoraque* en el bosque mixtode *Anogeissus latifolia*. Asteraceaefue la familia dominanteen todos los niveles de perturbación en ambos tipos debosque. La densidad de árboles fuemayor en el bosque mixtode *Anogeissus latifolia*, mientras que la densidad de arbustos y hierbas fue alta en el bosque de *Quercus leucotrichophora*, en comparación con la del bosque mixtode *Anogeissus latifolia*. Se registró unadisminución abrupta en la densidad y el área basal de los árboles conforme aumentó elnivel de perturbación en ambosbosques. La riqueza de especies (número deespecies por unidad de área) de árboles, arbustos y hierbas disminuyó conforme aumentó la perturbación, excepto en el bosque muy perturbado de *Anogeissus*, en donde la riqueza de especies fue mayor que en elbosqueno perturbado y el moderadamente perturbado.

Resumo: A bacia hidrográfica de Phakot, noCentro dos Himalaias abriga, dois tipos de florestas; a floresta subtropical seca decídua de *Anogeissus latifolia* (600 - 1200 m de altitude) e a floresta temperada húmida de *Quercus leucotrichophora* (1500 - 1900 m de altitude). Avaliámos o nível de perturbação nessas florestas e os seus efeitos sobre a composição e

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diversidade de espécies. Nos dois tipos de floresta e com base na cobertura do dossel, densidade arbórea e atenuação da luz identificaram-se três níveis de perturbação (intacta, moderadamente perturbada e altamente perturbadas). A cobertura de dossel e a atenuação da luz foram maiores na floresta de Quercus leucotrichophora, em comparação com a floresta decíduamista de *Anogeissus latifolia*. A Asteraceae foi a família dominante em todos os níveis de perturbação em ambos os tipos de floresta. A densidade arbórea foi maior na floresta mista de Anogeissus latifolia, enquanto a densidade de arbustos e ervas foi maior na floresta de Quercus leucotrichophoraquando comparada com a floresta mista de *Anogeissus latifolia*. Registou-se a queda brusca da densidade arbórea e da área basal com o nível crescente de perturbação em ambas as florestas. A riqueza de espécies arbóreas (número de espécies por unidade de área), arbustos e ervas diminuiu com a perturbação, exceto para a floresta altamente perturbada de *Anogeissus* que apresentava maior riqueza em espécies do que a floresta intacta ou moderadamente perturbada.

Key words: *Anogeissus latifolia*, disturbance*, Quercus leucotrichophora*, species density, species diversity, species richness.

Introduction

The forest ecosystems in the Himalaya are severely threatened by natural (landslide, landslip, cloudburst, torrent rains, etc.) and anthropogenic forces. Forest diversity is the main livelihood source for the people living in the state of Uttarakhand. The increasing population over the last few decades and consequent dependence on plant products has led to over exploitation of natural flora and fauna of this region (Ram *et al*. 2004). The forest biomass is removed through grazing, lopping and surface burning year round and plants often do not get enough time to recover (Singh 1998). These anthropogenic disturbances not only influence the soil, nutrient and water conditions but also influence microenvironment of the area. The biodiversity of these forests is indeed under great anthropogenic pressure.

Several authors have studied the effect of disturbance on Himalayan forests. The effect of anthropogenic disturbance on plant diversity and community structure in the forest of north eastern Himalaya, India was studied by Khan *et al*. (1987); Misra *et al.* (2004) and Rao *et al*. (1990). Plant diversity in two forest types along a disturbance gradient in Dewalgarh watershed, Garhwal Himalaya was studied by Uniyal *et al.* (2010), in six forest types in Uttarakhand by Ram *et al*. (2004), and tree diversity and population structure in undisturbed and human-impacted stands of tropical wet ever-green forest in Arunanchal Pradesh were studied by Bhuyan *et al*. (2003). All of the above studies reported that increased degree of disturbance caused loss of plant diversity and brought about a change in community characteristics.

Himalayan watersheds are under constant threat of mass wasting and erosion due to depletion of forest cover, unscientific agronomic practices and degradation of land. These forces have created an overall adverse impact, disturbance and imbalance in the ecosystem (Pokhriyal *et al.* 2009). It is estimated that 70 - 80 % of the hill population depends on land resources for livelihood. Forests play an important role in functioning of the Himalayan watersheds where the economic structure and social organizations are built around the primary relationship with natural resources (Negi *et al*. 1997). The development of the Himalayan region has not achieved the desired pace due to lack of ecological information at the watershed level. Watershed approach in the Himalayan region is being increasingly used for understanding land improvement measures (Khan 2002). If natural ecosystems and their function are to be kept in equilibrium, then there is a need to have a correct assessment of the availability of natural resources and the factors affecting the same. Species composition and forest diversity, which are the major constituents of natural resource, change over time due to anthropogenic disturbance. In this study, an attempt has been made to assess the impact of disturbance on species richness and diversity of the two forest types of Phakot watershed in Garhwal Himalaya, Uttarakhand.

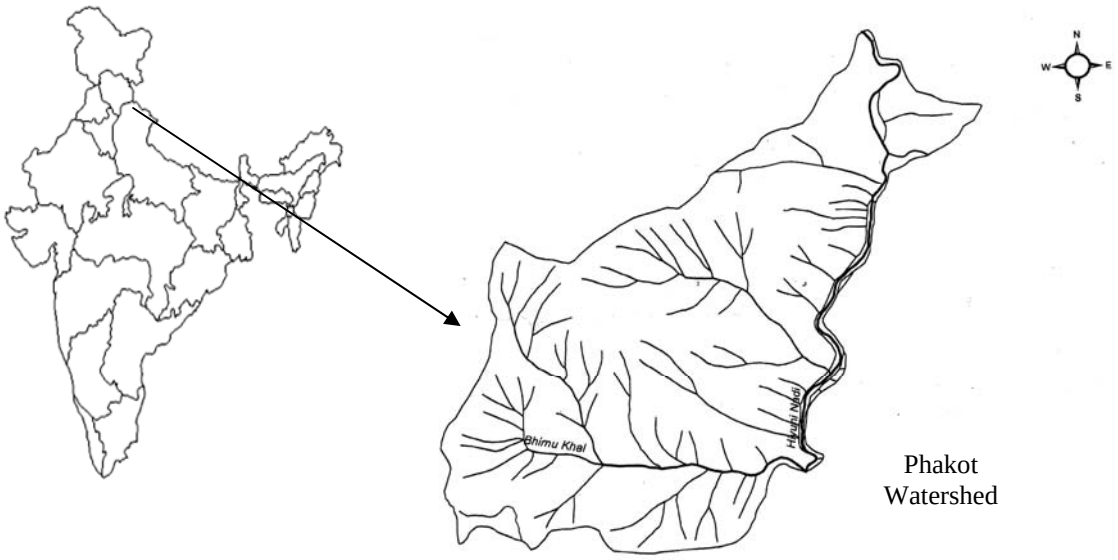

Fig. 1. Location of the study area.

Materials and methods

Study sites

Phakot watershed covers an area of 1466 ha and is a part of the Phakot beat of the Saklana Forest Range of Tehri Garhwal, Uttarakhand, India. It is approximately 35 km from Rishikesh town on either side of the National Highway No. 94 in Tehri district of Uttarakhand. It lies between 30° 13′ 04″ to 30° 15′ 48″ N lat and 78° 19′ 42″ to 78° 23′ 17″ E long, with the elevation ranging between 600 m and 1900 m asl (Fig. 1). The area is characterized by hillocks, escarpments, flat basins and flat topped ridges. The average annual rainfall in the study area is 70 cm and mean monthly minimum temperature ranges between 4 °C (January) and 13 °C (July) and mean maximum temperature between 10 °C (January) and 38 °C (May). Soil varies from loam to clay. Various land use categories such as cultivated land and village common land locally called "Civil and Soyam Land" are found. Land cover includes forest, scrub, grassland, isolated patches of fruit trees and government reserve forest. The study area is dotted with 17 villages.

Two types of forest, *Quercus leucotrichophora,* Himalayan moist temperate (1500 - 1900 m asl) and *Anogeissus latifolia,* mixed sub tropical dry deciduous (600 - 1200 m asl), are found in the Phakot watershed (Champion & Seth 1968). Based on the satellite data (IRS-P6 LISS III) the area of *Quercus leucotrichophora* forest is 16.67 ha, and that of *Anogeissus latifolia* mixed sub tropical dry deciduous forest is 204.25 ha. The remaining area of the watershed falls under non forest and agriculture land categories (Pokhriyal 2009).

Disturbance regime

A reconnaissance survey showed no recent natural calamity (disturbance); this was also confirmed by interviews of local population. Because the outer boundary of the watershed is dotted with human habitation, anthropogenic pressure was most visible. The level of disturbance in the two forest types was estimated in terms of tree density, canopy cover and light attenuation (Misra *et al.* 2004). On the basis of these parameters, three stands viz. (i) highly disturbed (HD), (ii) moderately disturbed (MD) and (iii) undisturbed (UD) were identified in each forest type (Table 1). It must be kept in mind that even the undisturbed forest is not an intact virgin forest but has suffered some degree of anthropogenic disturbance in the past. Canopy cover was recorded directly in the field by spherical densiometer and expressed as the percent ground area covered by the canopy. Densiometer has 24 grids and readings were taken in four directions amounting to total 96 grids. The number of covered grids was converted into % by multiplying with 1.04 (derived from 100/96). Incident light was measured as % of full sun light directly in the field by Lux meter (TES 1332 digital lux meter). The readings were recorded in the mid day in each plot (Pokhriyal 2009). Light attenuation by the canopy was calculated as 100 % incident light.

Table 1. Characterization of disturbance level in *Quercus leucotrichophora* and *Anogeissus latifolia* mixed forests of Phakot watershed.

Parameters	Undisturbed	Moderately disturbed	Highly disturbed
Quercus leucotrichophora forest			
Tree density ha^{-1}	1850 ± 21	1075 ± 17	800 ± 12
Canopy cover (%)	> 74	50 - 74	< 39
Light interception (%)	> 50	20 - 50	< 20
Anogeissus latifolia mixed forest			
Tree density ha^{-1}	1650 ± 22	1225 ± 19	925 ± 15
Canopy cover (%)	> 60	33 - 43	< 31
Light interception (%)	> 35	12 - 35	< 12

Methods

The study was conducted during 2005 and 2006. Stratified random sampling method was used for collecting vegetation data. Data for trees were collected from 10 m x 10 m plots and for shrubs and herbs in 1 m x 1 m plots. A total of 96, 10 m x 10 m plots in *Anogeissus latifolia* mixed forest (32 in undisturbed, 40 in moderately disturbed and 24 in highly disturbed) and 60 plots in *Quercus leucotrichophora* forest (16 in undisturbed, 24 in moderately disturbed and 20 in highly disturbed sites) were sampled**.** Similarly, a total of 384, 1 m x 1 m plots in *Anogeissus latifolia* mixed forest (128 in undisturbed, 160 in moderately disturbed and 96 in highly disturbed) and 240 plots in *Quercus leucotrichophora* forest (64 in undisturbed, 96 in moderately disturbed and 80 in highly disturbed sites) were also sampled. Number of plots in each forest type varied because area covered by *Anogeissus latifolia* mixed forest was greater than that covered by *Quercus leucotrichophora* forest. Thus the actually sampled area differed between forests and between disturbance regimes. However, species richness was calculated as number of species per unit area. In each plot, diameter at breast height (1.37 m) and height of all trees were measured individually and by species.

Density and total basal area of tree species were calculated according to Curtis & McIntosh (1950) and Misra (1968). Shannon-Wiener index (Shannon & Weaver 1963) was computed, separately for the three vegetation layers, by using density data in Biodiversity Pro, version II, software (1997).

Results

Light attenuation

In the undisturbed stand of *Q. leucotrichophora* forest, canopy cover was more than 74 % compared to 50 - 74 % in moderately disturbed stand and less than 39 % in highly disturbed stand. In *A. latifolia* forest, the canopy cover was more than 60 % in undisturbed stand, 33 - 43 % in moderately disturbed and less than 39 % in the highly disturbed stand. Light attenuation by the canopy in the three stands of *Q. leucotrichophora* forest decreased from 50 % in undisturbed stand to 20 % in the highly disturbed stand. Similarly, in *A. latifolia* forest light attenuation was 35 % in the undisturbed stand, 12 - 35 % in the moderately disturbed stand and 12 % in the highly disturbed stand (Table 1).

Density and total basal area

The undisturbed stands were denser in terms of trees and herbs as compared to moderately and highly disturbed stands. However, maximum shrub density was recorded in the moderately disturbed stand in both forest types (Table 2). Tree density decreased with increasing level of disturbance in both the forests. Total basal area of tree species (> 31.5 cm cbh) also decreased with increasing level of disturbance in both types of forest (Table 2).

Species richness and diversity

A total of 144 species (20 trees, 45 shrubs and 79 herbs) was recorded in *Q. leucotrichophora* forest (Table 2). Total number of species recorded was

Table 2. Density, total basal cover and species richness of the undisturbed, moderately disturbed and highly disturbed stands of *Quercus leucotrichophora* and *Anogeissus latifolia* mixed forests of Phakot watershed.

Parameters	*Quercus leucotrichophora* forest			*Anogeissus latifolia* mixed forest		
	Undisturbed	Moderately disturbed	Highly disturbed	Undisturbed	Moderately disturbed	Highly disturbed
Total no. of plots for trees	16	24	20	32	40	24
Actual sampled area for tree (ha)	0.16	0.24	0.20	0.32	0.40	0.24
Total no. of plots for shrub & herb	64	96	80	128	160	96
Actual sampled area for shrub & herb (m^2)	64	96	80	128	160	96
Tree density (trees ha^{-1})	1363 ± 33.7	971 ± 28.9	685 ± 19.8	1600 ± 23.6	1175 ± 25.7	817 ± 21.5
Tree total basal area ($m^2 ha^{-1}$)	0.46 ± 0.19	0.38 ± 0.12	0.29 ± 0.11	0.48 ± 0.10	0.43 ± 0.07	0.31 ± 0.09
Number of tree species in the total sampled area	12	15	10	24	26	19
Number of tree species per 0.1 ha	7.5	6.3	5.0	7.5	6.5	7.9
Shrub density (plants m^{-2})	1.4 ± 0.98	2.6 ± 1.43	0.72 ± 0.69	1.4 ± 0.86	1.7 ± 1.12	1.6± 1.02
Number of shrub species in the total sampled area	29	32	27	28	32	21
Number of shrub species m^{-2}	0.45	0.33	0.34	0.22	0.20	0.22
Herb density (plants m^{-2})	37 ± 12.4	34 ± 9.3	19 ± 8.2	22 ± 11.4	14 ± 9.6	11± 5.5
Number of herb species in total sampled area	43	52	46	45	52	37
Number of herb species per m^2	0.67	0.54	0.58	0.35	0.33	0.39
Number of families	41	42	37	48	47	38
Dominant tree	*Quercus leucotrichophora*	*Quercus leucotrichophora*	*Quercus leucotrichophora*	*Mallotus philippensis*	*Anogeissus latifolia*	*Anogeissus latifolia*
Dominant shrub	*Eupatorium adenophorum*	*Eupatorium adenophorum*	*Eupatorium adenophorum*	*Murraya koenigii*	*Lantana camara*	*Murraya koenigii*
Dominant herbs	*Leucus lanata*	*Apluda mutica*	*Apluda mutica*	*Boerhaavia diffusa*	*Andropogon munroii*	*Chrysopogon fulvus*
Dominant families	Asteraceae & Lamiaceae	Asteraceae	Asteraceae & Fabaceae	Asteraceae	Asteraceae	Asteraceae

Table 3. Shannon index for undisturbed, moderately disturbed and disturbed stands of *Quercus leucotrichiphora* and *Anogeissus latifolia* mixed forests of Phakot watershed.

	Quercus leucotrichophora forest			*Anogeissus latifolia* forest		
	Undisturbed	Moderately disturbed	Highly disturbed	Undisturbed	Moderately disturbed	Highly disturbed
Tree layer	1.44	1.47	1.16	2.42	2.44	2.41
Shrub layer	2.89	2.93	2.52	2.52	2.55	2.11
Herb layer	3.31	3.55	4.02	3.39	3.23	3.08

highest in the moderately disturbed stand with 15 tree, 32 shrub and 52 herb species followed by the undisturbed stand with 12 tree, 29 shrub and 43 herb species. However, species richness per unit area was highest in the undisturbed stand with 7.5 tree species per 0.1 ha, 0.45 shrub species per m^2 and 0.67 herb species per m^2 . The next highest values were 6.3 (tree species richness, moderately disturbed stand) and 0.34 and 0.58 (for shrub and herb species richness, highly disturbed stand). Number of families of tree, shrub and herb species was higher in the moderately disturbed stand than other stands (Table 2). In the moist temperate forest, *Q. leucotrichophora* was the dominant tree species in all the three stands followed by *Bauhinia semla*, *Myrica esculenta* and *Lyonia ovalifolia*. Among shrubs, *Eupatorium adenophorum* was dominant at all three levels of disturbances followed by *Indigofera cassioides*, *Myrsine africana*. Among the herbs, *Apluda mutica* was dominant in the moderately and highly disturbed stands while *Leucas lanata* was dominant in the undisturbed stand. Asteraceae and Lamiaceae were the dominant families in the undisturbed stand, Asteraceae in the moderately disturbed stand and Asteraceae and Fabaceae in the highly disturbed stand.

In *A. latifolia* forest, a total of 157 species was identified, among which 39 were tree, 44 shrub and 74 herb species (Table 2). Highest number of species in the total area sampled in tree (26 species), shrub (32 species) and herb (52 species) strata was found in the moderately disturbed stand. However, on unit area basis, highest species richness in tree (7.9 species per 0.1 ha), shrub (0.22 species per m^2) and herb (0.39 species per m^2) strata was found in the highly disturbed stand followed by the undisturbed stand with corresponding values of 7.5 for tree, 0.22 for shrub and 0.35 for herb species. *A. latifolia* was the dominant species in the moderately and highly disturbed stands while *Mallotus phillippensis* was the dominant species in the undisturbed stand. Among the shrub species, *Murraya koenigii* was dominant in undisturbed and highly disturbed stands whereas *Lantana camara* was dominant in the moderately disturbed stand. Among the herbs, *Boerhaavia diffusa* was the dominant species in the undisturbed stand, *Andropogon munroii* in moderately disturbed and *Chrysopogon fulvus* in the highly disturbed stand. Asteraceae was dominant family in all the three levels of disturbances (Table 2).

Shannon index of species diversity for tree species was higher in the moderately disturbed stand in both types of forest as compared to undisturbed and highly disturbed stands. Similarly, shrub species diversity was also higher in the moderately disturbed stand in both the forest types as compared to undisturbed and highly disturbed stands. The herb diversity was highest (Shannon index = 4.02) in the highly disturbed stand of the *Q. leucotrichophora* forest (Table 3). However, while considering the Shannon index one has to keep in mind that the index was calculated from the data collected from sample size which differed across forest types as well as disturbance regimes.

Discussion

Large-scale tree felling for timber and other industrial raw materials during the colonial period and after that up to 1970s, and conversion of forest into agricultural land were the major causes of forest destruction in the Uttarakhand Himalaya (Tucker 1983). Even today broadleaf evergreen species like *Quercus* are extensively lopped for fodder, fuel wood and for making agricultural implements by the local people. At higher altitudes, lopping of tree leaves is done for animal bedding especially during winter, which is then used for compost. High concentration of grazing animals is another major cause of forest destruction in the region (Negi & Todaria 1993). Recurrent burning is also used to promote the growth of grasses which

are used for grazing and for off season animal stall feeding (Kumar & Ram 2005). Regular human interventions for collection of fuel wood and minor forest product and grazing and trampling by animals are also common in the watershed.

In *Q. leucotrichophora* forest, tree species richness on per unit area basis, declined with increasing level of disturbance, but in *A. latifolia* mixed forest tree species richness was higher in the highly disturbed stand as compared to un-disturbed and moderately disturbed stands. Thus the two forests differed in their response to disturbance. It is argued that stability increases with the complexity of ecosystem, i.e. with the number of species and with the number of interactions between them (Leigh 1965). However, the highly disturbed stand of *A. latifolia* mixed forest can hardly be more stable than the undisturbed stand. In these forests, the stem density declined with the increasing disturbance. This decline may be due to a gradual and consistent increase in the extraction of fuel wood and fodder as *Q. leucotrichophora* and *A. latifolia* are the dominant species in these forests which are extensively used as fuelwood and fodder. *A. latifolia* mixed forest had higher tree density, but *Q. leucotrichophora* forest had greater shrub and herb density. Opening of canopies favours herb and shrub growth, which gives overall stability to the watershed (Uniyal *et al.* 2010). Here total basal area also declined with disturbance level that agreed with earlier findings (Bhuyan *et al.* 2001; Bhuyan *et al.* 2003; Ramirez *et al.* 2001), that showed decreasing density and total basal area with increasing disturbance intensity. Total basal area has also been correlated with the rate of disturbance (Ramirez *et al.* 2001).

A decrease in the species richness along the disturbance gradient may reflect high utilization pressure (Bhat *et al.* 2000). Our findings are in contrast to the earlier observations of Bhuyan *et al.* (2003) and Misra *et al.* (2004), who recorded more number of species in the moderately disturbed stand as compared to undisturbed and highly disturbed stands. According to intermediate disturbance hypothesis (Connell 1978; Huston 1979), with no or little disturbance, only the competitive dominants can survive, while at sufficient high level of disturbance only fugitive species can survive, therefore, the diversity is maximum at the intermediate level of disturbance (Abugov 1982). The mild disturbance provides greater opportunity for species turnover, colonization and persistence of high species richness (Whittaker 1975). However, our data on species richness per unit area do not support the intermediate disturbance hypothesis.

Shannon diversity index was greater in *A. latifolia* mixed forest compared to the *Q. leucotrichophora* forest. The *A. latifolia* mixed forest located at lower elevation with warm climate and moderate rainfall had higher species richness as compared to *Q. leucotrichophora* forest located at higher elevation with humid climate. However, Shannon index was calculated from data collected by different sample size and, therefore, is not reliable for making comparisons. One would expect greater diversity in shrub and herb layers under disturbed forest canopy because better light condition in moderately disturbed stand is argued to promote the diversity of the undergrowth species, possibly by allowing several species to maintain their population in the open canopy (Ehrenfeld 1980; Huenneke 1983). This was not supported by our study where greater understorey density and diversity was recorded under undisturbed forest except for the highly disturbed *A. latifolia* mixed forest. Evidently, the undisturbed forest has also suffered some degree of disturbance, and there is a need for a more rigorous study with reference to disturbance and its effect.

Asteraceae along with Lamiaceae and Fabaceae dominated the undisturbed and highly disturbed stands in *Q. leucotrichophora* forest, while Asteraceae dominated all the three stands in *A. latifolia* mixed forest. Further, *A. latifolia* mixed forest contained greater number of families both in undisturbed and moderately disturbed stands. However, higher level of disturbance brought down number of families at the same level in both types of forests. Higher level of disturbance may lead to local loss of species and even families.

While investigating impact of anthropogenic pressure on forests of Mamley watershed in Sikkim, Sundriyal & Sharma (1996) recorded better regeneration and colonization by new species in two sites, which were, influenced more by anthropogenic disturbances as compared to other three sites, which were undisturbed. Similarly while comparing regeneration in two watersheds, Pokhriyal *et al.* (2010) showed that mild disturbance in one watershed was responsible for better regeneration whereas in another watershed, which was a protected area, because of low light penetration, seedling and sapling were low indicating lower regeneration status.

Thus anthropogenic disturbances play an important role in change, loss or maintenance of plant diversity of a watershed. However, watershed is

not composed of only forest, it encompasses agriculture, horticulture and other land uses. Watershed is mainly concerned with yield of water which is directly related to the conditions of all land uses and especially of forests. It has been suggested that large scale and permanent deforestation could reduce rainfall in down wind parts of the watershed (Salati *et al*. 1983; Salati & Vose 1984). However, effective precipitation reaching the ground is less than the actual precipitation and depends on the density/canopy of forest. Similarly, interception losses are generally greater for a dense forest than for any other vegetation type or landuse.

The undisturbed, closed forest is unquestionably the best situation in any watershed as this permits the canopies, litter, soil organic layer and root systems to have the greatest role in minimizing erosion of all kinds. A hierarchy of human uses can be considered, each with an increasing order of disturbance to adversely affect this protective function (Hamilton 1987).

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