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Changes in soil properties and vegetation during postlandslide succession in pine forests of Central Himalaya

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Abstract. Changes in soil properties, vegetation composition and plant biomass in an age-series of landslide-damaged sites adjacent to pine and mixed-pine-oak forests in Central Himalaya were studied. Fine soil content and soil nutrients were lower than in adjacent undamaged forest and increased with the age of the site. The herb species content and herbaceous cover increased with age and showed a positive relation with fine soil content, total soil nitrogen and soil organic carbon. Similarity in vegetation between damaged and undamaged sites increased with age for the herb layer. Herb species diversity increased from two years and the concentration of dominance and species evenness were lower for older sites. Shrubs appeared at 9 years. Above- and below- ground herb biomass increased with age. Total herb biomass was positively related with fine soil content, total soil nitrogen, soil organic carbon and other soil nutrients. Soon after disturbance seedlings of the early successional tree species *Pinus roxburghii* colonized and second-growth *P. roxburghii* trees were present at 18- and 25-year-old sites.

Key words: Landslide-disturbance, species content, species diversity, succession, Central Himalaya

Introduction

The mountain range of the Himalaya supports a wide variety of forest types from tropical dry deciduous forest in the foothills to alpine shrubland near the timberline (Singh and Singh 1992). Increasing concentration of human settlements, and consequent logging, lopping, grazing and occasional fires have reduced the forest area to a great extent. Singh, Pandey and Pathak (1983) hypothesized that the Himalayan catchments are predominantly subsurface flow systems and are prone to landslides and landslips. In this region, landslides are an important cause of vegetation disturbance. Each year about 24 million m^3 of sediment slides down the slopes, destroying vegetation, smothering springs and developing stream blockades in the Central Himalaya (Valdiya 1985). The landslides are initiated due to the combined effects of intensive human activity, including excavation for roads and mines, torrential rainfall, soil under-cutting by eroding streams or rivers, deforestation and earthquakes. There is a need to restore the sites disturbed by landslide, however a knowledge on the mechanism of ecosystem redevelopment following disturbance is a prerequisite. In the present study we examine the changes in selected soil properties and vegetation components on an age series of landslide damaged sites located predominantly in pine and pine-oak dominated forests in the Central Himalaya, in order to enhance our understanding of the process of recovery following landslide events.

Study Area

Eight landslide-damaged sites (29° 30' 5" - 29° 30' 56" N and 79° 30' 27" - 79° 30' 37" E) in an altitudinal range of 1,200-1,750 m in Central Himalaya were selected for this study. All the sites were located adjacent to pine or mixed pine-oak forests. Site 1 experiences recurring landslide and was considered to be a 1-year old site. Sites 2-8 were 2,3,4,8,9,18 and 25-years old, respectively. The age of the landslide-damaged sites was determined from the records of the State Forest Department and information gathered from the local people. The undamaged sites markedly vary in age but were several decades older than the damaged sites. Adjacent undamaged areas of each site were considered as controls. The soil is a residue originating from the rocks of the Krol Group, Bhimtal volcanics and Bhowali volcanics. The geology of the study area has been well documented by Valdiya (1980). Details of the sites are given in Tabl. 1.

Climate

The description of the climate is based on temperature and rainfall records for 1977-1986 at Nainital (Source, State Observatory, Nainital). The climate of the study area is of a subtropical monsoon type with warmer temperatures towards lower elevations and cooler temperatures towards higher elevations. Usually, a rise of 270 m in altitude corresponds to a fall of 1°C in the mean temperature up to 1,500 m, above which the decline is more rapid (Singh and Singh 1987a). The pattern of rainfall is governed by the south-west monsoon. The annual

Site No.	Years since disturbance	Altitude (m)	Slope (°)	Aspect	Dominant woody species in undamaged part of the site
1	1	1,600	33	SW	*Pinus roxburghii*
2	2	1,700	29	SE	*Pinux roxburghii* and *Quercus leucotrichophora*
3	3	1,750	33	NW	*Pinus roxburghii* and *Quercus leucotrichophora*
4	4	1,680	36	SE	*Pinus roxburghii* and *Quercus leucotrichophora*
5	8	1,600	14	SW	*Pinus roxburghii*
6	9	1,200	42	NW	*Bauhinia retusa*, *Mallotus philippensis* and *Pinus roxburghii*
7	18	1,580	28	SE	*Pinus roxburghii*
8	25	1,680	18	SW	*Pinus roxburghi*

Table 1. Site characteristics of landslide-damaged areas in Central Himalaya.

Age (yrs)	Soil depth (cm)	Fine soil (%)	Organic carbon (mg/g)	Organic matter (mg/g)	Nitrogen (mg/g)	Available phosporus (mg/g)	Exchangeable calcium (mg/g)	Exchangeable potassium (mg/g)
1	0-10	12.4 ±1.9	13.6 ±0.2	23.4 ±0.4	0.6 ±0.05	0.019 ±0.001	0.17 ±0.017	0.08 ±0.00
	10-20	9.8 ±1.9	2.8 ±0.2	4.8 ±0.3	0.3 ±0.1	0.005 ±0.005	0.14 ±0.03	0.07 ±0.01
	20-30	5.9 ±1.4	2.0 ±0.2	3.4 ±0.5	0.2 ±0.1	0.003 ±0.001	0.11 ±0.01	0.04 ±0.00
2	0-10	18.0 ±1.1	12.3 ±0.1	21.2 ±0.3	0.8 ±0.0	0.016 ±0.003	0.24 ±0.02	0.12 ±0.01
	10-20	12.4 ±2.0	3.2 ±0.2	5.5 ±0.3	0.3 ±0.0	0.004 ±0.005	0.18 ±0.04	0.09 ±0.02
	20-30	9.8 ±2.4	2.6 ±0.1	4.4 ±0.2	0.2 ±0.0	0.002 ±0.008	0.15 ±0.02	0.60 ±0.01
3	0-10	19.5 ±2.8	13.2 ±0.1	22.7 ±0.2	0.8 ±0.0	0.019 ±0.002	0.27 ±0.04	0.14 ±0.02
	10-20	13.2	3.6	6.2	0.3	0.004	0.19	0.10

Table 2 continued

Table 2 continued

		±1.2	±0.2	±0.4	±0.0	±0.001	±0.05	±0.01
	20-30	10.3	2.9	5.0	0.3	0.002	0.16	0.07
		±1.9	±0.2	±0.4	±0.0	±0.000	±0.03	±0.02
4	0-10	22.4	14.5	24.9	0.9	0.025	0.33	0.23
		±1.1	±0.2	±0.3	±0.0	±0.002	±0.01	±0.01
	10-20	14.4	3.9	6.7	0.4	0.010	0.23	0.15
		±2.6	±0.1	±0.3	±0.0	±0.001	±0.03	±0.02
	20-30	10.6	3.1	5.3	0.3	0.005	0.19	0.09
		±1.7	±0.1	±0.1	±0.0	±0.001	±0.05	±0.002
8	0-10	24.6	16.4	28.2	1.1	0.027	0.36	0.28
		±2.8	±0.2	±0.4	±0.2	±0.004	±0.03	±0.04
	10-20	16.5	5.3	7.4	0.5	0.011	0.25	0.17
		±2.1	±0.2	±0.3	±0.1	±0.001	±0.02	±0.03
	20-30	11.4	3.8	6.5	0.3	0.007	0.21	0.10
		±1.5	±0.3	±0.5	±0.1	±0.001	±0.01	±0.004
9	0-10	25.4	16.8	28.9	1.2	0.029	0.51	0.30
		±1.5	±0.4	±0.8	±0.2	±0.004	±0.05	±0.03
	10-20	18.2	4.6	7.9	0.5	0.013	0.34	0.20
		±1.3	±0.3	±0.5	±0.1	±0.002	±0.02	±0.02
	20-30	12.6	4.1	7.0	0.3	0.007	0.27	0.11
		±2.2	±0.2	±0.3	±0.1	±0.001	±0.04	±0.001
18	0-10	27.3	22.6	38.9	1.4	0.034	0.77	0.60
		±2.0	±0.3	±0.5	±0.2	±0.002	±0.04	±0.05
	10-20	22.3	8.6	14.8	0.7	0.021	0.58	0.22
		±1.4	±0.2	±0.4	±0.2	±0.001	±0.03	±0.01
	20-30	16.2	5.8	9.9	0.5	0.013	0.39	0.11
		±1.9	±0.4	±0.7	±0.1	±0.001	±0.05	±0.02
25	0-10	32.2	24.6	42.4	1.7	0.040	0.95	0.65
		±1.3	±0.3	±0.6	±0.2	±0.002	±0.02	±0.03
	10-20	28.0	9.8	16.8	0.9	0.024	0.66	0.26
		±2.3	±0.4	±0.7	±0.1	±0.002	±0.03	±0.03
	20-30	23.1	6.5	11.2	0.6	0.016	0.46	0.11
		±1.8	±0.2	±0.4	±0.1	±0.002	±0.02	±0.01
Undamaged forest	0-10	36.5	35.5	61.3	2.4	0.070	1.62	0.71
		±0.4	±0.4	±0.8	±0.1	±0.003	±0.22	±0.01
	10-20	32.6	14.2	24.4	1.3	0.040	1.08	0.31
		±0.2	±0.2	±0.4	±0.1	±0.002	±0.11	±0.01
	20-30	28.8	13.2	22.6	1.0	0.030	0.79	0.14
		±0.2	±0.1	±0.2	±0.1	±0.001	±0.08	±0.01

Table 2. Fine soil content, organic carbon and nutrient concentration in landslide-damaged sites in Central Himalaya (mean ± 1 SE). Values for undamaged forest sites were averaged over sites U_1-U_8.

average rainfall at Naini Tal is 231.2 cm. The average monthly rainfall ranges from 0.26 cm in November to 65.3 cm in July. The mean monthly temperature ranges from 8.0°C (January) to 21.1°C (June). The year is divisible into three seasons, namely, rainy (mid-June to September), winter (November to February) and summer (April to mid- June). The months of March and October constitute transitional periods, respectively, between winter and summer and between rainy and winter seasons.

Methods

Soil samples were collected from three randomly chosen locations at each site from 0-10 cm, 10-20 cm and 20-30 cm soil depths at the end of the rainy season. Each sample was processed and analysed separately. The soil samples were air-dried and were gently broken and passed through a 0.2 mm sieve to assess the fine soil content. The fine soil (<0.2 mm) was used for chemical analysis.

Organic carbon was analysed by the wet oxidation method (Piper 1944). Organic carbon was multiplied by a factor of 1.724 to obtain the organic matter content. Kjeltech Auto-analyser was used to determine total nitrogen. Available phosphorus was determined colorimetrically (Jackson 1958). Exchangeable calcium and potassium were analysed (after leaching soil samples with 1N ammonium acetate solution) by flame photometry (Jackson 1958).

Nomenclature follows: Oșmaston (1926) and Naithani (1985).

The herbaceous vegetation was recorded by taking ten 1 m^2 quadrats located at random on each site in the last week of August, i.e. during the peak growth period. Relative frequency, relative density and relative basal area for each species were calculated following Curtis (1959). For the determination of herb layer cover a line interception method was followed (Misra 1968). Shrub vegetation, tree seedlings (less than 30 cm in height) and saplings (less than 1.5 m and greater than 30 cm in height) were studied from ten 2 x 2 m randomly located quadrats on each site. Tree vegetation (individuals >10.0 cm diameter at breast height, dbh, or more than 1.5 m in height) was sampled from ten 10 x 10 m quadrats selected at random.

The values of relative frequency, relative density and relative basal area for each species were added to get the importance value index (IVI) (Curtis and Cottam 1956). Community coefficients were calculated following Sorensen (1948) by using IVI data. Species diversity (H) was determined by the Shannon-Wiener (Shannon and Weaver 1963) information index:

$$H = - \sum_{i=1}^{S} (Ni/N) \log_2 (Ni/N)$$

Where Ni is the total number of individuals of species i, and N is the total number of individuals of all species in a site. Concentration of dominance (Cd) was measured by Simpson's index (Simpson 1949):

$$cd = \sum_{i=1}^{s} (Ni/N)^2$$

Where Ni is the total number of individuals of a species, and N is the total number of individuals of all species.

Evenness was calculated as H/log S, following Pielou (1966), where H is the Shannon-Wiener index and S is the number of species.

Herbaceous biomass was determined at the peak growth stage, i.e. in the last week of August. Five soil monoliths, each 25 x 25 x 30 cm were excavated from random locations on each site. The monoliths were washed and separated into above and below-ground plant components, oven-dried and weighed. For shrub biomass, five individuals of approximately average basal circumference for different species were harvested, roots were dug upto 60 cm depth, oven-dried and weighed. The total tree biomass for all sites was determined by using regression equations developed by Chaturvedi and Singh (1982) and Negi, Rawat and Singh (1983). The regression equations were of the form: Ln Y = a+b Ln X, where Y = dry weight (kg), X = cbh (cm).

Parameters	Soil depth (cm)	a	b	r
Age x fine soil (%)				
	0-10	16.88	0.625	0.896
	10-20	11.09	0.667	0.987
	20-30	7.57	0.569	0.965
Age x organic carbon (mg/g)				
	0-10	12.34	0.510	0.987
	10-20	2.56	0.294	0.985
	20-30	2.31	0.177	0.987
Age x nitrogen (mg/g)				
	0-10	0.714	0.040	0.974
	10-20	0.27	0.024	0.992
	20-30	0.20	0.015	0.970
Age x available phosphorus (mg/g)				
	0-10	0.018	0.00089	0.956
	10-20	0.004	0.00088	0.977
	20-30	0.002	0.00058	0.985
Age x exchangeable calcium (mg/g)				
	0-10	0.180	0.031	0.990
	10-20	0.133	0.021	0.987
	20-30	0.122	0.013	0.989
Age x exchangeable potassium (mg/g)				
	0-10	-0.177	0.024	0.982
	10-20	0.095	0.007	0.928
	20-30	0.069	0.002	0.800

Table 3. Regression equations (Y = a+bX) relating age (X, years following landslide) to soil parameters (Y) in landslide disturbed sites in Central Himalaya. All r values are significant at $p<0.01$.

Parameters	Soil depth (cm)	a	b	r
FS x organic carbon (mg/g)				
	0-10	2.54	0.637	0.860
	10-20	-2.07	0.425	0.962
	20-30	0.20	0.292	0.957
FS x nitrogen (mg/g)				
	0-10	-8.21	0.057	0.964
	10-20	-0.11	0.036	0.983
	20-30	0.01	0.026	0.953
FS x available phosphorus (mg/g)				
	0-10	-0.0013	0.0012	0.919
	10-20	-0.0100	0.0012	0.968
	20-30	-0.0045	0.0009	0.914
FS x exchangeable calcium (mg/g)				
	0-10	-0.463	0.041	0.906
	10-20	-0.215	0.031	0.971
	20-30	-0.043	0.022	0.962
FS x exchangeable potassium (mg/g)				
	0-10	-0.67	0.031	0.901
	10-20	-0.03	0.010	0.961
	20-30	0.04	0.004	0.798*

Table 4. Regression equations (Y = a+bX) relating fine soil (FS) content (X, %) to soil chemical properties (Y) in disturbed sites in Central Himalaya. *Significant at $p<0.05$; all other r values are significant at $p<0.01$.

Parameters	Soil depth (cm	a	b	r
SOM x nitrogen (mg/g)				
	0-10	-0.244	0.046	0.949
	10-20	0.077	0.046	0.967
	20-30	0.007	0.050	0.966
SOM x available phosphorus (mg/g)				
	0-10	-0.003	0.0010	0.964
	10-20	0.003	0.0016	0.964
	20-30	0.005	0.0018	0.974
SOM x exchangeable calcium (mg/g)				
	0-10	-0.547	0.0346	0.978
	10-20	-0.054	0.0429	0.992
	20-30	-0.054	0.0450	0.993
SOM x exchangeable potassium (mg/g)				
	0-10	-0.752	0.027	0.987
	10-20	0.039	0.013	0.889
	20-30	0.036	0.001	0.861

Table 5. Regression equations (Y = a+bX) relating soil organic matter (SOM) (X, mg g^{-1}) to soil chemical properties (Y) in disturbed sites in Central Himalaya. All r values are significant at $p<0.01$.

Results

Physico-chemical properties of soil

The soil physico-chemical properties in all three soil layers viz. surface (0-10 cm), upper subsurface (10-20 cm) and lower subsurface (20-30 cm) improved with the age of the site. Minimum fine soil content, organic carbon and nutrient contents (nitrogen, available phosphorus and exchangeable calcium and potassium) were recorded for the 1-yr old site, while the highest values were recorded for the 25-yr old site (Table 2). These parameters were generally higher in the surface soil than in the subsurface soils (Table 2). Analysis of variance showed that the differences due to sites (age) and depth in fine soil content, organic carbon, organic matter, total nitrogen, available phosphorus and exchangeable potassium were significant at $p<0.01$ and the interaction between sites and depth were also significant at $p<0.01$. Fine soil content, organic carbon and nutrients showed significant positive relationships with the age of the site (Table 3). Soil nutrients also showed significant positive relations with the fine soil content (Table 4) and organic matter content (Table 5).

Herb species

The herb species content increased with age of the site (Fig. 1; r^2 = 0.944, $p<0.01$) and ranged from 15 species on the 2-year-old site to 26 species on the 25-year-old site (Table 6). For undamaged sites, the herb species content varied from 26 to 32 and averaged 29. Herb species content showed significant positive relations with fine soil content, soil organic carbon and total soil nitrogen (Table 7). The herbaceous cover was minimum (3%) at the 2-year-old site and increased with the age of the site (Fig. 2; r^2 = 0.930, $p<0.01$). Herb cover showed significant positive relations with fine soil content, soil organic carbon and total soil nitrogen (Table 7).

There was no consistent effect of site age on herb species diversity except that the latter increased between 2 and 9 years. Herb species diversity ranged from 4.02 to 4.68 and averaged 4.42 for all undamaged sites. Concentration of dominance was inversely related with the age of the site (r^2 = 0.935, $p<0.01$). For undamaged sites, concentration of dominance fluctuated between 0.0010 to 0.0012 and averaged 0.0011. In the landslide-damaged sites evenness was maximum at 1-year-old site and showed a significant negative relation with the age of the site (r^2 = -0.986, $p<0.01$).

Across the developmental stages *Arthraxon nudes, Campanula colorata, Cnicus argyracanthus, Galium aparine, Justecia simplex* and *Rumex hastatus* were the dominant herb species. On the undamaged sites the important herbs were: *Arthraxon nudes, Galium aparine, Justecia simplex, Micromeria biflora* and *Oxalis corniculata* (Table 8). The per cent similarity in the composition of the herb layer between damaged and undamaged sites varied from 25% to 45.2% (Table 9). Similarity between disturbed sites of successive ages in herb vegetation did not show any consistent pattern with age.

Age of site (years)	Species content	Concentration of dominanc	Species diversity	Evenness
1	21	0.0082	4.30	1.40
2	15	0.0072	3.67	1.36
3	17	0.0060	3.90	1.38
4	18	0.0043	3.96	1.37
8	20	0.0032	4.03	1.34
9	23	0.0028	4.25	1.36
18	23	0.0016	3.87	1.23
25	26	0.0010	3.73	1.14
Undamaged forest site				
	29	0.0011	4.42	1.30

Table 6. Certain herb layer characteristics of an age series of landslide-damaged sites in Central Himalaya. Values for undamaged forest sites were averaged over site U_1-U_8. .LH8

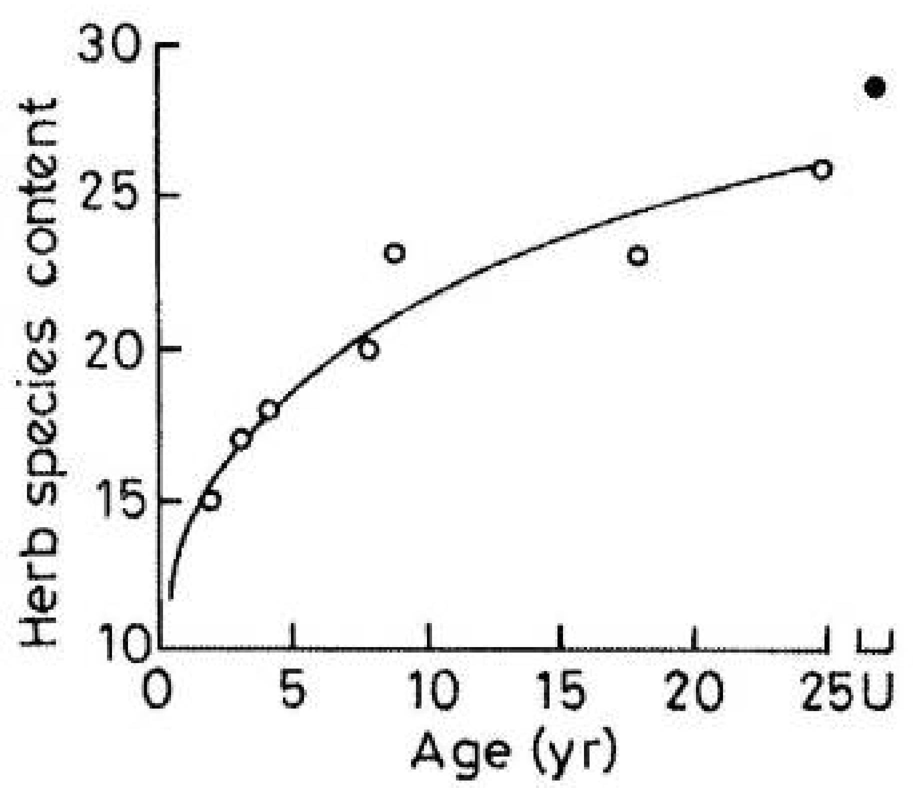

Fig. 1: Relationship between age of the sites (yrs) and herb species content ($Y = 13.45\ X^{0.20}$), ($r^2 = 0.944$, $p<0.01$) in landslide-damaged sites in Central Himalaya. Solid circle indicates the average value for undamaged sites. The regression was calculated and curve fitted by using Statgraphics (1986).

Shrub species

Shrubs first appeared at 9-year old site. *Hypericum oblongifolium* and *Lantana camara* were dominant at this site. *L. camara* was the sole dominant species at the 18-year old site and the 25-year old site was dominated by *Colquhounia coccinea* and *L. camara*. Shrub species content was maximum (3 species) at the 9-year old site and minimum (1 species) at the 18-year old site, with no particular pattern over time. On the undisturbed sites, shrub species content varied from 2 to 8, and averaged 3. *L. camara* was dominant on 4 sites and *Rubus ellipticus* on 2 sites. Percent similarity between paired damaged-undamaged sites in terms of the shrub layer varied from 27.8% at the 9-year old site to 32.8% at the 18-year old site (Table 9). Similarity between disturbed sites of successive ages in shrub vegetation increased with the age of the site.

X	Y	a	b	r
Fine soil content (%)	Herb species content	12.121	0.469	0.730**
Soil nitrogen (mg/g)	Herb species content	12.669	12.353	0.806**
Soil organic carbon (mg/g)	Herb species content	11.445	1.042	0.828**
Fine soil content	Herb cover (%)	-6.737	0.914	0.909*
Soil nitrogen	Herb cover	-5.166	22.912	0.955*
Soil organic carbon	Herb cover	-7.120	1.897	0.962*
Fine soil content	Total herb biomass (t ha^{-1})	-0.521	0.088	0.958*
Soil nitrogen	Total herb biomass	-0.333	2.150	0.979*
Soil organic carbon	Total herb biomass	-0.476	0.173	0.960*
Soil available phosphorus (mg/g)	Total herb biomass	-0.055	72.65	0.984*
Soil exchan-geable calcium (mg/g)	Total herb biomass	0.155	2.531	0.968*
Soil exchan-geable potassium (mg/g)	Total herb biomass	0.091	5.037	0.975*

Table 7: Regression equations (Y = a+bX) for relationships between certain soil properties (mean of 0-30 cm depth) and selected vegetation parameters in landslide-damaged sites in Central Himalaya.
* significant at p<0.01,**significant at p<0.05.

	Disturbed sites age (yrs)								Undisturbed sites							
	1	2	3	4	8	9	18	25	U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8
HERBS																
Arthraxon nudes	-	-	20.4	-	33.2	-	19.6	63.2	14.8	6.8	6.3	7.7	8.1	-	26.2	12.5
Bidens biternata	8.2	-	5.4	-	-	-	-	5.8	2.2	1.7	-	2.0	-	-	1.1	0.9
Campanula colarata	4.1	5.7	4.2	7.7	1.9	-	2.2	-	-	-	-	-	-	-	-	-
Cnicus argyracanthus	10.7	11.5	2.4	1.7	6.7	-	1.6	0.3	-	-	-	-	-	-	-	-
Erigeron alpinus	3.3	6.5	-	6.9	1.6	-	-	-	-	2.9	1.0	-	1.1	-	0.4	-
Galium aparine	4.1	7.2	6.6	-	3.8	-	3.7	2.1	8.2	5.7	12.0	5.3	7.6	-	5.1	6.5
Geranium nepalensis	6.6	-	-	1.7	2.9	2.5	-	0.4	0.7	2.8	-	1.5	2.9	1.1	-	2.2
Justecia simplex	-	16.6	7.2	-	5.1	6.9	0.8	0.2	1.8	4.1	5.3	2.4	4.3	1.7	9.6	4.7
Mazus rugosus	-	9.4	4.2	-	-	-	-	0.2	6.6	0.4	-	6.6	1.9	-	-	2.5
Micromeria biflora	2.4	-	4.2	5.6	-	-	1.6	1.8	5.8	1.6	9.9	3.5	6.3	-	8.5	7.3
Oxalis corniculata	4.1	6.5	-	1.7	7.4	-	0.3	1.6	6.5	4.3	3.3	6.2	5.1	-	3.5	8.3
Polygonum nepalensis	8.2-	3.6	5.6	-	-	0.6	-		-	1.4	-	4.7	1.3	-	3.2	-
Rumex hastatus	6.6	7.2	4.2	-	3.8	2.3	1.5	0.8	-	-	-	-	-	-	-	-
Other species	17.4	7.9	13.2	24.3	20.4	22.7	4.4	1.3	14.9	1.6	-	10.2	11.6	33.9	-	11.2
SHRUBS																
Colquohonia coccinea	-	-	-	-	-	-	-	50.0	-	-	-	14.7	-	-	-	-
Hypericum oblongifolium	-	-	-	-	-	53.6	-	-	-	-	-	-	-	-	-	-
Inula cappa	-	-	-	-	-	-	-	-	56.5	17.6	41.3	-	-	-	-	76.0
Lantana camara	-	-	-	-	-	28.6	100.0	50.0	-	27.0	58.6	67.6	76.1	12.5	29.6	24.0
Rubus ellipticus	-	-	-	-	-	-	-	-	43.4	18.8	-	17.6	23.8	-	70.3	-
Other species	-	-	-	-	-	17.9	-	-	-	37.4	-	-	-	89.3	-	-
TREES																
Pinus roxburghii	-	-	-	-	-	-	100.0	100.0	100.0	81.3	72.7	90.2	100.0	16.6	73.1	100.0
Quercus floribunda	-	-	-	-	-	-	-	-	-	-	16.3	2.4	-	-	-	-
Quercus leucotrichophora	-	-	-	-	-	-	-	-	-	11.6	10.9	7.3	-	-	7.3	-
Other species	-	-	-	-	-	-	-	-	- 6.9	-	-	-	83.1	19.6	-	

Table 8.: Relative density values for some important herb, shrub and tree species in landslide-damaged and undamaged forest sites in Central Himalaya . U_1-U_8 represent undisturbed sites adjacent to 1,2,3,4,8,9,18- and 25-yr old disturbed sites, respectively.

Shrub species diversity was 1.41, 0 and 0.9 at 9, 18- and 25- year old sites, respectively. The concentration of dominance varied from 0.42 (9-yr) to 1.0 (18-yr). Evenness was similar at 9- and 25-year-old sites (1.29). In the undamaged sites, shrub species diversity varied from 0.91 to 2.66, and averaged 1.33. Concentration of dominance ranged from 0.197 to 0.636 and averaged 0.44. Evenness varied from 1.11 to 1.42.

Tree species

Seedlings of *Pinus roxburghii* were found from the 2-year old site onwards. A mixture of seedlings and saplings were present at the 8-, 18- and 25-year old sites. On the undamaged sites *P. roxburghii* exhibited good regeneration both in seedling and sapling layers. Second-growth trees of *P. roxburghii* were present at 18- and 25-year-old sites.

On the adjacent undamaged sites the dominant tree species were *Bauhinia retusa* and *Mallotus philippensis* on one site and *P. roxburghii* on all other forest sites. *Quercus leucotrichophora* was codominant on two sites and *Quercus floribunda* and *Rhododendron arboreum* on one site each.

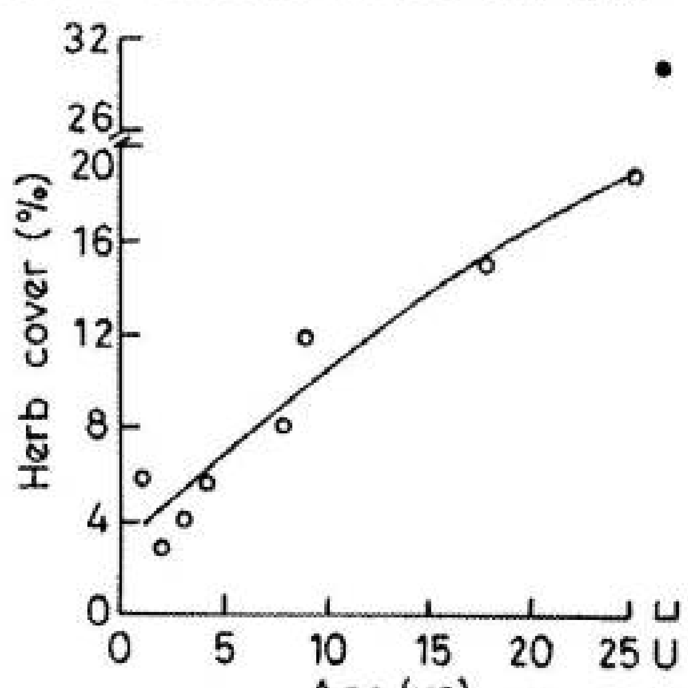

Fig. 2: Relationship between age of the sites (yrs) and herb cover (%) ($Y = 2.92+0.83 x - 0.008 X^2$) ($r^2 = 0.930$, $p<0.01$) in landslide-damaged sites in Central Himalaya. Solid circle as in Fig. 1. The regression was calculated and curve fitted by using Statgraphics (1986).

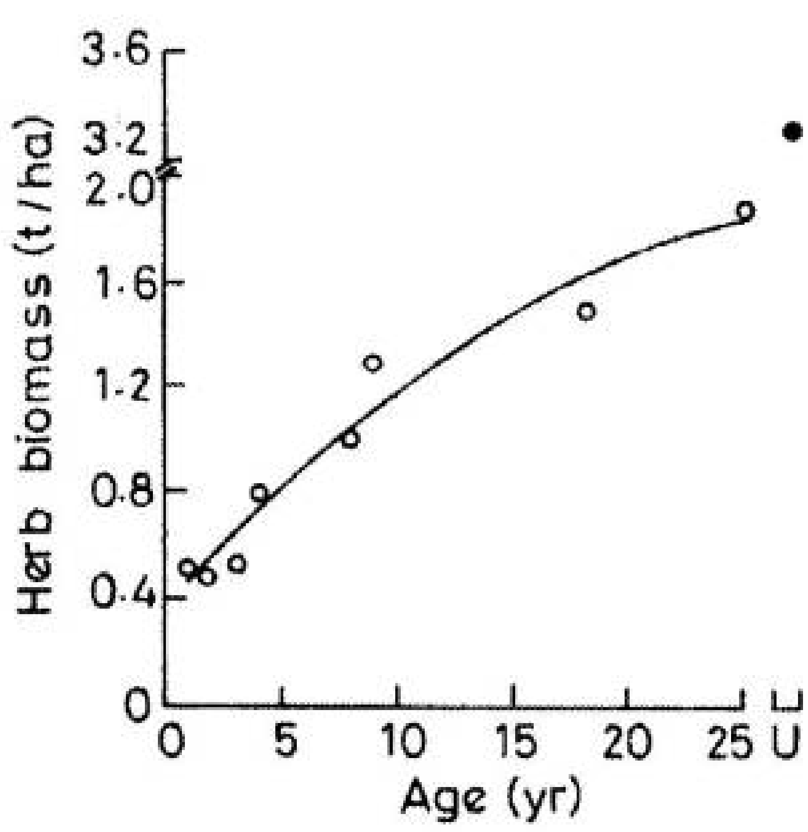

Fig. 3: Relationship between age of the sites (yrs) and total herb biomass (t ha^{-1}) ($Y = 0.37+0.097 x - 0.0154 X^2$), ($r^2 = 0.960$, $p<0.01$) in landslide-damaged sites in Central Himalaya. Solid circle as in Fig. 1. The regression was calculated and curve fitted by using Statgraphics (1986).

Plant biomass

The total herb biomass (above- and belowground) increased over time (Fig. 3; $r^2 = 0.960$, $p<0.01$). The herb biomass was positively related with fine soil content, soil organic carbon and total soil nitrogen (Table 7). The above- and belowground biomass varied, respectively, from 1.3 to 1.8 t ha^{-1} and 1.7 to 2.1 t ha^{-1}, on the undamaged forest sites and the total herb biomass ave raged 3.3 t ha^{-1}.

The total shrub biomass was higher at the 9-year old site (1.053 t ha^{-1}) and lower at the 18-yr old site (0.111 t ha^{-1}), with no consistent pattern over time. It averaged 1.01 t ha^{-1} on the undamaged forest sites.

The total tree biomass at the 18-yr old site was 0.25 t ha^{-1} and 2.53 t ha^{-1} at the 25-yr old site. For undamaged sites, it varied from 111.2 to 267.9 t ha^{-1}, and averaged 178.7 t ha^{-1}. The total stand biomass (herb + shrub + tree) increased with the age of the site ($r^2 = 0.971$, $p<0.01$) according to:

$$Y = 0.54236\ X$$

where Y = total biomass (t ha^{-1}) and X = age of the site (years).

Discussion

Disturbance due to landslide activity severely changes the soil properties and vegetation composition. The particle size distribution (fine soil content) is a major factor which governs the soil stability, the successful establishment of vegetation on drastically disturbed sites and influences vegetative diversity (Toy and Shay 1987). In the present study, surface soil layer (0-10 cm) was richer in fine soil content, organic matter and nutrients compared to deeper layers in landslide-damaged sites. Fine soil content, organic matter and nutrients in the 1 and 2- year old sites were remarkably low. At 8- and 9-year old sites soil conditions were favourable for plant growth compared to 1- and 2-year old sites. Soil conditions at the 25-year old site were distinctly different from those of the younger sites and represented an advanced stage of development in terms of build up of soil physico-chemical properties. The soil conditions of disturbed sites, except for the oldest site (25-years) were quite different from those of the adjacent undisturbed forest sites. The fine soil content, soil organic matter and nutrient concentrations even at the oldest site (25-years) were lower than in the corresponding undamaged site (Table 2). Pandey and Singh (1985) reported that concentrations of nutrients in oak forest soil in Central Himalaya following disturbance reached the characteristic level of the reference forest stand in a period of 40-60 years. Similarly, Bush and Van Auken (1986) reported the lowest levels of soil organic carbon for younger successional ecosystems and highest levels for the mature stages, for the disturbed plains of San Antonio River, South Texas, U.S.A.

In the present study, soon after disturbance, the landslide- damaged sites were colonized by ruderal herbaceous species such as *Bidens biternata, Cnicus argyracanthus, Erigeron alpinus, Galium aparine, Geranium nepalensis, Oxalis corniculata* and *Polygonum nepalensis*. These annual herbs are either immigrants to

Site pairs	Similarity in herb layer (%)	Similarity in shrub layer (%)	Succesive ages	Similarity in herb layer (%)	Similarity in shrub layer (%)
1-yr old x U_1	31.1	0	1-yr old x 2-yr old	48.4	0
2-yr old x U_2	27.6	0	2-yr old x 3-yr old	36.9	0
3-yr old x U_3	25.0	0	3-yr old x 4-yr old	13.9	0
4-yr old x U_4	30.9	0	4-yr old x 8-yr old	25.8	0
8-yr old x U_5	34.1	0	8-yr old x 9-yr old	17.2	0
9-yr old x U_6	34.9	27.8	9-yr old x 18-yr old	15.7	27.5
18-yr old x U_7	40.0	32.8	18-yr old x 25-yr old	41.6	35.3
25-yr old x U_8	45.2	30.8			

Table 9. Similarity in herb and shrub vegetation between site pairs and between disturbed sites of successive ages in Central Himalaya. U_1 - U_8 represent undisturbed sites adjacent to 1,2,3,4,8,9,18- and 25-yr old disturbedsites, respectively.

the disturbed site or emerged from the buried seeds exposed due to landslide-disturbance. With increasing site age, the shade-intolerant annual herbs decreased while shade tolerant perennial herbs increased (Table 8). Inouye *et al.* (1987) stated that annuals decreased as the soil nitrogen content increased in Minnesota sand plains.

In the present study, the number, cover, diversity and biomass of herb species increased with the developmental stages but were lower than in corresponding undamaged forest stands even at the 25-year old site. The increase in the herb species content and cover was associated with an increase in fine soil content, soil organic matter and total soil nitrogen. Shafi and Yarranton (1973), Purdie and Slatyer (1976) and Mellinger and McNaughton (1975) reported that species diversity increases during succession and concentration of dominance decreases. Chaturvedi *et al.* (1988) reported a species diversity value of 3.67 for herb vegetation in pine forests of Central Himalaya. The herb species diversity values of the landslide-damaged sites in the present study were higher (3.67-4.30) than the above value. Singh and Singh (1987b) stated that among the forest ecosystems in Central Himalaya, herb ve-getation in pine forest is most diverse where there is high availability of sunlight at ground level. Higher plant biomass at the older sites is mainly due to improved species content, higher number of perennial species, increased density and favourable soil conditions. Shrubs appeared at 9 years, after substantial improvement of soil conditions had occurred. Lower shrub species content (1-3 species) is apparently due to low seed-bank diversity in the pine forest stands (Singh and Singh 1987a). Reddy and Singh (in press) have found elsewhere that the shrub species content in landslide- damaged sites of oak forests is higher than in pine forests. Shrub biomass was erratic over time and much of it was contributed by *Lantana camara* which is considered a weed species (Singh and Singh 1992).

Community coefficients express the floristic similarity of two communities. In this study per cent similarity in herb vegetation between damaged and corresponding undamaged sites increased with the age of the site. However, similarity between successive ages of disturbed sites did not follow any consistent pattern. This indicates that each pair of sites may reflect individualism in species change through time (MacMahon 1980).

In the present study, significant positive relation between soil nutrients and herb biomass indicated the interdependence between nutrients and plant growth during succession. Aweto (1981) stated that increases in soil organic matter and nutrients lead to an increase in vegetation biomass. Inouye *et al.* (1987) reported that early stages of succession were characterised by low soil nitrogen and low plant biomass while the later stages exhibited higher nitrogen and high plant biomass. This study is consistent with the above generalization.

In the landslide-disturbed sites, tree seedlings appeared soon after disturbance. Seedlings of *Pinus roxburghii* appeared after 1 year and persisted throughout the developmental stages. Saplings of *P. roxburghii* appeared at 8 years and second-growth trees occurred in the 18 years site. Thus, in the landslip sites studied only *P. roxburghii*, which was abundant on the adjacent undamaged sites, colonized the tree layer.

In the present study there was a continued dominance throughout the developmental stages by *Pinus roxburghii*. Pine is an early successional species with very small seed size and colonizes the barren land surfaces soon after disturbance. Once *P. roxburghii* colonizes the site, the latter becomes inaccessible to nitrogen- demanding broad-leaf species due to the nutrient conservation strategy of pine (Singh *et al.* 1984).

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