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Diversity and distribution of endemic and exotic earthworms in natural and regenerating ecosystems in the central Himalayas, India

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Abstract

A comparative analysis of earthworm communities was carried out in the central Himalayas to understand 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 forest sites with varying degree of disturbances at monthly intervals over a period of 1 year. Eight species belonging to four families were recorded from these sites, Lumbricidae (*Bimostus parvus*, *Octolasion tyrtaeum*), Octochaetidae (*Octochaetona beatrix*), Megascolecidae (*Amynthas corticis*, *Eutyphoeus festivus*, *E. nanianus*, *E. waltonii*) and Moniligastridae (*Drawida* sp.). The loss of natural climax vegetation led to the loss of endemic *E. nanianus*, endemic *E. festivus* and *E. waltoni* and three exotic species *A. corticis*, *B. parvus* and *O. beatrix* sp. and *Drawida* sp. appeared in the regenerating sites. Due to the process of deforestation and degradation a general decline in the density of the endemic species and the dominance by exotics were observed. The maximum number of species were recorded in 40 year-old pine forest. The present study emphasised the fact that in the central Himalayas the functional guild (endogees–anecics) change under different vegetation type; organic matter characteristics could be an important factor for this. Biological invasion was also observed in the climax forest due to the presence of exotic *O. tyrtaeum*. Except for *A. corticis* all other species had significantly higher density during the rainy season. *A. corticis* had maximum winter population in both 6 and 40 year-old pine forest. Population size of earthworms were significantly correlated with soil moisture, temperature and organic matter.

Fire in the subclimax mixed forest caused significant decline in the population density of earthworm species. The accidental fire in the subclimax forest affected population recovery differently for different species. Thus *O. tyrtaeum* and *E. nanianus* improved significantly after 60 and 120 days after the fire.

Keywords: Diversity; Earthworms; Climax; Regenerating; Ecosystem; Himalayas

1. Introduction

The change in the population structure of earthworm species due to disturbance and degradation of natural forest has been reported by Satchell (1983) for temperate regions and by Fragoso and Fernandez (1994) for tropical regions. These studies have shown that earthworms constitute the largest part of invertebrate biomass in most of the soils, and the large-scale destruction of natural forests has severely affected the diversity of this faunal group (Lavelle et al., 1994; Bhaduria and Ramakrishnan, 1991).

The central Himalayas have inherently weak soil structure which easily degenerates under existing climatic conditions (Ramakrishnan et al., 1993). They also represent the region which was once covered with primary forest but now has a mosaic of disturbed and degraded (due to anthropogenic activities, soil erosion, landslides, intensive agriculture practices) ecosystems (Ramakrishnan et al., 1992) as well as a few sparsely distributed patches of climax forests. This region forms an ideal location to study the impact of degradation of natural vegetation/deforestation and subsequent regeneration of forests on the soil faunal diversity. Therefore, the present study has been undertaken to assess the impact of forest disturbances/degradation, and subsequent regeneration on earthworm communities. Besides studying the interhabitat variation of earthworm communities, the present study also examines the seasonal variation in the population density of earthworms across six different sampling sites over a period of 1 year (December 1993–December 1994). Fire effect on earthworm density in the mixed forest was studied over a period

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Table 1
Description of sampling sites in central Himalayas, India

Site	Description	Vegetation
Climax forest	A moist evergreen broad leaved mixed forest, undisturbed climax forest.	*Quercus leucotrichophora*[a], *Q. floribunda*, *Litsae umbrosa*, *Themeda anathera*[b], *Imperata cylindrica*
Subclimax mixed forest	Relatively undisturbed oak-pine mixed forest, slightly logged at present.	*Q. floribunda*, *Pinus roxburghi*, *Q. leucotrichophora*, *Crataegus cremulata*, *Themeda anathera*[b], *Myrsine africana*
Subclimax mixed forest (exposed to fire)	Same as above, but exposed to fire which caused extensive burn of litter layer.	Same as above
Open grassland	Deforested site which was initially used for agricultural purposes and subsequently abandoned. They are highly degraded due to grazing by animals, poor vegetation cover and heavy losses of top surface soil.	*Heteropogon contortus*[b], *Chrysopogon fulvus*, *Arthrozon* sp.
6 year-old pine forest	A naturally regenerating pine forest, the site was moderately disturbed due to removal of litter layer, grazing by cattle, poor vegetation cover resulting in the loss of surface soil layer, and seasonal burn during dry phase.	*P. roxburghii*[a], *Rubus ellipticus*[b], *Chrysopogan serrulatus*, *Heteropogon contortus*
40 year-old pine forest	A naturally regenerating pine forest representing a seral phase during secondary succession. Exposed to perturbation pressure like tree lopping, grazing by cattle and occasional burning during dry season.	*P. roxburghii*[a], *C. fulvus*[b], *Thalictrum foliolosum*, *H. contortus*

[a] Trees.
[b] Herbs and grasses.

of 1 year (1 week before fire and 1 month after fire and subsequently at an interval of about 30 days) (April 1994–April 1995).

2. Materials and methods

For each vegetation type three distinct hill slopes (sites) under similar aspect were selected in the Central Himalayan district of Almora (29°34′30″N and 79°77′30″E) were identified for earthworm sampling. A plot of $40 \times 50\ m^2$ size was marked at each of these sites under study. These sites were: (a) broad leaved temperate climax forest (1900–2000 m); (b) mixed oak–pine subclimax forest (1900–2000 m); (c) mixed oak–pine subclimax forest exposed to accidental fire (1900–2000 m); (d) 40 year-old pine forest (1700 m); (e) 6 year-old pine forest (1600 m); and (f) open grassland (1600 m) (Table 1). All the study sites are located within 20 km of Almora town

2.1. Geology

Study sites belong to Himadri and Darma-Johar geographical regions in South–North sequence (Joshi et al., 1983). The rocks are mostly micaceous with quartzite and limestone (Wadia, 1978). The soils are mostly brown forest, podzolic and quartzite in origin (Sehgal et al., 1992).

2.2. Climate

Climate is cool temperate with winter extending from December to March. Frosts are severe at all sites. Summer is brief and extends from April to June. Rainy season extends from July to September with an average rainfall of 1162 mm. October is the transitional period between rainy seasons and winter and March, between winter and summer.

2.3. Soil sampling and physico-chemical analysis

Soil sampling was performed over a period of 12 months (December 1993–December 1994) on all the sites except in the mixed forest exposed to fire, which was sampled between April 1994–April 1995. At each of the three sites a plot size of $40 \times 50\ m^2$ was demarcated for earthworm sampling as well as soil sampling. Six $25 \times 25 \times 40\ cm^3$ soil monoliths were randomly sampled from each replicate plot at regular monthly intervals. Each monolith was subdivided into 0–10, 10–20, 20–30 and 30–40 cm blocks. In the mixed forest exposed to fire, soil sampling was done as mentioned above, but the sampling period involved collection of soil samples 1 week before fire (−7 days), 1 month after fire (+30 days), 60 and 120 days subsequent to fire, and subsequently at an interval of 1 month until April 1995. The soil samples collected were air dried (bigger lumps crushed) and sieved through a 2 mm sieve. A representative sample was stored for subsequent analyses (Okalebo et al., 1994).

Soil temperature was recorded every month at 0–10 and 10–20 cm depth using a soil thermometer. However the values (°C) presented here are for the depth 0–10 cm.

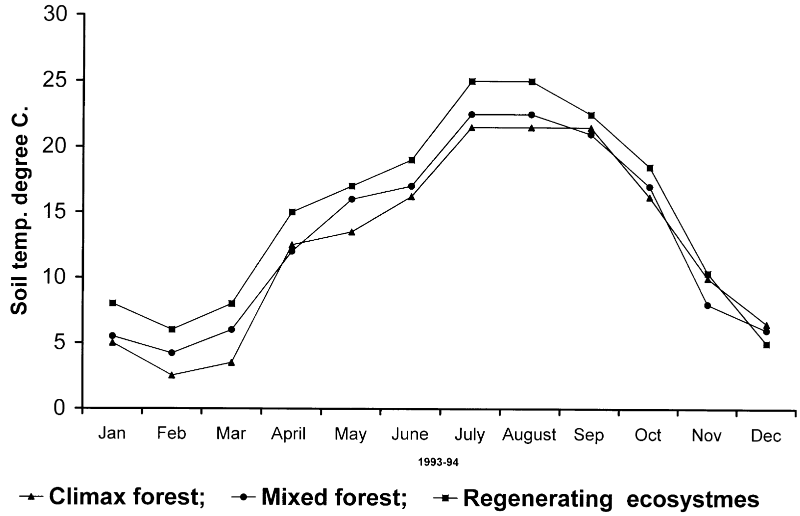

Fig. 1. Monthly fluctuations in soil temperature in the central Himalayas.

Moisture was determined monthly at 0–10 and 10–20 cm depth and was expressed as a percentage of the weight of the soil sample after oven drying at 105°C. Soil pH was measured in 1:2.5 soil/water solution. Organic carbon was determined using the complete oxidation method (Nelson and Sommers, 1975). Soil nitrogen was analysed by the microkjeldahl method (Okalebo et al., 1994). Available phosphate was measured colorimetrically by the molybdenum blue method after extraction with sodium bicarbonate extracting solution (Watanabe and Olson, 1965). The analysis of soil texture was done as per Bouyoucos (1962). From this data, using a soil textural triangle, soils were assigned to a textural class.

2.4. Sampling of earthworm population

Earthworms were sampled using the tropical soil biology and fertility methodology (Anderson and Ingram, 1993). On each site in a plot of 40×50 m^2, earthworms were collected at regular monthly intervals over a period of 12 months (December 1993–December 1994) from 15 sampling points 5 m apart along a transect with a random origin. In the mixed forest exposed to fire earthworms were collected 1 week before fire (−7 days), 1 month (+30 days) after fire, 60 and 120 days and subsequently at a gap of monthly intervals till April 1995 after the fire.

Earthworms were extracted by handsorting, after digging a trench up to 30 cm deep around a 25×25 cm^2 area at each sampling point to get soil monolith. These soil monoliths were divided into three layers (0–10, 10–20, 20–30 cm) and earthworms were sampled from each layer. They were washed, wiped dry on a filter paper, their fresh weight taken and then preserved in 4% formalin (Anderson and Ingram, 1993) for their taxonomic identification.

2.5. Statistical analysis

Variation in the density and biomass of earthworm species and soil characteristics across different sampling sites was tested using one-way ANOVA and Newman–Keuls multiple range test. Seasonal variation in density and biomass of earthworm species at all the sites was tested with Kruskal–Wallis test of variance (*H*-test) and Newman–Keuls multiple range test. The effect of fire on earthworm species density was tested using one-way ANOVA and multiple range test.

Earthworm density (individuals/unit area) and dominance (individuals of species as a fraction of the total no of all the species) were calculated under different field treatments. Sample standard error was calculated as standard error of the mean.

The correlation between soil parameters and earthworm species was calculated as a simple correlation coefficient (r).

3. Result

3.1. Site characteristics

The surface soil temperature declined sharply during the winter months ($F = 8.2$, $P < 0.05$) with a minimum in January–February and a maximum in June–August at all the sites (Fig. 1). The soil temperature did not vary significantly between different sites.

Soil sand percentage was significantly lower in the climax forest and mixed forest as compared to the other sites ($F = 18.50$, $P < 0.05$) (Table 2). Grassland as well as both the 6 and 40 year-old pine forest had very similar soil texture. Soil moisture was significantly higher in the climax forest ($F = 11.68$, $P < 0.05$); it did not vary significantly between grassland and 6 and 40 year-old pine forest. Soil moisture was maximal at all the sites during monsoon (Fig. 2). Soil had mildly acidic pH (6.1–6.2) at all the sites to acidic pH (5.5–5.8) in the 6 and 40 year-old pine forest. Soil organic matter was significantly higher

Table 2
Soil characteristic across different sampling sites (mean ± SE) in the central Himalayan district of Almora (average mean values for 1 year; numbers followed by the same letter are not significantly different ($P < 0.05$))

Sites	Sand (%)	Silt (%)	Clay (%)	Moisture (%)	pH	Organic matter (%)	PO_4^{-P} (mg/100g)	K (meq 100/g)	Ca
Climax forest	62.3^a	24.7^a	13.0^a	42 ± 4^a	6.1	3.4 ± 0.2^a	1.7 ± 0.1^a	0.46 ± 0.02^a	3.5 ± 0.2^a
Mixed forest	61.1^a	22.2^b	16.6^b	36 ± 3^a	6.2	3.0 ± 01^a	1.4 ± 0.1^a	0.21 ± 0.06^b	2.7 ± 0.04^a
Grassland	73.1^b	15.4^c	12.2^c	20 ± 1.8^b	6.2	2.0 ± 0.3^b	1.0 ± 0.03^a	0.05 ± 0.001^c	1.1 ± 0.08^b
Pine Forest (6 year-old)	69.1^b	17.8^c	13.1^d	25 ± 2^b	5.5	2.3 ± 0.1^b	1.8 ± 0.01^a	0.3 ± 0.01^d	1.8 ± 0.2^c
Pine forest (40 year-old)	68.2^b	18.2^c	13.6^d	26 ± 2^b	5.8	2.8 ± 0.1^b	2.7 ± 0.02^b	0.45 ± 0.002^e	2.4 ± 0.1^c

($F = 4.66$, $P < 0.05$) in the climax forest as compared to all the sites except in the mixed forest, it did not vary significantly between the grassland and 6 and 40 year-old pine forest. Phosphate phosphorus ($F = 21$, $P < 0.05$) and potassium ($F = 16.3$, $P < 0.05$) were present in significantly larger amounts in the 40 year-old pine forest as compared to mixed forest, 6 year-old pine forest and the grassland. Concentration of calcium was significantly higher ($F = 12.6$, $P < 0.05$) in the climax forest as compared to the regenerating ecosystems.

3.2. Effect of fire

Soil moisture had declined 30 days after fire but it increased significantly 120 days after fire ($F = 8.64$, $P < 0.05$) (Table 3). Soil pH did not vary significantly as a result of post fire loss. Organic matter declined subsequent to fire ($F = 8.86$, $P < 0.05$). On the other hand, potassium ($F = 21$, $P < 0.01$) and calcium ($F = 10.24$, $P < 0.01$) content increased significantly after the burn but declined subsequently after 120 days.

3.3. Community structure

Of the eight species recorded here the lumbricid species *Octolasion tyrtaeum* (Savigny) and megascolecid *Eutyphoeus nanianus* (Michaelsen) were present in the mixed forest and the climax forest. The latter species was absent at the other sites whereas the former species was present in the grassland. The megascolecid *Amynthas corticis* (Baird) and *Eutyphoeus festivus* (Gates) occurred in grassland and in both the 6 and 40 year-old pine forests. The megascolecid *E. waltonii*, lumbricid *Bimastos parvus* (Eisen), moniligastrid *Drawida* sp. and octochaetid *Octochaetona beatrix* (Beddard) were present in the 40 year-old pine forest alone. Of the eight species recorded *A. corticis*, *B. parvus*, *O. beatrix* and *O. tyrtaeum* are exotic species whereas *Drawida* sp., *E. festivus*, *E. waltonii* and *E. nanianus* are endemic to the central Himalayas. The exotic *A. corticis* and *O. tyrtaeum* were dominant in the 6 year-old pine forest and in the grassland, whereas the endemic *Drawida* sp. and *E. nanianus* were dominant in the 40 year-old pine forest and the climax forest. Total density of endemic species declined with the increase in perturbation pressure (Fig. 3).

Mean density and biomass values of earthworms varied significantly across different sampling sites (Table 4). The mean earthworm density ($F = 7.55$, $P < 0.05$) and biomass values ($F = 12.35$, $P < 0.01$) were significantly higher in the 40 year-old pine stand as compared to the other sites. These values did not vary significantly between the grassland and the 6 year-old pine forest. Mean earthworm biomass was significantly higher in the climax forest ($F = 7.5$, $P < 0.05$) than in the mixed forest.

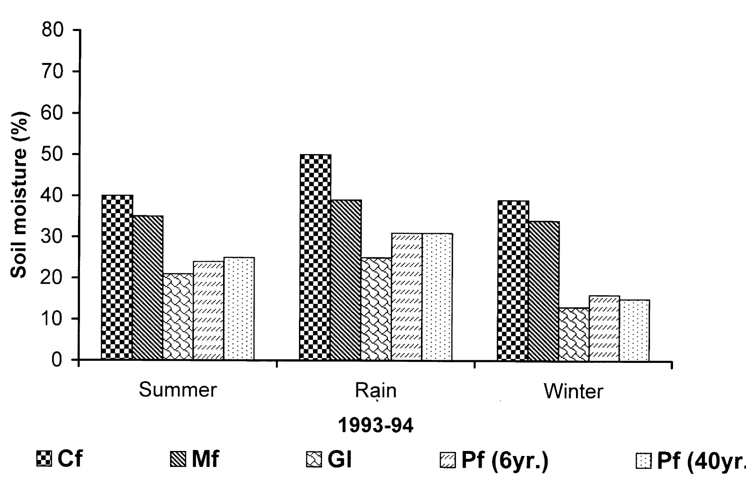

Fig. 2. Seasonal fluctuation in soil moisture (%) in the climax forest (Cf); mixed forest (Mf); and the regenerating ecosystems — grassland (Gl); 6 year-old pine forest (Pf 6 yr); 40 year-old pine forest (Pf 40 yr).

Table 3
Soil characteristics in the mixed forest exposed to surface burn in the central Himalayas (±SE) (average mean values for 1 year; numbers followed by same letter are not significantly different ($P < 0.05$))

Days before and after fire	Sand (%)	Silt (%)	Clay (%)	Moisture (%)	pH	Organic matter (%)	PO_4^{-P} (mg/100g)	K (meq100/g)	Ca
−7	61.3[a]	22.3[a]	15.5[a]	39 ± 1.6[a]	6.2	3.2 ± 0.3[a]	1.5 ± 0.3[a]	0.2 ± 0.03[a]	1.76 ± 0.03[a]
+30	62.4[a]	23.8[a]	13.8[a]	36 ± 2.4[b]	6.1	2.0 ± 0.1[b]	2.2 ± 0.1[b]	0.53 ± 0.04[b]	3.0 ± 0.01[b]
60	62.2[a]	23.5[a]	13.2[a]	38 ± 1.7[b]	6.1	2.2 ± 0.1[b]	2.24 ± 0.1[b]	0.40 ± 0.03[b]	2.1 ± 0.21[b]
120	63.4[a]	23.7[a]	13.7[a]	44 ± 3.2[c]	6.1	2.2 ± 0.14[b]	2.6 ± 0.2[b]	0.25 ± 0.02[c]	1.1 ± 0.04[c]
360	63.4[a]	23.7[a]	13.4[a]	43 ± 3.1[c]	6.1	2.2 ± 0.13[b]	2.9 ± 0.1[b]	0.28 ± 0.02[c]	1.5 ± 0.03[c]

3.4. Interhabitat variation

Population density of *A. corticis* increased significantly ($H = 23.7$, $P < 0.01$) along the perturbation gradient in the 6 year-old pine forest with no significant change in the older pine forest (Table 5). *E. festivus* on the other hand had maximum population density in the grassland which declined significantly ($H = 9.78$, $P < 0.01$) in the secondary successional pine forests. *B. parvus*, *Drawida* sp., *E. waltonii* and *O. beatrix* were restricted to the 40 year-old pine forest alone (Table 5). *E. nanianus* ($H = 10.22$, $P < 0.05$) and *O. tyrtaeum* ($H = 14.84$, $P < 0.05$) had significantly higher population density in the climax forest than in the mixed forest. *O. tyrtaeum* had significantly higher population density ($H = 14.84$, $P < 0.05$) in the climax forest as compared to the grassland.

3.5. Seasonal variation

Except for *E. waltonii*, the density of *A. corticis*, ($H = 7.61$, $P < 0.05$), *B. parvus*, ($H = 7.98$, $P < 0.05$), *Drawida* sp. ($H = 7.40$, $P < 0.05$), *E. festivus*, ($H = 6.54$, $P < 0.05$), *O. beatrix*, ($H = 8.29$, $P < 0.05$), *O. tyrtaeum* ($H = 7.76$, $P < 0.05$) and *E. nanianus* ($H = 7.5$, $P < 0.05$) varied significantly seasonally (Table 6). Except for *A. corticis* which showed significant ($H = 7.26$, $P < 0.05$) increase in the population density during the rainy season in the grassland and during the winter months in both the 6 ($H = 8.75$, $P < 0.05$) and 40 year pine forests ($H = 4.94$, $P < 0.05$), all other species were more abundant during the rainy season at all the other sites (Table 6). The juveniles of all the species except *A. corticis* peaked in summer at all the sites except in the grassland, here the juveniles of all the species present; (*A. corticis*, *E. festivus*, *O. tyrtaeum*) peaked during the rainy season. (Fig. 4a–h). Unlike other species the juveniles of *A. corticis* had maximum population during either the rainy season (40 year-old pine) or in winter (6 year-old pine).

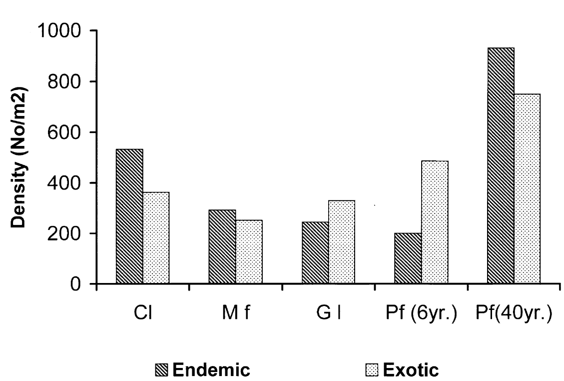

Fig. 3. Density of endemic versus exotic earthworms in the climax forest (Cf), subclimax mixed forest (Mf), grassland (Gl), 6 year-old pine forest (Pf 6 yr) and 40 year-old pine forest (Pf 40 yr).

3.6. Correlation coefficient

A significant positive correlation was seen between the size of earthworm populations and physical factors such as temperature, moisture and organic matter (Table 7). All the species except *B. parvus* showed either negative *A. corticis* ($P < 0.05$) or positive correlation ($P < 0.01$; $P < 0.05$) to soil temperature. *A. corticis*, *B. parvus*, *E. nanianus*, *E. waltonii* and *O. tyrtaeum* showed strong positive correlation ($P < 0.01$) to soil organic matter, whereas *Drawida* sp., *E. festivus* and *O. tyrtaeum* showed positive correlation to soil moisture ($P < 0.05$). *O. beatrix* was positively correlated to soil organic matter ($P < 0.05$).

3.7. Fire effect

The total density of earthworms was markedly affected due to post fire loss (Fig. 5). There was a significant decline ($F = 25.6$, $P < 0.01$) in the population density of both *E. nanianus* and *O. tyrtaeum* (adults and juveniles) 1 month after fire in the mixed forest. However the adult and juvenile density of *E. nanianus* increased significantly ($F = 9.26$, $P < 0.01$) 60 days after burn ($q = 3.26$, $P < 0.05$). Population dynamics of *O. tyrtaeum* increased significantly 120 days after burn ($q = 3.31$, $P < 0.05$), after which both the species showed decline in the number of individuals. *E. nanianus* however increased significantly ($q = 3.52$, $P < 0.01$) 240 days after fire, *O. tyrtaeum* showed no such trend. Juveniles population of both the species after showing an initial decline after 120 days of fire improved significantly ($F = 8.53$, $P < 0.05$) (*E. nanianus*; $q = 4.23$, $P < 0.05$) and (*O. tyrtaeum*; $q = 4.72$, $P < 0.05$) during later days. Population density of both the species in the fire-affected site was significantly lower ($F = 18.52$, $P < 0.01$) than the climax forest, mixed forest and 40 year-old pine forest (Table 4).

Table 4
Density (mean ind. m^{-2}) and biomass (mean g m^{-2}) of earthworms across different sampling sites in the central Himalayas (±SE)

Sites	Density (mean ind. of earthworms m^{-2})	Biomass mean values (g m^{-2})
Climax forest	189 ± 20[a]	6.25 ± 0.3[a]
Mixed forest	149 ± 11[a]	4.1 ± 0.2[b]
Mixed forest (exposed to fire)	60 ± 4[a]	1.33 ± 0.2[c]
Grassland	68 ± 4[a]	1.9 ± 0.1[c]
Pine forest (6 year-old)	65 ± 3[a]	1.40 ± 0.2[c]
Pine forest (40 year-old)	395 ± 20[b]	7.10 ± 0.4[d]

4. Discussion

The consequences of deforestation arise from site degradation through erosion (Zacher, 1982) which leads to strong modification of soil properties (Miragaya and Caceras, 1990). This in turn causes the depletion of soil macrofauna (Lavelle et al., 1994) Earthworm communities are more directly altered by these changes (Dotson and Kalisz, 1989; Bhaduria et al., 1997; Blanchart and Julka, 1997). The elimination of the climax forest and its replacement with the regenerating grassland followed by pine forests led to the disappearance of the endemic *E. nanianus*, but other endemic *E. festivus* and three exotic species namely *A. corticis*, *B. parvus* and *O. beatrix* appear; the exotic *O. tyrtaeum* is already present in the climax stage. The disappearance of the endemic *E. nanianus* and the appearance of more exotic species could probably be related to the changed edaphic conditions in the grassland and in the pine forest sites, as has also been reported by Fragoso and Fernandez (1994) for earthworm communities in the disturbed natural systems of the tropical east Mexico.

All the species in the present study except the lumbricid *B. parvus* and moniligastrid *Drawida* sp. are endogees, *B. parvus* is an epigeic species and *Drawida* sp. is anecic (J.M. Julka, personal communication). The higher density of endogeic soil feeders in both the natural and disturbed ecosystems suggests that this group is better adapted to the soil conditions here. The presence of epigeic *B. parvus* in the pine forest alone could be explained on the basis of thick litter layer accumulating in this forest (Klemmedson, 1992), but absent elsewhere due to faster decomposition rates. The high density of anecic *Drawida* sp. in the pine forest was probably due to their preference for sites where mineral soil is relatively free of organic matter deposits in the surface layers. The present study shows functional guild (endogees vs anecic) change under different vegetation types. Organic matter characteristics could be an important factor for this. Under perturbation gradient a general trend of decline in the total density and biomass of the endemic species and dominance by exotic was observed similar to other studies (Standen, 1988; Sanchez et al., 1997; Fragoso

Table 5
Interhabitat variation of earthworm species across different sampling sites in the central Himalayas. Density (D) ind m^{-2} $year^{-1}$, biomass (B) g m^{-2} $year^{-1}$ (numbers followed by the same letter are not significantly different ($P < 0.05$))

	A. corticis		*B. parvus*		*Drawida* sp.		*E. festivus*		*E. nanianus*		*E. waltonii*		*O. beatrix*		*O. tyrtaeum*	
	D	B	D	B	D	B	D	B	D	B	D	B	D	B	D	B
Climax forest	0	0	0	0	0	0	0	0	532 ± 48[a]	27	0	0	0	0	362[a]	25.4 ± 30
Mixed forest	0	0	0	0	0	0	0	0	292 ± 18[b]	18	0	0	0	0	261[b]	14.3 ± 18
Grass land	184 ± 15[a]	16	0	0	0	0	244 ± 15[a]	49	0	0	0	0	0	0	145[c]	9.6 ± 11
Pine forest (6 year-old)	486 ± 47[b]	5.58	0	0	0	0	200 ± 18[a]	45	0	0	0	0	0	0	0	0
Pine forest (40 year-old)	352 ± 30[b]	49	203 ± 18	0.5	625 ± 60	66	101 ± 8[b]	27	0	0	205 ± 15	14	195 ± 18	18	0	0

Table 6
Seasonal variation in earthworm population density across different sampling sites in central Himalayas (numbers followed by same letters are not significantly different ($P < 0.05$); * indicates the absence of the species, therefore the data for summer, rain and winter are not represented here

	A. corticis	*B. parvus*	*Drawida* sp.	*E. festivus*	*E. waltonii*	*E. nanianus*	*O. tyrtaeum*	*O. beatrix.*
Climax forest*	0	0	0	0			0	
Summer					93^{a}	63^{a}		
Rain					275^{b}	251^{b}		
Winter					164^{c}	48^{c}		
Mixed Forest	0	0	0	0	0			0
Summer					66^{a}	90^{a}		
Rain					175^{b}	134^{a}		
Winter					51^{c}	37^{b}		
Grassland		0	0		0	0		0
Summer	47^{a}			52^{a}			28^{a}	
Rain	98^{b}			160^{b}			95^{b}	
Winter	39^{c}			32^{c}			22^{c}	
Pine forest (5 year-old)		0	0		0	0	0	0
Summer	81^{a}		64^{a}					
Rain	164^{b}		123^{a}					
Winter	242^{b}		13^{b}					
Pine forest (40 year-old)						0	0	
Summer	24^{a}	29^{a}	140^{a}	13^{a}	90^{a}	45^{a}		
Rain	142^{b}	157^{b}	365^{b}	76^{b}	65^{a}	135^{b}		
Winter	187^{b}	17^{c}	120^{c}	12^{c}	50^{a}	15^{c}		

et al., 1997). Unlike other studies biological invasion here also occurs in climax forest. This is true in the present study as seen from the dominance of exotic species in disturbed ecosystems (Ramakrishnan, 1991). The latter observation agrees with that of Usher (1991) who observed a similar situation for higher animals in the nature reserve.

Seasonal increase in the adult population of all the earthworm species except *A. corticis* during the monsoon season at all the sites is more common and is due to favourable soil moisture and temperature conditions (Valle et al., 1997) and improved microbial activity (Fragoso and Lavelle, 1992). Winter peaking of *A. corticis* in both the 6 and 40 year-old pine forests is suggestive of its lower temperature tolerance. Similar results were reported earlier by us for this species in north-east India (Bhaduria and Ramakrishnan, 1991). The absence of other species in soil during winter may be due to the presence of frost, as earthworms are known to be killed by even moderate frost in soil (Hopp and Linder, 1947).

4.1. Fire effect

A significant decline in the total density of earthworms a month subsequent to fire could be more directly related to the post fire loss of moisture and organic matter (Ahlgren, 1974). The more prominent response of exotic *O. tyrtaeum* to the fire could probably be due to the presence of this species in greater abundance in the upper soil layers (Shakir and Dindal, 1997) and therefore being more directly affected by the intensity of the burn. The significant improvement in the population density of both the endemic *E. nanianus* and exotic *O. tyrtaeum* after 60 and 120 days was probably due to the migration of some individuals from the adjacent unburnt areas (Standen, 1988) and also due to improved soil moisture and nutrient conditions.

The mean density and biomass values observed in the present study for earthworm communities in the grassland (68 ind m^{-2}, 1.90 g m^{-2}) and in 6 year-old pine forest (65 ind m^{-2}, 1.4 g m^{-2}) are lower than that reported by Gruia (1969) for earthworm communities of grassland in Romania, and by us (Bhaduria and Ramakrishnan, 1991) for earthworm communities in the regenerating pine forest in north-east India. The total number of species present in the pine forest at our study site is also less than that reported by Bouche' (1978) for pine forest from France.

These differences may be related to poor soil fertility due to non-replenishment of nutrients lost during transition from natural forests to regenerating ecosystems (Ramakrishnan et al., 1993). The mean density and biomass values (395 ind m^{-2} and 7.10 g m^{-2}) of earthworms observed in the present study in the 40 year-old pine forest is more than that reported by Zajonc (1971) for earthworm communities in the temperate forest and by Bhaduria and Ramakrishnan (1991) in the Khasi pine forest in north-east India. This could be related to faster litter break down due to high insolation rate (Pandey and Singh, 1981). On the other hand the mean population density of 189 ind m^{-2} for the climax oak forest is similar to the population density of earthworms reported for the Oak forest in the temperate climate (Zajonc, 1971).

5. Conclusion

1. The destruction of the natural forests leads to the modification and the alteration of the soil conditions, which in

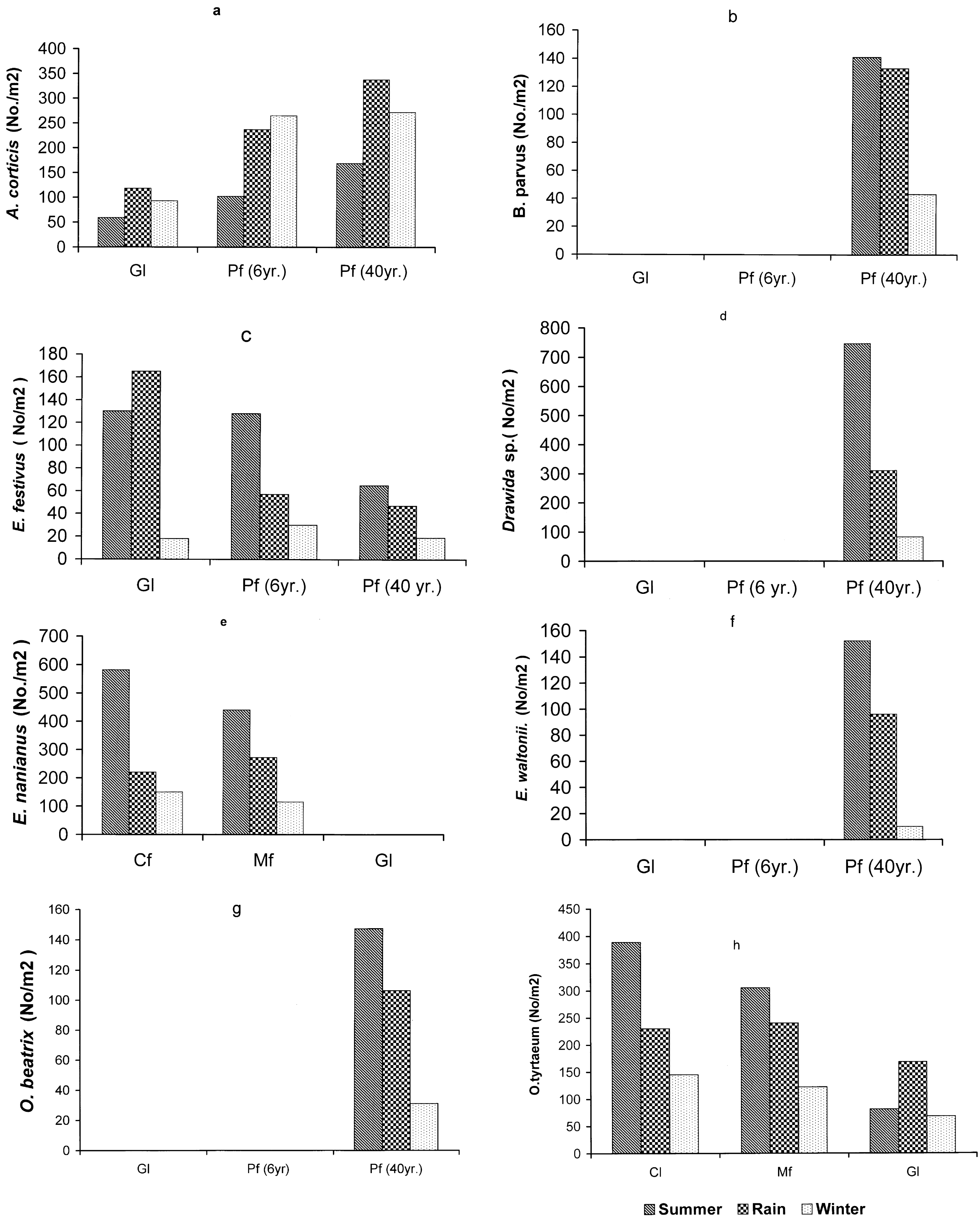

Fig. 4. Seasonal variation of juvenile population (number m^{-2}) in the natural and (a–h) regenerating ecosystem in the central Himalayas during summer, rain and winter.

Table 7
Correlation coefficient (*r*) for soil parameters and earthworm species in central Himalayas

Species	Moisture	Temperature	Organic matter
A. corticis	0.27	−0.81*	0.91**
B. parvus	0.64	0.63	0.91**
Drawida sp.	0.88*	0.81*	0.67
E. festivus	0.82*	0.88*	0.44
E. nanianus	−0.49	0.97**	0.90**
E. waltonii	−0.14	0.92*	0.99**
O. beatrix	0.60	0.92*	0.85*
O. tyrtaeum	0.96*	0.91*	0.91**

[a] * indicates $P < 0.05$;
[b] ** indicates $P < 0.01$.

turn results in the loss of some endemic species and in the appearance of other exotic /endemic species.

2. Functional guild (endogees vs anecic) changes under different vegetation type; organic matter characteristics could be an important factor for this.
3. Unlike other studies, biological invasions also occur in climax forest.
4. One suitable way to sustain the fertility of the soil would be to manipulate the existing earthworm fauna in the regenerating ecosystems by introducing a mixture of native and exotic earthworm species having wider ecological amplitude and good adaptation to low soil nutrient conditions/disturbances as were observed in the 40 year-old pine forest.

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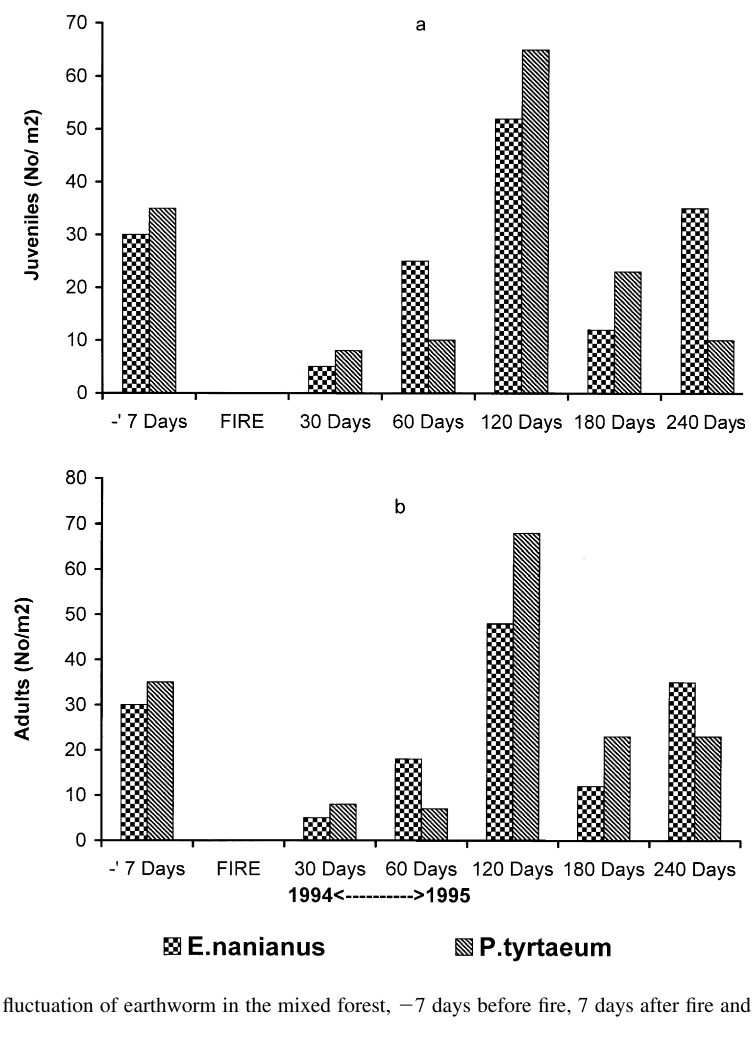

Fig. 5. Population fluctuation of earthworm in the mixed forest, −7 days before fire, 7 days after fire and 30 days after fire.

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