Community structure and recolonization by earthworms in rehabilitated ecosystems in Garhwal Himalayas, India

Abstract

Consequences of deforestation arise from site degradation leading to modification of soil properties which significantly affect both incidence and abundance of soil macro fauna. Earthworm communities are more directly altered by these changes. Endemic and exotic species co-existed in the study area following deforestation and intensive cultivation. That native species were dominant in the undisturbed sites and disturbance and degradations leads to invasion by the exotic species holds true in our study. The sites under study represented the degraded areas as none of the species reported from the present experimental plots were endemic to the region, all the species are either peregrine exotic or peregrine endemic to the area as many of the endemic species of this region probably exterminated during the last Quaternary Glaciation. The numbers of species present at our sites ranged between 2 to 5. The presence of litter layer and lower perturbation pressure resulted in the numerical dominance of Lennogaster pussilus in the Oak forest (OF) and the higher biomass of A. alexandri may be because of the larger size of the earthworm. B. parvus, L. pussilus and P. excavatus are litter-associated taxa which were more directly affected by OF clearance and the resulting decrease in available litter, thus explaining their disappearance in the changed ecosystems, however improved soil moisture and temperature as well as input of organic matter in rehabilitated agricultural land (RAL) could probably be favourable factor for decolonization and dominance of L. pussilus. A. alexandri had wider ecological amplitude occurring under all land use types as reported in our studies, conversion of two other land use types resulted in lower species diversity. Our results show that the abandoned agriculture land (AAL) remains closer to the AL(T) than to the forest because in these land use types the overall vegetation diversity remains low corresponding to a low diversification of the organic resources thus explaining the similarity between the earthworm communities in land use types. Seasonal rhythmic pattern was exhibited by all the species identified.

Keywords: deforestation, rehabilitation, earthworm community, functional guild, ecological categories, diversity index

Introduction

Himalaya is a vast and diverse mountain system. Agro forestry land use covering (20%) of geographical area of Indian Himalayas is distributed as patches in the matrix of forest covering (52%) area. Forest based tree- crop livestock integrated farming is the predominant traditional land use in central Himalayas.1 Hill agriculture appears to be key threat to soil biodiversity and ecosystem service due to huge amount of biomass extraction to sustain live stock and produce manure for managing soil fertility and also in terms of direct loss of forest cover due to agriculture land use. This problem has been further accentuated by extensive deforestation and unsustainable land use causing extensive degradation of the mountains. A pilot project was carried out to restore and rehabilitate the abandoned agriculture land site and degraded forest land site through agro forestry and forestry plantations.2 Land degradation implies a decline in the useable natural resource base and therefore loss of biodiversity and ecosystem functions. The interacting functions of soil organisms and the effects of human activities in managing land for agriculture and forestry affect soil health and quality.4 Soil faunal biodiversity is an important resource for environmental monitoring and natural resource management, changes in the variety and abundance of organisms in response to ecosystem disturbance, degradation and rehabilitation provide important management information.5 Soil management options can have dramatic effects upon soil invertebrate communities.6,7 Earthworm communities are the result of both interactions between species8 and sensitivity to ecological factors9 presence or absence of ground vegetation and changes in its composition are known to affect the composition of earthworm communities.10 This is the first systematic study where work is focused primarily on the ecological impact, the extent, causes and consequences of varying land degradation and subsequent rehabilitation strategies on earthworm fauna in Central Himalayas. Micro scale variability in earthworm community in traditional agro ecosystem will also be focused by comparing two types of micro sites viz below tree canopy from (1-3m) the bole and outside tree canopy (1-3m) from canopy margin. Changes in the vegetation cover (forest clearance, tree plantation) change the soil microclimate condition therefore present study also aims to analyze how these changes affected the functional guild of the earthworms.

Soil fauna vary through time as they have seasonal rhythms mainly regulated by temperature and moisture and thus constitute one of the important factors of changes in the species assemblage structure.11,12 Consequently, the way seasonal variations of earthworm communities impacted by land-use changes occurs as well as its impact on biomass
and density of earthworms have been examined across the sampling sites.

**Materials and methods**

**a. description of study site**

The study was carried out at Banswara village located at 1200m above mean sea level in Chamoli district, Garhwal (latitude 30°27’N and 79°5’E). The climate is typical monsoon, monthly minimum and maximum temperature varying in the range of 6-21°C and 18-35 °C, respectively, with an average annual rainfall of 1700mm. 80% of total rain fall is received during the monsoon period of July to September (Figure 1A) (Figure 1B). Soil moisture and temperature are as presented in Figure 2(A) & Figure 2(B). The soil is sandy loam to loamy sand in texture (Table 1) derived from felspathic quartz schists, quartz muscovite schists and quartz chlorite schist. To study the impact of changed land use practices on earthworms following land uses were identified in the village Banswara.

**Table 1** Soil characteristics of different land use/cover types in central Himalayan (±SE), India (Average mean values for one year. Values followed by different superscript letters are significantly (P < 0.05) different.

| Land use/cover                      | pH  | Bulk density (g cm⁻³) | Organic carbon (g kg⁻¹) | Total nitrogen (g kg⁻¹) |
|-------------------------------------|-----|-----------------------|-------------------------|-------------------------|
| Oak forest (OF)                     | 6.1⁺| 1.11⁺                 | 12.6⁺                   | 1.2⁺                    |
| Microhabitat below agro forestry tree patches AL(T) | 6.4⁺| 1.04⁺                 | 18.1⁺                   | 0.9⁺                    |
| Microhabitat without agro forestry tree patches (ALWT) | 6.2⁺| 1.10⁺                 | 13.2⁺                   | 1.9⁺                    |
| Abandoned agricultural land(AAL)    | 6.4⁺| 1.4⁺                  | 8.6⁺                    | 0.8⁺                    |
| Rehabilitated agricultural land (RAL) | 6.3⁺| 1.12⁺                 | 15.0⁺                   | 1.4⁺                    |
| Degraded forest land(DFL)           | 6.2⁺| 1.42⁺                 | 8.3⁺                    | 0.7⁺                    |
| Rehabilitated forest land (RFL)     | 5.8⁺| 1.14⁺                 | 12.4⁺                   | 1.7⁺                    |

**Figure 1 (A)** Monthly maximum and minimum atmospheric temperature for study area in Garhwal Himalayas during the study period from July 2008-2009.

**b. Old secondary forest (OF)**

The reserved forests are unmanaged old-growth sub tropical warm temperate forest dominated by Quercus samicarpifolia, Q.floribunda Cedrus.

**c. Traditional rainfed farming systems**

The farming system is characterized by settled rainfed organic agriculture on terraced slope with scattered multipurpose trees.
j. Experimental design

**Soil sampling:** In each land use type a plot of $40 \times 50m^2$ was demarcated for earthworms and for soil sampling, three composite soil samples were prepared in each experimental plot. Six $25cm \times 25cm \times 30cm$ deep soil monoliths were randomly sampled from each replicate plot at regular bimonthly intervals. Each monolith was subdivided into 0-10, 10-20, and 20-30cm blocks, the soil samples were air dried and sieved through a 2mm sieve. A representative of the sub-sample was stored for subsequent analysis.\textsuperscript{14} Soil temperatures were recorded weekly at 0-10 and 10-20cm depths; however, the values presented here are mean monthly values for 0-10 cm depth. Soil moisture was recorded every month at 0-10 and 10-20cm depths, but the values presented here are mean monthly values for 0-10cm depth and are expressed as % oven dry weight at 105 °C. Bulk density was estimated following standard methods.\textsuperscript{14} The analysis of soil texture was done using a hydrometer method,\textsuperscript{15} soil pH was measured as 1: 2.5 (soil: water) solution, and organic C through the.\textsuperscript{16} Soil N was analyzed using the semi-micro Kjeldahl method following the procedures described.\textsuperscript{17}

**Soil fauna sampling:** Earthworms were sampled using the soil biology and fertility methodology (17). On each site in a plot of $25cm \times 25cm$ earthworms were collected at regular bimonthly intervals over a period of 12 months, i.e. between June 2007 and June 2008. Earthworms were collected from 10 sampling points 5 m apart along a transect with a random origin, they were extracted by hand sorting after digging a trench up to 30 cm deep around a $25cm \times 25cm$ area at each sampling point to get a soil monolith. These soil monoliths were divided into three layers (0-10, 10-20, 20-30cm) and earthworms were extracted from each layer, they were then washed and preserved in 5% formalin for further identification.\textsuperscript{17}

**i. Statistical analysis of the data:** Statistical analysis was done following the biostatistical methods described in (18).

a) Significant differences in physicochemical characteristics of the soil across different sampling sites were carried out using one-way ANOVA.

b) Significant differences in the density and biomass of earthworm species across different sampling sites (interhabitat variations) were tested using non-parametric one-way ANOVA (F-test), and the New Mann Keul’s multiple range test.

c) Significant differences in functional guild changes of earthworm’s species in the same site and functional guild changes of earthworm species across different sampling sites were tested using non-parametric one-way ANOVA (F-test), and the New Mann Keul’s multiple range test.

d) Seasonal variations in total density and biomass of earthworm species in sampling sites were tested using the non-parametric Kruskal-Wallis test of variance and New Mann Keul’s multiple range test.

e) Diversity index was calculated as Simpsons Index of Diversity

$$D = 1 - \sum_{i=1}^{n} \frac{m_i(n_i - 1)}{N(N-1)}$$

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**Figure 2 (A)** Soil moisture (%) under different land use.

**Figure 2 (B)** Soil temperature (°C) under different land use.

f. Abandoned agriculture land (AAL)

Degraded abandoned agriculture land represented the agriculture terraces which had been abandoned due to poor soil fertility status, they were degraded and exposed to uncontrolled grazing.

g. Rehabilitated agriculture land (RAL)

The rehabilitated land site was the abandoned agriculture land site where the terraces were repaired and agricultural crops were grown providing supplemental irrigation and organic manure along with the planted trees following traditional farming practices. This site was protected from grazing and other human disturbances.

h. Degraded forest land (DFL)

Degraded Forest Land represented degraded community forest land which had negligible tree cover and was exposed to uncontrolled grazing. Soils on the degraded land were considerably eroded with respect to abandoned agriculture land.

i. Rehabilitated forest land (RFL)

The Rehabilitated forest site represented the plantation of trees on degraded community forest land which had more stressful environment as compared to the RAL. This site was protected from grazing and other human disturbances.
Table 2 Selected attributes of sampled earthworm species across different land use types in Garhwal Himalayas

| Species               | Color            | Length*(mm) | Diameter(mm)* | Family                   | Peregrine Species | Native region          | Ecological Catagories |
|-----------------------|------------------|-------------|---------------|--------------------------|-------------------|------------------------|-----------------------|
| Amynthas alexandri    | Dark Brown       | 180         | 8             | Megascoleidae            | Exotic            | S.E.Asia               | Endogeic              |
| Bimastos parvus       | Dark brown       | 70          | 2             | Lumbriciidae             | Exotic            | N.America              | Epigeic               |
| Drawida nepalensis    | Light whitish    | 140         | 7             | Moniligastridae          | Native            | Himalayas              | Endogeic/           |
|                       |                  |             |               | peregrine                |                   |                        | Aneic                 |
| Lennogaster pussilus  | Light brown      | 50          | 2             | Octochaetidae            | Native            | Himalayas              | Endogeic              |
| Metaphire anamala     | Dark brown       | 140         | 4             | Megascoleidae            | Exotic            | S.E.Asia               | Endogeic              |
| Metaphire birmanica   | Blackish brown  | 160         | 4             | Megascoleidae            | Exotic            | Burma                  | Endogeic              |
| Octochaetona Beatrix  | Light Pink       | 120         | 4             | Octochaetidae            | Native            | Himalayas              | Endogeic              |
| Perionyx excavatus    | dark violet /    | 76          | 3             | Megascoleidae            | Native            | Himalayas              | Epigeic               |
|                       | Purple           |             |               |                          |                   |                        |                       |

Measurements of largest individuals indicating the maximum achievable size

**d. Changes in earthworm species composition across different land use types**

Three peregrine exotics *Amynthas alexandri, Bimastos parvus, Metaphire anamala* and two peregrine native species *Lennogaster pussilus, Perionyx excavatus* were present in the OF. Conversion of the forest to agro ecosystems led to the change in the community structure with the loss of exotics *Bimastos parvus* and natives *Lennogaster pussilus, Perionyx excavatus* in AL (T) and AL (WT), but recolonisation by exotic *Metaphire birmanica, Octochaetona*...
beatrix and natives *Dravida nepalensis* occurred here. *M. anamola, M. birmanica* and *D nepalensis* were present in AAL, however rehabilitation of degraded ecosystems RAL resulted in loss of *M. birmanica* and recolonization by *L. pusillus* and *A. alexandri*. Only exotic *A. alexandri* and *M. birmanica* were present in DFL, but *A. alexandri, M. anamola* and *M. birmanica* were present in RFL (Figure 3). *B. parvus* and *P. excavatus* did not recolonize any rehabilitated ecosystems whereas *A. alexandri* and *M. anamola* were absent in RAL and DFL though they were present on all the other sites under study (Table 4).

Table 3 Effect of land use patterns on earthworm species richness across different land use types in Garhwal Himalayas

| Land Use Pattern                      | Species Number |
|---------------------------------------|----------------|
| Old secondary Forest OF               | 5              |
| Microhabitat below agro forestry tree patches AL(T) | 5 |
| Microhabitat without agro forestry tree patches AL(WT) | 5 |
| Abandoned Agriculture LandAAL         | 3              |
| Rehabilitated Agriculture LandRAL     | 4              |
| Degraded Forest Land DFL              | 2              |
| Rehabilitated Forest Land RFL         | 3              |

e. Total density and biomass of earthworm species across different land use types

Total density (*F*$_{0.05,6,14}^{}$ = 228.24) as well as biomass (*F*$_{0.05,6,14}^{}$ = 403.78) of earthworm’s varied significantly between different land use types due to changes in land use practices. Conversion of forest to agro ecosystem resulted in significantly higher density (*q*$_{0.05,14,4}^{}$ = 122.73) and biomass (*q*$_{0.05,14,4}^{}$ = 109 values) in AL(T). Density (*q*$_{0.05,14,4}^{}$ = 114) and biomass of earthworms (*q*$_{0.05,14,4}^{}$ = 112) also increased significantly in rehabilitated ecosystems RAL and RFL when compared to AAL and DFL (Table 5).

f. Endemic and exotics earthworm species

The density and biomass of exotic peregrine earthworm species varied significantly between different sites (Figure 4A) (Figure 4B). These values were significantly higher in AL (T) followed by AL (WT) (*q*$_{0.05,12,6}^{}$ = 102) and did not vary significantly between RAL, DFL and AAL. The biomass values of exotic species also did not vary significantly between OF and RFL. The density (*F*$_{0.05,6,14}^{}$ = 211) and biomass (*F*$_{0.05,6,14}^{}$ = 248) of endemic peregrine species also varied significantly between different sites and were significantly higher in AL(T) as compared to other sites. The biomass values of endemic species did not vary significantly between OF and AAL.

Within the same sites the density of exotic and endemic peregrine earthworm species did not vary significantly in OF, but exotic species had higher biomass (*t*$_{12,05,4}^{}$ = 7.5) as compared to endemics species. Exotic earthworm species were significantly more abundant (*t*$_{12,05,4}^{}$ = 57.32) with higher biomass (*t*$_{12,05,4}^{}$ = 25.5) values in AL(T) than endemic species. In AL (WT) and in AAL endemic species were more abundant numerically and had significantly higher biomass value than exotics species. Endemic species had significantly higher abundance in RAL (*t*$_{12,05,4}^{}$ = 5.75) as compared to exotic species but biomass values of exotic and endemic earthworm species did not vary significantly in here. Endemic species were absent in DFL and RFL.

g. Functional guild changes in earthworm communities

Functional guild diversity varied under different land use types (Figure 5A) (Figure 5B), all the three functional categories were present in RAL. Anecics were absent in OF and AAL, in AL (T), AL (WT), DFL and RFL epigeic species were absent, where as in AAL only endogeics species were present. Epigeic were significantly more abundant (*F*$_{0.05,2,6}^{}$ = 12.23) with higher biomass values (*F*$_{0.05,2,6}^{}$ = 7.54) in OF. Both endogeics and anecics earthworm species were significantly more abundant (*F*$_{0.05,2,6}^{}$ = 58.54) and had higher biomass values (*F*$_{0.05,2,6}^{}$ = 42.63) at AL(T) compared to all other sites.

Within the same site, numerically epigeics formed the dominant (*F*$_{0.05,2,6}^{}$ = 37.19) functional group under OF and in RAL (*F*$_{0.05,2,6}^{}$ = 18.54), whereas endogeic were dominant under AAL(T) (*F*$_{0.05,2,6}^{}$ = 11.7), AL(WT) (*F*$_{0.05,2,6}^{}$ = 28) and RFL(*F*$_{0.05,2,6}^{}$ = 7.54), in AAL they were the...
only functional group present. Endogeics had significantly higher ($F_{0.05,2,6} = 19.4$) biomass in OF and RAL when compared to epigeic and anecics. Anecics had lower abundance and biomass compared to other functional groups within the same sites.

The species had significantly higher population density ($q_{0.05,12,6} = 7.54$) and biomass ($q_{0.05,12,6} = 8$) during Sep at all sites except in AL(WT) and where it had higher biomass ($q_{0.05,12,6} = 7.34$) during July and in RFL where species showed a minor increase in population density during January. B. parvus was present only in the oak forest and did not show any significant variation seasonally in density as well as biomass values.

![Figure 3](image3.png)

**Figure 3** Changes in earthworm species composition across different land use types in Garhwal Himalayas.

![Figure 4 (A)](image4a.png)

**Figure 4 (A)** Abundance of exotics/native earthworm species under different land use changes.

**h. Seasonal variation for earthworm communities**

Seasonal variation for different earthworm species abundance and biomass (Figure 6 (A-H)).

- **A. Alexandri** All the species showed significant seasonal variation. The density and biomass varied significantly seasonally in OF ($F_{0.05,5,12} = 124.6$), AL(T) ($F_{0.05,5,12} = 133.8$), AL(WT) ($F_{0.05,5,12} = 23.04$) and RFL ($F_{0.05,5,12} = 8$). It did not vary significantly in RAL and DFL.

![Figure 5 (A)](image5a.png)

**Figure 5 (A)** Functional categories of earthworms under different land use types.

![Figure 5 (B)](image5b.png)

**Figure 5 (B)** Functional categories of earthworms under different land use types.

**Figure 4 (B)** Biomass of exotics/native earthworm species under different land use changes.
Figure 6 (A-H) Seasonal variation of earthworms species abundance under different land use types.
Community structure and recolonization by earthworms in rehabilitated ecosystems in garhwal himalayas, India

i. D. nepalensis: Density and biomass varied significantly seasonally in AL(T) \( F_{(2,85.5,12)} = 83.83 \), AL(WT) \( F_{(2,85.5,12)} = 437.33 \), AAL \( F_{(2,85.5,12)} = 16.6 \) and in RAL \( F_{(2,85.5,12)} = 7.53 \). The species showed higher population density \( q_{(3,0.05,12,6)} = 10.56 \) and biomass \( q_{(3,0.05,12,6)} = 9.67 \) in Sep in AL(T) \( q_{(2,0.05,12,6)} = 5.87 \), AL(WT) \( q_{(2,0.05,12,6)} = 7.22 \) and AAL \( q_{(2,0.05,12,6)} = 7.65 \), however it also showed a minor peak of growth during March in AL(T). In RAL it had higher density \( q_{(2,0.05,12,6)} = 12.78 \) and biomass \( q_{(3,0.05,12,6)} = 6.58 \) in July and a minor increase in population was observed in November, though the difference in abundance of the species did not vary significantly between Sep and November.

ii. M. anamola: Population abundance varied significantly seasonally in AL(T) \( F_{(2,85.5,12)} = 130.5 \) and AL(WT) \( F_{(2,85.5,12)} = 14.93 \). At these sites population improved significantly during the period of September, however the biomass of these species was higher during November in AL(T) \( q_{(2,0.05,12,6)} = 6.65 \), AL(WT) \( q_{(2,0.05,12,6)} = 7.43 \). Population abundance of M. anamola did not show significant variation seasonally in AAL, RAL and RFL but the biomass of these species was higher during September in AAL \( q_{(2,0.05,12,6)} = 5.76 \), RAL \( q_{(2,0.05,12,6)} = 6.22 \) and RFL \( q_{(2,0.05,12,6)} = 5.49 \) and declined subsequently.

iii. M. birmanica: Population abundance \( F_{(2,85.5,12)} = 62.32 \)and biomass \( F_{(2,85.5,12)} = 84.45 \) of M. birmanica varied significantly seasonally and showed increased population density \( q_{(2,0.05,12,6)} = 9.02 \) during September in AL(T) with decline subsequently. Population abundance did not show seasonal variation in other sites. It showed higher biomass during Sep in AL(T) \( q_{(2,0.05,12,6)} = 11.23 \), AL(WT) \( q_{(2,0.05,12,6)} = 6.65 \) and RAL \( q_{(2,0.05,12,6)} = 10.56 \), but in RFL it showed biomass during November \( q_{(2,0.05,12,6)} = 12.67 \).

iv. L. pussilus: Population abundance varied significantly \( F_{(2,85.5,12)} = 206 \) seasonally in OF and RAL and it had higher density \( q_{(4,0.05,12,6)} = 112.67 \) and biomass \( q_{(4,0.05,12,6)} = 18.43 \) during September in both these sites.

v. O. beatrice: Population abundance varied significantly \( F_{(2,85.5,12)} = 346 \) seasonally in AL(WT) and it had higher density \( q_{(3,0.05,12,6)} = 13.58 \) and biomass \( q_{(3,0.05,12,6)} = 15.43 \) values during September.

vi. P. excavatus: Population abundance of P. excavatus also varied significantly \( F_{(2,85.5,12)} = 58.40 \) seasonally and had higher density \( q_{(3,0.05,12,6)} = 14.54 \) and biomass \( q_{(4,0.05,12,6)} = 16.55 \) during the September in OF.

i. Diversity index for earthworm communities between different land use types

The Simpsons Diversity Index within the earthworm communities under different land use types was lowest in AAL and maximum in OF. The diversity index was similar between OF and RAL. Within the agro ecosystem the diversity Index was lower in AL (WT) compared to AL (T), but rehabilitation of degraded ecosystem led to improved diversity Index in RAL and RFL (Figure 7).

j. Earthworm species dominance (%)(a) abundance (b) biomass (values in parenthesis) within the same land use types

L. pussilus was dominant numerically in OF but A. alexandri had higher biomass values as compared to other species. At AL(T), AL(WT) and AAL D. nepalensis was dominant numerically as well having a higher biomass percentage, L. pussilus was dominant numerically at RAL but D. nepalensis had higher biomass here. A. alexandri was dominant numerically as well as higher biomass values in DFL and RFL but M. anamola had higher biomass percentage at the RFL site (Table 6).

Figure 7 Earthworm species diversity index under different land use changes.

| Table 6 Earthworm species dominance (%) Abundance & Biomass (Values in parenthesis) within the same land use types in Garhwal Himalayas |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| OF              | AL(T)           | AL (WT)         | AAL             | RAL             | DFL             | RFL             |
| A. alexandri   | 16.5            | 11.84           | 4.57            | 0               | 12              | *57.15          | *36             |
| (*39)           | (12.7)          | (6)             | (19)            | (*57)           | (29)            |
| B. parvus      | 7.22            | 0               | 0               | 0               | 0               | 0               |
| (3.1)           | (0)             | (0)             | (0)             | (0)             | (0)             |
| D. nepalensis  | 0               | *40             | *44.87          | 61              | 21              | 0               |
| (*38)           | (*53)           | (*56)           | (*41)           | 0               | 0               |
| M. anamola     | 26.8            | 16.9            | 5.71            | 12              | 8               | 0               |
| (32)            | (16)            | (6)             | (24)            | (16)            | (0)             | (*39)           |
| M. birmanica   | 0               | 30.71           | 8.37            | 27              | 0               | 42.86           |
| (0.3)           | (11)            | (20)            | (21)            | (16)            | (0)             | (32)            |
| *32.99          | (0)             | 0               | 0               | *59             | 0               | 0               |
| *32.99          | (0)             | (0)             | (0)             | (0)             | (0)             | (0)             |
| L. pussilus    | (31)            | (0)             | (0)             | (0)             | (0)             | (0)             |
| (10.1)          | (0)             | (0)             | (0)             | (0)             | (0)             | (0)             |

k. Morisita’s index of similarity for earthworm communities between different land use types

Morrisitas index of similarity indicated that the earthworm community in AL (T) was more similar to AAL than AL (WT). Rehabilitation of degraded agro ecosystem showed that the community structure of RAL was more similar to the OF where as community structure between RFL and DFL were closer to one another (Table 7).
Table 7: Morisita’s index of similarity for earthworm communities between different land use types

|       | OF | AL(T) | AL(WT) | AAL | RAL | DFL | RFL |
|-------|----|-------|--------|-----|-----|-----|-----|
| OF    | 0  | 0.248 | 0.08   | 0.088| 0.72| 0.252| 0.51|
| AL(T) | I  | 0.688 | 0.91   | 0.32 | 0.491| 0.625|     |
| AL(WT)| I  | 0.75  | 0.273  | 0.181| 0.15 |     |     |
| AAL   | I  | 0.315 | 0.24   | 0.311|     |     |     |
| RAL   | I  | 0.142 | 0.175  |     |     |     |     |
| DFL   | I  | 0.81  |        |     |     |     |     |
| RFL   | I  |        |        |     |     |     |     |

Table 8: Correlation coefficient(r) for soil moisture (%); temperature (°C) and earthworm species abundance in Garhwal Himalaya

|        | A. alexandri | B. parvus | D. nepalensis | M. anamola | M. birmanica | L. pessilus | O. beatrix | P. excavatus |
|-------|--------------|-----------|----------------|------------|--------------|-------------|------------|-------------|
| M (%) | -0.03        | 0.30      | **0.96**      | ***0.95**  | A            | A           | 0.34       | 0.41        | *0.89       | *0.87       | *0.92       | *0.9       |
| T (°C) | *0.88       | *0.84     | **0.97**      | *0.95      | A            | A           | 0.55       | **0.98**    | *0.96       | A           | 0.62       | **0.92**   |
| AL(T) | *0.88       | *0.87     |                |            |              |             |            |             |             |             |            |            |
| AL(WT) | *0.85       | *0.87     | **0.99**      | *0.87      | 0.56         | 0.18        | 0.18       | 0.58        |             |             |            |            |
| AAL   | A           | A         | A              | **0.96**   | A            | A           | A          | A           | A           |            |            |
| RAL   | **0.98**    | *0.95     | *0.88          | A          | 0.83         | **0.98**    | 0.96       | A           | *0.85       | *0.89       | A           |            |
| DFL   | **0.97**    | *0.96     | A              | A          | A            | A           | A          | A           | A           | A           |            |            |
| RFL   | 0.31        | 0.27      | A              | A          | A            | A           | A          | A           | A           | A           | A           | A          |

*indicates P < 0.05. **indicates P < 0.01

Discussion

Consequences of deforestation arise from site degradation leading to strong modification of soil properties. This in turn can significantly affect both incidence and abundance of soil macro fauna. Earthworm communities are more directly altered by these changes. Endemic and exotic species co-existed in the study area following deforestation and disturbance. The elimination of old secondary forest and its replacement with agroecosystem also led to changes in species composition due to altered habitat with peregrine exotics M. birmanica, O. beatrix and peregrine natives D. nepalensis replacing peregrine exotics B. parvus and natives L. pessilus and P. excavatus in AL (T) and in AL (WT), similar results have also been shown through the studies. Extreme degradation of agriculture ecosystems due to faulty land management practices probably led to the loss of peregrine exotics A. alexandri, M. anamola and O. beatrix in AAL as has also been shown through the studies in land use types in Northern

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Kwazulu Natal South Africa. The disappearance of peregrine exotics A. alexandri and peregrine natives L. pussilus in RAL could probably be related to changed vegetation and edaphic conditions in RAL as has also been reported by Fragoso C et al.13 For earthworm communities in disturbed natural systems of tropical East Mexico and rehabilitation of RAL through various trees and crops probably led to invasion of peregrine exotic M. birmanica and M. anamola in these areas. Higher level of degradation leading to replacement of OF to degraded forest land led to loss of exotic B. parvus, M. anamola and natives L. pussilus, P. excavatus. Resistance to invasion by endemic species in DFL and RFL could be a function of physical and chemical characteristics of the site24 and the unsuitability of the habitat probably impeded the invasion by the endemic species in the ecosystems under study.25 The absence of original species composition in RAL and DFL as compared to OF even after a period of 15 to 20 years suggest that this is probably still the secondary successional stage over a time scale of 15 years.26

m. Total density and biomass

Land-use alteration generally results in changes of vegetation and these changes have a significant effect on soil macrofauna.1 Study done by19 in South Africa showed most land uses supported between five and seven species, but the number of species present at our sites were lower ranging between 2 to 5. The statement that earthworm populations in cultivated lands are generally lower than those found in undisturbed habitats30 does not hold true in our studies, the traditional agriculture probably have a positive effect on earthworms through improved food supply as a result of recycling of crop residues, and organic manure added to the soil resulting in loosening of soil to an extent that facilitates burrowing by earthworms.30 This also explains the increased abundance and biomass of earthworm in AL(WT) as compared to OF. With lower bulk density and higher carbon percentage, coupled with reduced disturbance this effect was more prominent in AL(T). In RAL the supplemental irrigation and organic manure along with the planted trees following traditional farming practices favored the increase in total earthworm density as well as biomass. The smaller community under AAL and DFL than OF is attributable to loss of species when the land was cleared and cultivated. More stress full environment in DFL as compared to AAL due to heavy grazing pressure and lower soil moisture2 probably caused significant difference in the density and biomass of earthworm between AAL and DFL. In the present study the numerical abundance of earthworms in OF is lower compared to similar land use type from Kumaon Himalayas. Besides variation in ecological characteristics probably the land use history of the ecosystems contributes to this variation, the sub-temperate climate in the study area and the relatively lower inputs of organic matter apparently provide poor conditions for earthworm populations to flourish. As a result total numbers were very low ranging from 8 to 348 m-2 as compared to high ranging from 250 to 2400 m-2 in Northern Kwazulu Natal South Africa.19 Earthworm biomass showed broadly similar trends with land use to those for abundance.

n. Interhabitat variation

Interactions between species and sensitivity to ecological factors, presence or absence of and changes in ground vegetation composition are known to affect the composition of earthworm communities through changes in the distribution and the quality of litter, soil climate, and water availability. The presence of litter layer and lower perturbation pressure probably explains the numerical dominance of L. pussilus in the OF and the higher biomass of A. alexandri could be due to the larger size of the earthworm. B. parvus, L. pussilus and P. excavatus are litter-associated taxa which were more directly affected by OF clearance and the resulting decrease in available litter, thus explaining their disappearance in the changed ecosystems, however improved soil moisture and temperature as well as input of organic matter in RAL could probably be favorable factor for decolonization and dominance of L. pussilus. A. alexandri has wider ecological amplitude occurring under all land use types. Major determinants of earthworm communities’ structure in an agro ecosystem are the quantity and quality of organic matter added, soil type and the perturbation pressure.25 With better adaptation and tolerance to various disturbances during agro forestry practices. D. nepalensis was confined only to agroecosystems and was numerically dominant during cropping in AL (WT), in AL (T) and also in AAL. M. anamola was more directly affected due to perturbation pressure and soil degradation caused through conversion of forest to agro ecosystem.25 The increased population density of A. alexandri, D. nepalensis and M. anamola in AL (T) as compared to AL(WT) is likely due to amelioration of the surface soil temperature and moisture by litter, and tree leaf biomass incorporated into the soil. The lower density and biomass of D. nepalensis under AL(WT) as compared to AL(T) could be the result of perturbations caused to the soil due to agricultural practices besides here the decline in D. nepalensis abundance in AAL and its subsequent increase in RAL could probably be because of lower soil bulk density and higher carbon percentage here and also because this land use categories maintain a year round canopy and litter layer.2 The lower biomass of A. alexandri in RFL may be due to species specific competition between M. anamola and A. alexandri as both occupy the same niche. Most changes in the distribution of earthworm species are explained by microclimate variations in soils thus low soil water content, high soil temperature, and incident radiation probably resulted in the decline in abundance and biomass of M. birmanica. In AAL and DFL as has also been shown through the studies of26 in the land use systems in eastern Zambia however improvement of soil conditions through the rehabilitation of forested land led to recurrence of this species. The traditional farming practices under rain fed conditions probably favored the population of O. beatrix species and thus explains its presence in agro ecosystem only.

o. Similarity index

Our results show that the AAL remains closer to the AL (T) than to the forest, because in these land use types the overall vegetation diversity remains low corresponding to a low diversification of the organic resources thus explaining the similarity between the communities in land use types.25 The shift in plant composition in RAL resulted in a shift in organic input from a below ground pattern in AAL to an above and below ground input here. This increase in above ground litter input created habitat in the plantation floor similar to that of OF and this probably was the reason for community structure of RAL to similar to the OF as has also been shown through the studies done by workers13 who suggested that the community structure under tree plantations is typically similar to that under native forest. The rehabilitation of DFL only caused an increase in the abundance of earthworm species in RFL resulting in community structure of RFL and DFL being closer to one another.

p. Functional guild

The size and species composition of earthworm communities are important because any shifts in earthworm community may result in significant changes in soil properties, epigeic earthworms, which

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usually inhabit upper soil and litter layers, may be more exposed than endogeic and anecic species that live primarily in subsurface soil. The conversion of OF to agro ecosystems led to a shift in functional categories from epigeic dominated species community to endogeic and anecic dominated composition, as has also been shown through studies of where the loss of the surface litter layer when rain forest is converted to agricultural use resulted in a dramatic decrease in the number of epigeic and anecic species and increase in numbers by endogeics species. The epigeics are litter-associated and thus were more directly affected by forest clearance and the resulting decrease in available litter leading to their loss in all the experimental plots except in RAL where with the deposition of litter the epigeics recurred. P. excavates and B. parvus species cannot therefore survive in areas with less plant cover and litter availability and thus can be said to be bioindicator of land use that leads to these conditions. Anecic species need plant litter and specific microclimatic conditions in the soil thus the cropping activities with the removal of litter layer in AL (WT) prior to rice crop plantation resulted in decline of the anecics here. The increase in above ground litter input in AL (T) created microhabitat in the below canopy promoting the colonization of both endogeics and anecic species. Further anecics are generally sparse in tropical environments, the experimental studies in the rehabilitated plots by Butt KR et al. have shown anecics to be slow colonizers in the reclaimed sites and this could probably explain their lower density in the RAL and RFL. Endogeics being geophagus, their predominance in the AL (T), AL (WT) AAL and RAL could be because probably these habitats offered favorable base resource to the species which migrated from the surrounding plots to colonize and establish themselves in the new habitats. Dominance of endogeics in the disturbed habitats has also been shown through the studies of As a consequence, while epigeics does not significantly alter the soil surface, casts produced by endogeics highly modify soil surface properties.

q. Diversity index

As reported in our studies conversion of OF to other land use types resulted in lower species diversity, similar result were also obtained through the studies of where conversion of forests to pastures resulted in decline of earthworm species diversity. Rehabilitation of these ecosystems in RAL and RFL resulted in improved diversity index of the community structure, this increase in earthworm diversity could probably be related to a shift in organic input from a below ground pattern in AAL and DFL to an above and below ground input in RAL and RFL. The lower overall vegetation diversity in AAL probably corresponded to a very low diversification of the organic resources and this can explain a lower diversity of earthworms here as low resource diversity leads to impoverished species diversity.

r. Seasonal variation

Seasonal variation has been shown for macro faunal assemblages for temperate, for tropical and for semiarid region, similar seasonal rhythm for all the species was also observed in our studies. Earthworm exhibit temporal variabiliy, population density and biomass as well as the average depth of an organisms’ position in the soil profile is greatly affected by soil temperature and humidity, such seasonal rhythms of soil macro fauna were clearly expressed in the experimental land use type. Large differences in the number of earthworms were found in the different seasons highest catches were in monsoon, with lower numbers in winter and a large reduction in summer. Many soil organisms display strong seasonality in their life cycles. Few earthworms were found in summer compared to monsoon months , suggesting that all species hatch during early monsoon grow to adulthood over the monsoon period and decline in winter months, the lower mean catches in summer can be attributed to a response to drought by some species, the increase in the population density and the biomass of all earthworm species during the rainy season could be attributed to better soil moisture and temperature condition which favored the growth and maturity of earthworms. Seasonal temperature variations commonly induce vertical movements of earthworms in as soil profile as was also observed in D. nepalensis in the AL(T) which retreated to deeper soil to escape lower temperature and drought by diapausing during winter.

Conclusion

This study has shown that earthworm communities are directly affected by alteration of land use patterns. The numbers of species present at our sites ranged between 2 to 5. All the ecological categories such as endemic and exotics co-existed in the study area following deforestation and intensive cultivation, and the disturbance and degradations led to invasion by the exotic species and the native species dominated the undisturbed sites. The sites under study represented the degraded areas and none of the species reported from the present experimental plots were endemic to the region, all the species are either peregrine exotic or peregrine endemic to the area, as many of the endemic species of this region probably exterminated during the last Quaternary Glaciation. The presence of litter layer and lower perturbation pressure resulted in the numerical dominance of epigeic L. pussilus in the Oak forest (OF) and the higher biomass of A. alexandri may be because of the larger size of the earthworm. Litter-associated taxa (Epigeics) such as B. parvus, L. pussilus and P. excavates are more directly affected by primary OF clearance and the resulting decrease in available litter, thus explaining their disappearance in the changed ecosystems. However improved soil moisture and temperature as well as input of organic matter in rehabilitated agricultural land (RAL) were probably one of the favorable factor for decolonization and dominance of epigeic L. pussilus. Endogeic species probably are not much affected by deforestation and degradation process and therefore A. alexandri had a wider ecological amplitude occurring under all land use types, however conversion of primary OF to other land use types resulted in lower species diversity. Our results show that the earthworm diversity in abandoned agriculture land (AAL) remains closer to the AL(T) than to the forest because in these land use types the overall vegetation diversity remains low corresponding to a low diversification of the organic resources thus explaining the similarity between the earthworm communities in land use types. All the species identified at study sites showed seasonal rhythmic pattern.

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Conflicts of interest

There is no financial or any conflict of interest exists.
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