IMPACT OF LAND USE CHANGE AND HABITAT DEGRADATION ON BIOGEOGRAPHICAL AND FUNCTIONAL DIVERSITY OF EARTHWORMS IN RAEBARELI, UTTAR PRADESH INDIA

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Abstract: In the semi-arid region of central Uttar Pradesh, anthropogenic activities have caused forests converted to agricultural land for crop production and then left as fallow for soil fertility regeneration. Overgrazing, loss of vegetation cover, surface soil layer, cause depletion of soil fertility and soil faunal diversity. The reclamation of degraded agroecosystems using biological means has caused it to change from externally regulated to an internally regulated sustainable ecosystem. Earthworms are a good indicator of change occurring in soil health due to anthropogenic modification in land management. Earthworm species richness was similar along a fertility gradient linked to the litter, organic matter, and better soil moisture and temperature condition. The ecological distribution of earthworm species was impacted, due to land management changes, with exotic species *M.formosae* dominating when the forest transmuted to agroecosystem. Compared to exotics, endemic species are more sensitive to changes in land management practices. But exotic *Metaphire formosae* could not invade into fallows subsequent to conversion of an agroecosystem. Colonization of endemic species in fallows and reclaimed agroecosystem had better adaptation to the native vegetation. Thus endemic species offered biotic resistance and preventing the invasion by exotic species there. A marked change in community shift from anecic dominated to endogeic dominated occurred when the agroecosystem was converted to fallows and then reclaimed sites. Perturbation pressure under all the sites prevented an invasion by epigeic species. Under all the sites, seasonal variation and oscillation in earthworm populations occurred, with variation in soil temperature, moisture, and rainfall. The crop cycle in the agroecosystem also affects the earthworm species abundance and distribution. Reserved forest and reclaimed agroecosystem with a higher Simpson diversity index have heterogeneous biodiversity and are a stable ecosystem, fallow, has a lower diversity index, and represents an ecosystem that is vulnerable to environmental stress.

IndexTerms- **Land use, earthworms, diversity, exotics, endemics, functional guild**

I.INTRODUCTION

Over the last, one-century anthropogenic activities have caused forests converted to agricultural land for crop production, with some of them left as follows due to intensification. Subsequently, due to overgrazing and lack of vegetation cover, the land has degraded with the loss of the surface soil layer leading to depletion of soil fertility and soil faunal diversity. Soil biodiversity plays a crucial role in land management and management of above-ground diversity [1]. Soil macro-fauna are the players in managing below-diversity, with earthworms contributing to about 80% of soil faunal biomass [2]. Earthworms improve soil productivity, soil health and manage soil physicochemical properties through their functional attributes [3]. Degradation of the ecosystem is related to loss of soil faunal diversity but, this aspect of soil study has been least paid attention too [4]. Neglect of soil faunal biodiversity results in lowering ecosystem resilience and subsequent degradation [5]. Land management practices from forest conversion to the agriculture ecosystem and then fallow often modify earthworm communities both at geographical and functional levels [6]. Analytical studies about changes in earthworm communities due to changed land management practices are limited. Thus, the present study aimed to determine the effect of changed land management practices due to anthropogenic activities on the community structure of earthworms both at the biogeographical and functional level. With this aim, the study is done in the semi-arid region of central Uttar Pradesh in the Raebareli district to identify the most suitable species that could subsequently use as bioindicators for land management types.

II. RESEARCH METHODOLOGY

2.1 Area and Topography

The study sites represent the semi-arid region of the Raebareli district in Indogangetic planes, (latitude 25º49' and 26º36' North and longitude 80º41' and 81º34' East) in Uttar Pradesh, which is at an altitude between 8 to 10 m with fairly flat land and slope from NW to SE, winters are mild (Nov-Feb) with a minimum of 7.8ºC and maximum of 25ºC. Summer is hot and dry (March–June) with a maximum of 42.2ºC and a minimum of 38ºC (Fig 1).

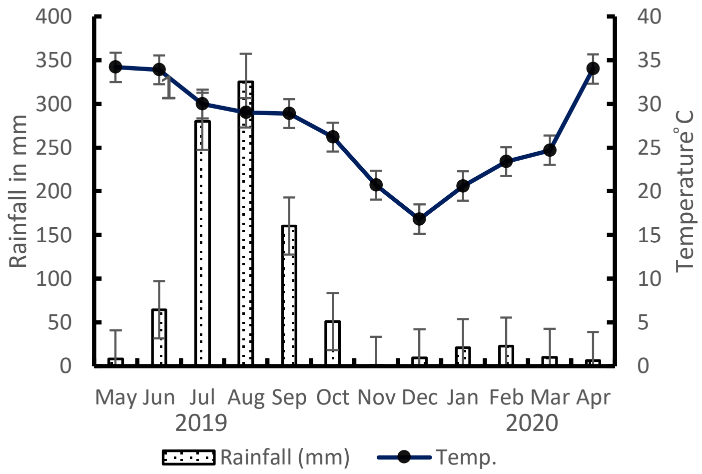


Fig. 1 Monthly fluctuations in average annual rainfall (mm) and temperature (ºC) in the Raebareli district of Uttar Pradesh.

The study site is incorporated under agroecoregion 4 representing a hot semi-arid ecosystem having alluvial soil deposits formed by the rivers comprising tributaries of Ganga and Gomti [7]. Soils are sandy loam to loam, dark grey with a texture that is coarse and has an inherently lower concentration of nitrogen and carbon. Soils are poorly drained and have low to poor permeability and high sodicity problems. Based on anthropogenic activities five different land management sites were identified, Reserved forest (RF), Intensive agroecosystem (AL), Fallow (FL), Degraded agroecosystem (DL) and Reclaimed agroecosystem (RL), of these five sites reserved forest (RF), was considered to be controlled as it was protected by the forest department as reserved forest and protected against anthropogenic activities, other details are mentioned in Table1.

Table 1: Description of study sites impacted by land use change and habitat degradation in Raebareli, Uttar Pradesh

Ecoregion	Indogangetic plane
Location	Raebareli (Uttar Pradesh)
Elevation	8-10 m (asl)
Reserve forest (RF)	Rajapur Forest is a protected forest by the state forest department,with very little human interference, the vegetation in forest included *Madhuca indica*, *Eucalyptus hybrid, Sepindus emarginatus vahl, Cordia dichotoma forest.f ,Prosopis julifolra , Annona Squamosa , Dalbergia sissoo , Morus laba , Tectona grandis , Albizzia procera , Strablus asperlour, Moringa oleifera , Shorea robusta gaern, Grevillea robusta ,Terminalia chebula , Acacia auriculiformis, Parkinsoina aculeate, Cuscutta reflexa , Trinospora malabarica , Dendrocalamus strictus ,Sporobolus marginatus , Chrysopogan fulvus.*
Intensive Agriculture (AL)	Mechanized agriculture, two crops/year with rice –wheat rotation. Small amount of organic manure is added during rice cultivation, during second crop (Wheat) there is addition of large quantity of chemical fertilizer and pesticide.
Fallow (FL)	Agriculture Land left abandoned subsequent to intensive cropping, with very poor vegetation cover, for cattle grazing and to regain its fertility.
Degraded Land (DL)	Faulty irrigation management practices, impeded drainage systems, and the deposition of sodic salts on the soil due to evaporation result in a degraded agroecosystem, with very high soil pH, bulk density, temperature, reduced concentration of available soil nutrients, and lack of vegetation cover .
Reclaimed agroecosystem (RL)	The degraded agroecosystem reclaimed 12 years back using biological methods such as farmyard manure / dung of cattle specifically that of sheep and cow, incorporation of crop byproduct in the soil and plowing back of weeds and root in to the soil with use of bio pesticides as nutrient source.

2.2 Soil Sampling

Under all land-use types, a plot size of 40x50 m^2 was demarcated for soil sampling. Ten 25x25x30 cm^3 deep soil monoliths were randomly sampled from all the experimental sites (3 replicates) at regular monthly intervals, samples were extracted in triplicate from each of the three depths (0-10, 10-20, and 20-30 cm) and then made into a composite sample separately for each depth at each experimental site. Soil samples were air-dried and sieved through a 2mm sieve and a representative of the subsample was stored for subsequent analysis [8] Soil temperature was recorded weekly in triplicate using a soil thermometer at 0-10 and 10-20cm depths, at each of the sites under study, however; the values here are mean monthly values for 0-10cm depth and are expressed as ºC. Soil moisture was determined at 0-10 cm depth and expressed as percentage moisture after oven drying at 105ºC. The analysis of soil texture was done using a hydrometer method [9], soil pH was measured as a 1:2.5 (Soil: Water) solution. Organic C was estimated following the Walkey Black method [10]. Soil N was analyzed using the semi-micro Kjeldahl method; available phosphorus was determined using spectrophotometer by molybdenum blue method after extraction with Olsen extractant. Cations were extracted from soil using 1M ammonium acetate at pH 7, thus exchangeable Ca was determined by EDTA titration method, K was estimated using a flame photometer and Mg was measured using atomic absorption spectrophotometer [11].

2.3 Earthworm population sampling

Samplings of earthworm population were done in the same experimental plots of size 40x50m^2 from where soil samples were collected. In the RF, FL and DL earthworms were extracted using hand sorting methods by digging 10 trenches of size (25x25 x30 cm^3) along a transect with random origin 5 meters, apart every month between March 2019-Feb 2020. Earthworms were enumerated from each soil monolith at four depths: 0-10, 10-20, 20-30, and 30-40cm. They were washed and narcotized in 70% alcohol for 24 hours and then transferred to 4% formaldehyde and stored for subsequent taxonomical identification. In agroecosystem, the same sampling methods were followed as above except the sampling was done following the crop cycle and enumeration of earthworms was done up till the crop root depth, i.e., 0-10, 10-20, and 20-30 in 10 pits. Earthworm biomass was measured using fresh specimens, worms were washed in water, wiped dry using a filter paper, and then weighed, and biomass was presented in a gram fresh weight [11].

2.4 Statistical Analysis

The statistical analysis was done using the following methods.

1. Significant differences in functional guild change and biogeographical distribution of earthworm species across different sampling sites and within the same sites were tested using one-way ANOVA (F-test), and New Mann Keul's multiple range tests. However, the biogeographical distribution of earthworms within the same sites was tested using a student t-test.
2. Seasonal variation in total density and biomass of earthworm species in sampling sites were tested using the Kruskal-Wallis test of variance and New Mann Keul's multiple range tests.
3. Diversity index was calculated as Simpsons Index of diversity and

$$\mathrm{D} = 1 - \sum_{i=1}^{n} ni(\mathrm{ni} - 1)/\mathrm{N}(\mathrm{N} - 1))$$

4. Dominance = Total number of individuals of species/Total number of individuals of all the species.
5. The SPSS 20 software for the window package (Systat Software Inc., San Jose, USA and [12] was used for all statistical tests.

III. RESULTS

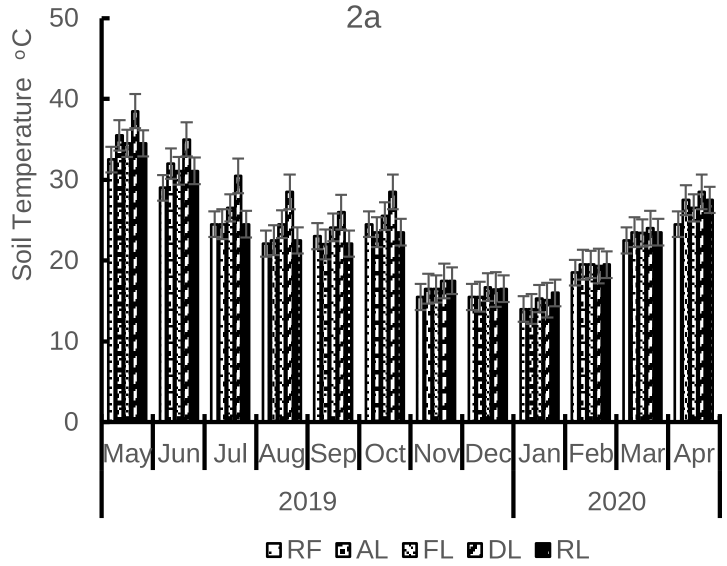
3.1Soil Characteristics

Soil sand percentage was significantly($P<0.05$) low in AL and DL Silt and clay percentage were higher($P<0.05$) in AL and RL. The soil had low porosity with very high bulk density in DL, followed by FL. It had neutral to mildly alkaline pH in RF and RL to alkaline in the FL with highly alkaline pH in DL (8-9.2) (Table 2a).

Table 2a: Impact of land use change and habitat degradation on physical characteristics of soil (±SE, n = 5), across different sampling sites in Raebareli, Uttar Pradesh. Numbers followed by same superscript alphabets are not significantly different (P< 0.05) between different sites

Site	Sand%	Silt%	Clay %	B.D.%	pH
Reserve forest(RF)	76^a±6.3	18^a±1	6^a±0.35	1.69	7.2
Intensive agroecosystem AL	59^b±4.3	31^b±1.9	10^b±0.27	1.66	6.9
Fallows FL	73^a±5.1	23^c±1,7	4^a±0.28	1.82	8.0
Degraded land DL	56	39^b	5^a	1.91	9.2
Reclaimed agroecosystem RL	65^c±2.8	27^c±1.5	8^b±0.13	1.64	7.2

Seasonal variations occurred in soil temperature, moisture under experimental sites (Fig. 2A and Fig. 2B). Soil organic matter



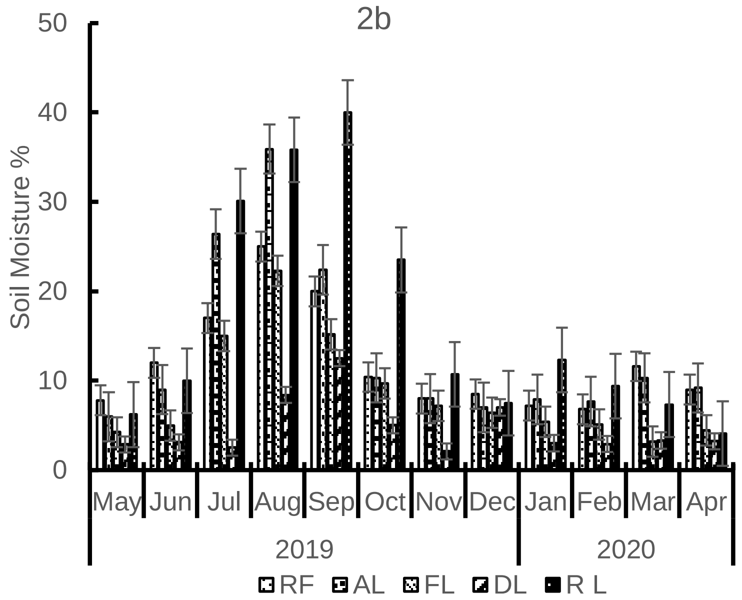


Fig. 2 (A)Monthly fluctuations in soil temperature (°C) and (B) moisture (%) in the Raebareli district of Uttar Pradesh

had a significantly higher (P<0.05) concentration in RL and RF (P<0.05) as compared to all other sites. These values did not vary between FL and DL with intermediate value in AL. All the soil nutrients studied in the experimental plots were significantly higher in the RL. Total nitrogen, organic carbon, and available phosphorus were higher (P<0.05) in RL, calcium and potassium were significantly higher (P<0.05) in RF, AL, and RL, Mg had a higher concentration in AL and RL. Soil nutrient concentration was low (P<0.05) in DL (Table 2b).

Table 2b: Impact of land use change and habitat degradation on chemical characteristics of soils (±SE, n = 5), across different sampling sites in Raebareli, Uttar Pradesh. Numbers followed by same superscript alphabets are not significantly different (P< 0.05) between different sites.

Sites	O.M%	N%	C%	PO_4-P mg\100g	Ca meq\100g	Mg meq\100g	K meq\100g
RF	0.61	0.11	0.45	1.87	9.45	11.1	3.43
	±0.03 ^{a}	±0.01 ^{a}	±0.02 ^{a}	±0.12 ^{a}	±0.41 ^{a}	±0.95 ^{a}	±0.47 ^{a}
AL	0.43	0.12	0.59	1.12	8.9	12.13	3.40
	±0.01 ^{b}	±0.01 ^{a}	±0.02 ^{a}	±0.12 ^{b}	±0.64 ^{a}	±0.76 ^{b}	±0.26 ^{a}

FL	0.23	0.1	0.40	1.24	7.85	10.25	2.70
	±0.04 [c]	±0.002 [a]	±0.03 [b]	±0.08 [c]	±0.32 [b]	±0.87 [c]	±0.18 [b]
DL	0.26	0.04	0.16	0.92	5.35	9.84	2.23
	±0.01 [c]	±0.002 [b]	±0.01 [c]	±0.05 [b]	±0.31 [c]	±0.66 [c]	±0.13 [c]
RL	0.73	0.16	0.54	2.32	8.75	12.46	3.66
	±0.04 [d]	±0.01 [c]	±0.02 [b]	±0.14 [a]	±0.52 [a]	±0.93 [b]	±0.12 [a]

3.2 Earthworm communities

Earthworm species belonging to two families were present in all the land-use types. The family Octochaetidae with a single genus *Eutyphoeus* had three species *Eutyphoeus incommodus*, *Eutyphoeus nicholsoni*, and *Eutyphoeus waltoni*, while family Megascolecidae had the only species *Metaphire formosae*. Earthworm species richness did not vary significantly between RF and AL but declined in FL. Rehabilitation of degraded ecosystems led to an increase in species richness in RL (Table-3)

Table 3: Impact of land use change and habitat degradation on earthworm species composition and richness in Raebareli, Uttar Pradesh.

Sites	Family	Species	Species Richness
RF	Octochaetidae, Megascolecidae	*E.nicholsoni,E.incommodus M.formosa*	3
AL	Octochaetidae, Megascolecidae	*E.nicholsoni,,E.waltoni M.formosa*	3
FL	Octochaetidae	*E.nicholsoni,,E.incommodus*	2
DL	0	0	0
RL	Octochaetidae	*E.nicholsoni,E.waltoni, E.incommodus*	3

Total abundance (P<0.05) and biomass (P<0.05) of earthworm increased significantly with the cutting down of RF into AL. Change in land management from AL to FL due to agricultural intensification resulted in a significant decline in total abundance (P<0.05) and biomass of earthworms in FL (P<0.05). Reclamation of degraded land for agriculture purposes RL resulted in invasion by earthworms with a significant increase in their total abundance and biomass in RL (Table 4)

Table 4: Impact of land use change and habitat degradation on total abundance and biomass of earthworm species. ±SE (n =5) in Raebareli, Uttar Pradesh Numbers followed by the same superscript alphabet are not significantly different (P<0.05) between different sites

Sampling Sites	Abundance (individuals/m^2/yr)	Biomass (g/m^2/yr)
RF	156±9.6 [a]	115.32±5.8 [a]
AL	207±15 [b]	139.56±1.7 [b]
FL	63±2.4 [c]	48.96±3.4 [c]
DL	0	0
RL	213±14 [b]	158.1±6.8 [d]

3.3 Biogeographical distribution of earthworm species

Land management practices affected the bio-geographical distribution of earthworm species. Of the four species present under all the land-use types studied, *E. nicholsoni*, *E. incommodus*, and *E. waltoni* are endemic to the region *M. formosa* is the only exotic species present here. The land use management practice determined the coexistence of earthworm species there. Thus, endemic *E. nicholsoni* was significantly ($P<0.05$) dominant and had higher abundance and biomass in RF compared with *E.incommodus* and exotic *M. formosa*.(Fig. 3)

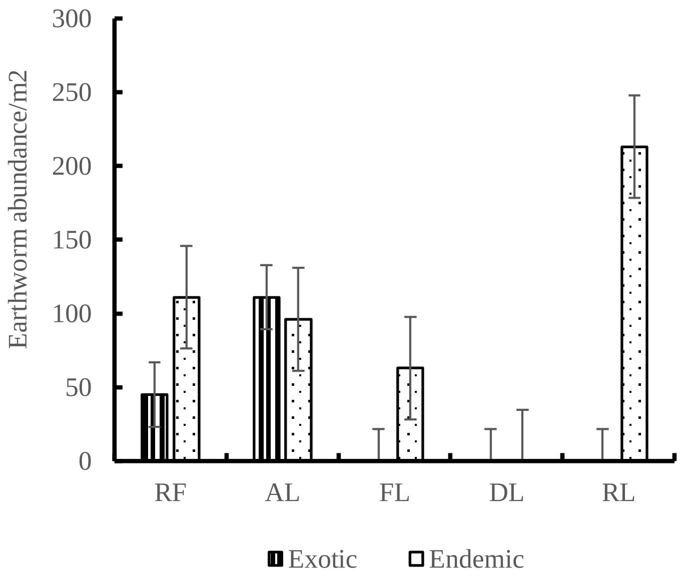


Fig. 3 Variations in the abundance of endemic and exotic species due to land-use change and habitat degradation in Raebareli. RF Reserve Forest; AL Intensive agroecosystem; FL Fallows; DL Degraded land; RL Reclaimed agroecosystem

The cutting down of forest RF to AL resulted in the loss of endemic *E.incommodus*, but another endemic *E.waltoni* invaded the AL. *M.formosa* became ($P<0.05$) significantly more abundant in AL with higher biomass over endemics *E.nicholsoni* and *E.waltoni*. Exotic *M.formosa* and endemic *E.waltoni* disappeared with the conversion of Al to FL, and endemic *E.incommodus* dominated significantly with higher ($P<0.05$) abundance and biomass values ($P<0.05$) over *E.nicholsoni* in FL. None of the earthworm species could survive in the DL. Reclamation of DL to RL led to the recolonization by endemic species *E.nicholsoni*, *E.incommodus*, and *E.waltoni*, exotic *M.formosae* was absent here. *E.incommodus* had significantly higher abundance and biomass ($P<0.05$), whereas *E.nicholsoni* and *E.waltoni* did not show any significant difference here (*E.waltoni* was restricted only to AL and RL and did not show variation in abundance and biomass between the two land-use types (Table 5).

Table 5**:** Impact of land-use change and habitat degradation on the biogeographical distribution of earthworm species. (A) Abundance and (B) biomass value (g/m^2/year) ±SE (n =5) Numbers followed by the same superscript alphabet are not significantly different ($P<0.05$) between different sites. Numbers followed by the same superscript Greek letter are not significantly different ($P<0.05$) between the same sampling sites.

(A) Abundance (individual/m^2/year)

	Endemic species			*Exotic species*
Site	*E.nicholsoni*	*E.incommodus*	*E.waltoni*	*M.formosae*
RF	$^{\alpha}$78±3.2^{a}	$^{\beta}$33±1.6^{a}	0	$^{\beta}$ 45±3.4^{a}
AL	$^{\alpha}$ 45±3.5^{b}	0	$^{\alpha}$ 51±5.7^{a}	$^{\beta}$ 111±5.7^{b}
FL	$^{\alpha}$ 18±1.0^{c}	$^{\beta}$ 45±3.2^{a}	0	0
DL	0	0	0	0
RL	$^{\alpha}$ 66±4.1^{a}	$^{\beta}$ 90±4.4^{c}	$^{\alpha}$ 57±4.3^{a}	0

(B) Biomass value (g/m^2/year)

	Endemic Species			Exotic species
Site	*E.nicholsoni*	*E.incommodus*	*E.waltoni*	*M.formosae*
RF	$^{\alpha}$60.33±3.9^{a}	$^{\beta}$25.59±1.5^{a}	0	$^{\beta}$ 29.85±2.2^{a}
AL	$^{\alpha}$ 36.03±1.8^{b}	0	$^{\beta}$ 27.39±1.8^{a}	$^{\gamma}$ 68.13±4.1^{b}
FL	$^{\alpha}$ 11.4±1.0^{c}	$^{\beta}$ 33.75±1.5^{a}	0	0
DL	0	0	0	0
RL	$^{\alpha}$ 55.47±3.7^{a}	$^{\beta}$ 64.77±4.3^{b}	$^{\gamma}$29.67±2.3^{a}	0

3.4 Functional Guild Change

Functional guild diversity did not vary between different land-use types. Functionally, only endogeic and anecic species were present under all the land use types, but their relative abundance and biomass values varied depending upon the types of land management practices (Fig.4).

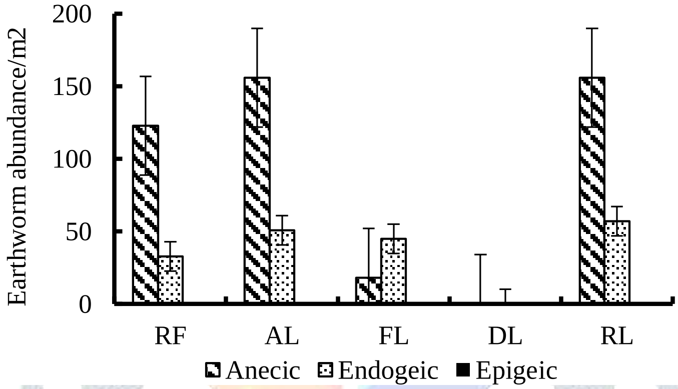


Fig.4 Variations in the abundance of functional groups (epiges,endoges and anecics) due to land-use change and habitat degradation in Raebareli.

Anecic species dominated over endogeic species with a higher abundance and biomass values in RF. Changes in land-use patterns from RF to AL also showed similar results. A shift in land-management practice from AL to FL resulted in the transformation from anecic dominated species to endogenic dominated ones, with an associated decline in abundance and biomass of both endogenous and anecic species. The reclaimed agroecosystem RL had recolonization by endemic and anecic earthworm species. The endemic species had a significantly higher abundance and biomass compared to anecic species. Epigeic species were absent in all the land-use types (Table 6).

Table 6**:**Impact of land-use change and habitat degradation on abundance (individual/m^2/year) and biomass value (g /m^2/year) of anecic and endogeic species(functional catagories) of earthworm in the Raebareli district. ±SE (n =5). Numbers followed by different superscript alphabets are significantly different (P<0.05) between different sampling sites.

	Anecic species		Endogeic species	
Sites	Abundance	Biomass	Abundance	Biomass
RF	123^{a}±10.1	90.18^{a}±4.2	33^{a}±1.4	25.59^{a}±3.4
AL	156^{a}±9.	104.16^{b}±5.8	51^{b}±5.2	27.39^{a}±2.6
FL	18^{b}±1.3	33.75^{c}±3.7	45^{b}±3.1	11.4^{b}±2.3
DL	0	0	0	0
RL	66^{c}±3.9	55.47^{d}±5.4	147^{d}±1.8	94.44^{c}±3.9

3.5 Seasonal Variation

The population abundance of the earthworm species significantly responded to the seasonal change. In RF *E. nicholsoni*, *E. incommodus*, and *M. formosa* had significantly (P<0.05) higher abundance and biomass during the rainy season. *E. nicholsoni* peaked once in October with a subsequent decline in November and showed another small peak in April. *M. formosa* showed a similar pattern of population growth as *E. nicholsoni* but with lower abundance with a smaller peak occurring only during the rainy season in RF. *M. formosae* showed diapause during winter months. In FL both *E. nicholsoni* and *E. incommodus* showed a higher population during the rainy season with a plateaued growth during August, September and then with a decline in population abundance and biomass with the onset of winter, they did not reappear during summers (Fig. 5A, 5B).

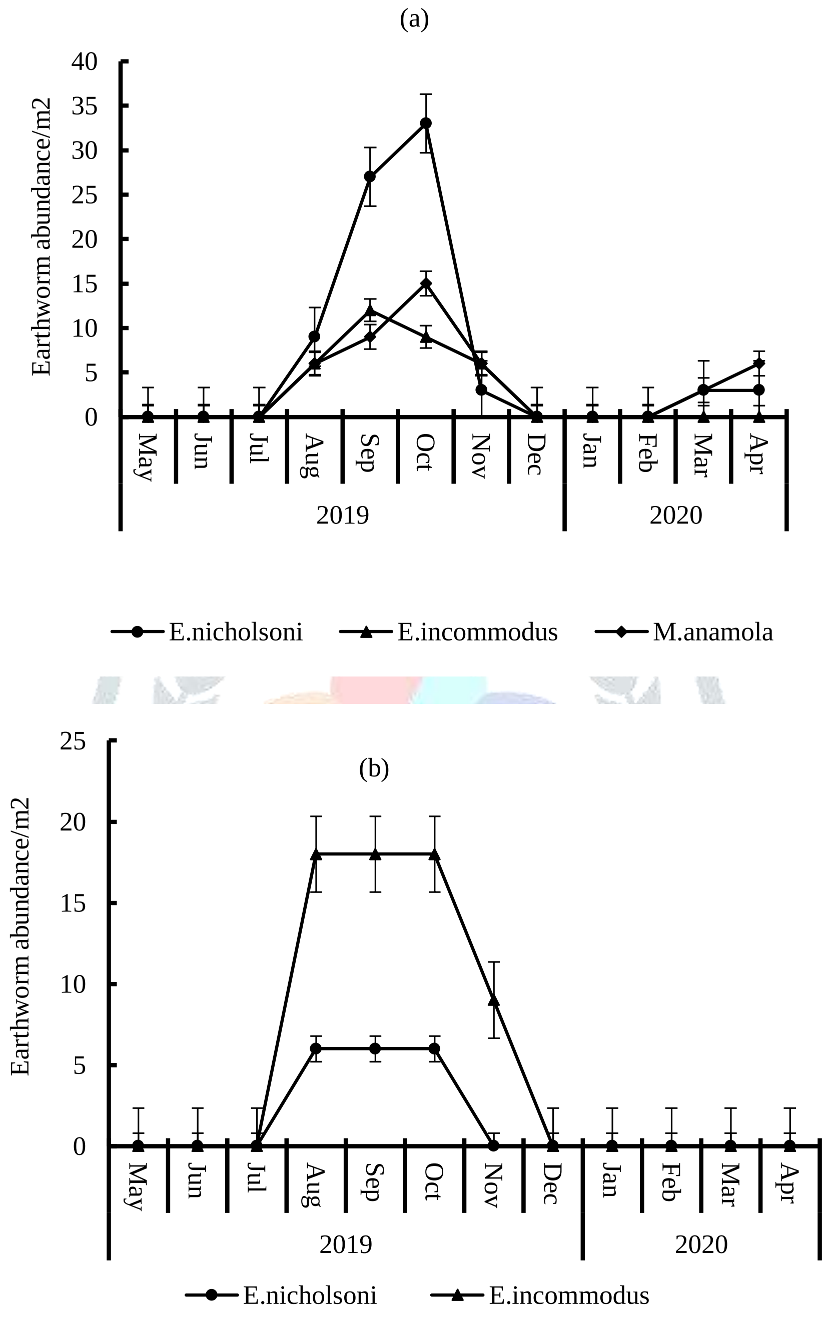


Fig. 5. Variation in abundance of different earthworm species due to seasonal fluctuations in (a)Reserve Forest(RF) : (b) Fallow(FL) in Raebareli

The species present in AL responded to seasonal changes with a peak in population growth during the monsoon months. However, the crop cycle affected the population abundance *E. nicholsoni* exhibited a similar growth curve as *M. formosa*. *E. waltoni* had two growth peaks during the crop cycle - in August-September, a second peak during March and April. The species present in AL responded to seasonal changes with population growth during the monsoon months, crop cycle also affected the population abundance, *E. nicholsoni* exhibited a similar growth curve as *M. formosa*, *E. waltoni* had two growth peaks during the crop cycle in August-September a second peak during March and April (Fig. 5C).In the reclaimed agroecosystem, RL earthworm species showed a peak in population growth during the rainy season. However, all three species present there peaked in the months following the cropping pattern. Thus, *E.incommodus* was dominant during rice cultivation and peaked during September (rice harvest), *E.nicholsoni*, and *E.waltoni*, on the other hand, had peak growth during November, a minor peak occurring during March none of the species were recorded during summer months (Fig. 5D)

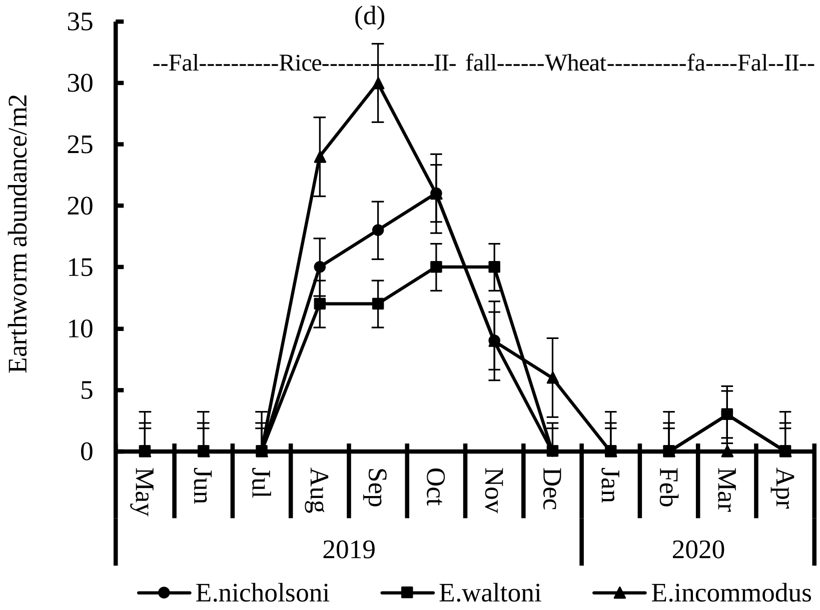


Fig. 5c Variation in abundance of different earthworm species due to seasonal fluctuations in intensive agroecosystem (AL) in Raebareli.

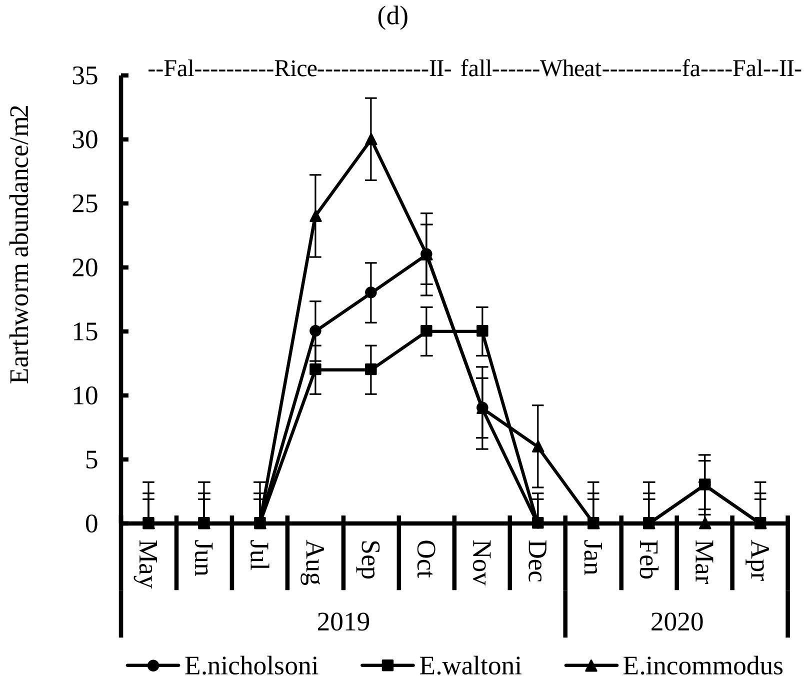


Fig. 5d Variation in abundance of different earthworm species due to seasonal fluctuations in reclaimed agroecosystem in Raebareli.

3.6 Simpsons Diversity Index

Earthworm species diversity index varied depending upon land management practices. Simpson's diversity index was higher in RF, change in land use management from RF to AL led to a decline in the species diversity index. The reclamation of the degraded ecosystem RL led to improvement in the Simpsons diversity index, which was higher than RF too (Table 7).

Table 7. Impact of land-use change and habitat degradation on Simpson diversity index of earthworm species in Raebareli, Uttar Pradesh.

Species	RF	AL	FL	DL	RL
E.nicholsoni	0.25	0.0441	0.081624	0.00	0.0961
E.incommodus	0.0441	0.000	0.51008164	0.00	0.17850
E.waltoni	0.000	0.061	0.00	0.00	0.07160
M.formosa	0.0784	0.287296	0.00	0.00	0.000
D I	0.372	0.392	0.592	0.00	0.346
(1-D x 100) (%)	62.8	60.8	40.8	0	65.4

IV. DISCUSSION

4.1 Community structure

The land-use system in the Raebareli district represents a gradient of increased land-use intensification due to anthropogenic activities. With the deforestation for agriculture and, agroecosystems left as fallows for regeneration of vegetation and soil fertility. Heavy grazing pressure, lack of vegetation cover, and soil erosion accentuated by higher pH value due to sodicity has resulted in the transformation of fallows into highly degraded ecosystems. The reclamation of agroecosystems using biological means has caused it to change from externally regulated to an internally regulated sustainable ecosystem. Change in land-use management practices alters above-ground diversity, and thus the below-ground soil microclimatic conditions, such as temperature, moisture, and organic matter, changing earthworm species distribution. Soil texture affects the earthworm's population distribution, and they are lower in sandy alluvial soil with poor soil moisture condition [13]), thus low earthworm diversity in the Raebareli district where, similar conditions prevail along with high soil pH and sodic conditions. From Parana state, Brazil, it has been reported that changes occur in earthworm distribution in response to the changed edaphic environment, also the total earthworm density in RF (156/m2) and AL (207/m2) is higher than those reported for similar ecosystems from Parana state Brazil 14]. Earthworm species richness was similar along a fertility gradient linked to the litter, organic matter, and better soil moisture and temperature condition. The species richness observed in the present study falls within the range of 1-7 reported in cultivated soils [15]

4.2 Biogeographical Distribution of Earthworms

Earthworms are a good indicator of change occurring in soil health due to anthropogenic modification in land management practices [16]. Sufficient quality of litter and biological processes occurring therein impact the population abundance and distribution of earthworms [17]. The sensitivity of different earthworm species differs in their response to varying levels of habitat disruption, and the same species behave differently under land management practices 18], this was also the case in our studies, endemics *E.nicholsoni* dominated the RF forest ecosystem, *E.waltoni* was confined only to AL and RL, *E.incommodus* dominated in RL, and exotic *M.formosa* was only reported in RF and AL and was absent in other sites. Thus *E.nicholsoni* had wider ecological amplitude and was present under all the sites. A decline in its abundance and biomass with the change in land management from AL to DL implicated its low tolerance to increased pH and soil bulk density. Perturbation causes invasion by the exotic species due to disturbance in vegetation cover and alteration of the habitat [19] this changes the soil properties and functional diversity of earthworms with loss of some endemic species.[20]. Such increased abundance and biomass of exotic *M.formosae* occurred with the conversion of RF to AL, [21] reported restriction of the endemic species to the natural forest or riparian habits only and exotics to disturbed ecosystems. But this was not the case in our studies where endemics *Eutyphoeus* sp. were dominant in degraded sites. With the passage of time and increase in perturbation pressure, endemic species disappear, but depending on species-specific differences in susceptibility to agriculture practices, some species adapt to changes and survive in the agriculture landscape,[22] this could be the reason for the loss of endemic *E.incommodus* and its replacement by another endemic *E.waltoni* and the persistence of *E.nicholsoni* and *E.waltoni* in the Al and their dominance in a disturbed ecosystem. Our earlier studies in Garhwal Himalayas [23] supported this view that endemics were abundant compared to exotic species in disturbed sites. Altered microhabitat conditions and faster grass-root turnover caused recolonization by endemic *E.incommodus* in FL but prevented the invasion by exotic *M.formosae* species in RF, DL, RL, such studies were also reported by others [24]. Probably endemic species are better adapted to the native vegetation, thereby possibly offering biotic resistance to invasion by exotic species [25]. But there is a need for further research to confirm this. Faulty irrigation management practices, impeded drainage systems, and the deposition of sodic salts on the soil due to evaporation result in a degraded agroecosystem [26] Very high soil pH, bulk density, temperature, reduced concentration of available soil nutrients, and lack of vegetation cover led to the loss of earthworms in DL. Conventional tillage method usage, the addition of decomposable litter layer, crop by-products, weed recycling, and farmyard manure conserved the soil moisture, decreased bulk density and improved soil nutrient status in RL. This favoured recolonization by endemic *E.nicholsoni*, *E.incommodus,* and *E.waltoni,* in higher abundance and biomass in RL. Such increase in earthworm abundance and biomass with the addition of organic matter and crop recycle is also reported by us in our earlier studies in the Central Himalayas {27]. The presence of endemic *E.waltoni* only in furrows of bunds in AL and RL was due to their migration to the area with high soil moisture percentage, low perturbation pressure and lower concentration of pesticide and chemical fertilizer, as compared to the central crop zone with more activity. The competition of *E waltoni* with *E.incommodus* could lower its abundance in RL. The same cropping pattern in a given year had both exotic and endemic species in AL, whereas, in RL, there was recolonization by only endemic species. Land management practices had all the three endemic species in RL in higher abundance than exotics, in Garhwal Himalayas, reclamation of degraded land using farmyard manure, cow dung, sheep faecal matter, and crop by-product during the cropping cycle resulted in increased abundance of endemic species over exotic species [28]

4.3 Functional guild changes in earthworms

A marked change in community shift from anecic dominated to endogeic dominated occurred when the agroecosystem was converted to fallows and then in reclaimed site. Under all the land uses only, two functional groups were present endogeic and anecic species. Earthworm functional group changes are due to changed microclimatic and physicochemical characters in land-uses, such as litter thickness, temperature, soil moisture, organic carbon, and nitrogen [29] Therefore, the presence of litter layer in the forest and the soil management practices involving ploughing back of crop by-product in the agriculture system during cropping resulted in increased abundance of anecic earthworms here along with endogeic in lower numbers. The amount and quality of available nutrients, soil moisture, habitat quality, and availability of suitable niches and substrate favoured the dominance of anecic in AL and RF. The higher sensitivity of anecic species to perturbation pressure and land-use change resulted in their absence in RF and RL sites. Complete elimination of epigeic species from any of the sites was because of their inability to survive in perturbed agroecosystems with practices involving intensive disturbances during cropping activities along with burning of the litter of harvested crops before field preparation for cropping. As endogeic and anecic species occur in deeper soil, they are less affected by surface disturbance and perturbation pressure and occurrence. The dominance of anecic species, in RL probably could be explained through habitat offering favourable substrate resources to the species along with agriculture management practices that favoured recolonization by endogeic species, as also shown by studies of [30].

Earthworm activity is affected due to fluctuation in soil moisture percentage because it respires through moist skin 31] Seasonal variation and oscillation in earthworm populations occurred due to variation in soil temperature, moisture, and rainfall [32] Earthworm populations showed higher density and biomass during the rainy season due to favourable soil moisture and temperature conditions, suggesting that all earthworms' species hatch during the early monsoon. *Metaphire formosae* exhibited seasonal diapause during the winter months, thus avoiding drier periods with a decline during winter. The absence of all species during the summer months at all the sites was due to very high soil temperature and low moisture conditions in the semi-arid zone of Raebareli [33] Before rice transplantation, supplements like organic manure, root and crop stumps are ploughed back into the soil thus, improving the soil nutrient availability, thus favouring the growth of earthworm species during the rice crops. Inorganic fertilizer and pesticides are added, during the planting of wheat (Second Crop), to the soil, which proves unfavourable for *E.nicholsoni* and, therefore, its population declined during November. *E.waltoni and M.formosae* were collected only from the borders of fields where they had migrated during the cropping season.

4.4 Diversity index

Habitat loss and soil degradation put substantial pressure on earthworm diversity, with the loss of some species [29]. FL with a lower diversity index represents an ecosystem that is vulnerable to environmental stress [34] RF and RL with a higher Simpson diversity index have heterogeneous biodiversity and are a stable ecosystem, fallow, has a lower diversity index, and represents an ecosystem that is vulnerable to environmental stress. Thus, to have a sustainable ecosystem, it is necessary to manage heterogeneous biodiversity.

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