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Comparative Studies on the Earthworm Community Structure in the Natural Mixed and Oak Plantation Sub-tropical Forests Ecosystem of Imphal, Manipur, India

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ABSTRACT

In view of paucity of information on the earthworms of Manipur, we studied the earthwork community in the reserve mix and oak plantation forests. We recorded 13 species of earthworms of which 6 species (*D. japonica*, *D. nepalensis*, *Kanchuria sumerianus, Dichogaster bolaui, Perionyx shillongensis,* and Enchytraeids) are new records. The earthworms belonged to eight genera and 5 families. Abundance varied between habitats with highest numbers found in reserve mix forest. *Pontoscolex corethrurus* was widely distributed in the plantation forest as compared to other species. *Eutyphoeus* sp. and *Perionyx shillongensis* were restricted to the reserve forest. *Drawida* sp. and *Eutyphoeus* sp. were abundant compared to other species in the reserve mixed forest. It also revealed greater diversity in natural mixed forest with twelve species and only four species in oak plantation forest. The soil physico-chemical characteristics (moisture, temperature, bulk density, porosity, organic carbon, Nitrogen, Phosphorus and pH) showed significant correlation with the changes in the population of earthworms. The soil of mix reserve forest was more favorable habitat for earthworm as compared to that of oak plantation forest. Our study suggests that changes in the landuse patterns can have great impact on the community structure and population of earthworms.

Key Words: Abiotic Factors; Biodiversity; Land Use Impacts.

INTRODUCTION

Manipur the North Eastern mountainous state of India is characterized by luxuriant growth of deciduous, humid evergreen and mixed coniferous types of forest vegetation. It is quite an unexplored area and needs exploration and nature conservation as it supports many unexplored new species. Though a considerable work has been reported in other parts of the country, however no elaborate studies has so far been done on earthworms of Manipur except for some taxonomic works by Stephenson (1921) who reported the presence of five earthworm species viz. *Branchiura sowerbyi*, *Eutyphoeus manipurensis* from around Thanga Island, Loktak Lake, *Pheretima hawayana*, *Pheretima heterochaeta* from Imphal near small streams and *Perionyx excavatus* from Langol Hills. And the presence of seven species reported by current authors Haokip and Singh (2012) in the sub-tropical forests ecosystem. There is no otheer study of the earthworms of Manipur.Therefore, an elaborate analysis of earthworm communities with respect to diversity, systematics and relationship to soil abiotic factors is attempted in this paper. The study was conducted in two types of forests: mix reserve and oak plantation sub-tropical forests of varying land use system at the forest range of Imphal, Manipur.

MATERIALS AND METHODS

The present investigation was carried out in two sub-tropical forests of Manipur, referred to as Sites I and II. Site I is located 11 km away from Imphal city at reserve mix sub-tropical forest ecosystem of Koirengei, which lies at 24^0 52' 51.363 North latitude and 93^0 54' 49.746 East longitude. Its altitude ranges from 800 to 917m above MSL. It has an area of 25 ha and it is protected from various biotic interferences. It has moderate to steep slopes at certain sites. Site II is the managed oak plantation forest ecosystem and is located in the valley area at Mantripukhri at an elevation of 786 m above MSL and is located 4 km away ($24^0$52 52.945 N, $93^0$56 0.169 E) from Imphal city.

The climate of the area is monsoonic with warm moist summer and cool dry winter. The year is divisible into three distinct season's viz. summer, rainy and winter. The months of March and October are the transitional ones between winter and summer and rainy and winter season respectively. The meteorological data during the study period of one year (January 2009–December 2009) showed the mean maximum air temperature varied from 25.64^{0}C (January) to 31.12^{0}C (July) and mean minimum air temperature varied from 5.63^{0}C (January) to 27.72^{0}C (June). Relative humidity was recorded to be maximum in the month of October (90.385%). Minimum monthly rainfall occurred in February (22.5mm) and maximum in August (203mm). The area received an average annual rainfall of 1001.6mm.

Sampling of Soil and Earthworms

Earthworms and soil sample were sampled using the tropical soil biology methodology of Anderson and Ingram (1993). Three plots measuring 10 × 10 m each were demarcated and divided into 1x1 m subplots I, II, III, IV, V and VI, i.e. six replicates were made in both the study sites. Again from each replicate, another four 25 × 25 × 30 cm soil monoliths were randomly sampled at both the study sites. Earthworms were collected at regular monthly intervals for a period of one year. Earthworms were extracted by hand sorting after digging a trench up to 30 cm deep around 1×1 m area at each sampling point. Worms were counted and preserved in 4% formalin for identification. Soil samples collected from 0-10cm depth of the soil monolith were brought in the laboratory, air dried (bigger lumps crushed) and sieved through 2 mm sieve and stored for subsequent chemical analysis. Soil temperature was recorded every month at 0-10cm depth using soil thermometer. Bulk density was measured using 10 cm diameter corer at 0-10 cm depth. Moisture was determined by gravimetric method monthly at 0-10 cm depth and was expressed as a percentage of the weight of the sample after oven drying at 105^{0}C. Soil porosity was calculated using bulk density reading and assuming a mineral soil particle density of 2.65g cm^{-3}. Soil pH was measured in 1:2 soil water solutions. Organic carbon was determined after modified Walkley and Black Method and soil total N by acid digestion Kjeldahl procedure as given by Anderson and Ingram (1993). Available phosphorus was determined by ammonium molybdate stannous chloride method (Sparling et al. 1985) and potassium by atomic absorption spectrophotometric method (Perkin-Elmer AAS 200). Soil texture was determined by international pipette method (Poonia et al. 1972).

RESULTS

The study revealed the presence of thirteen earthworm species belonging to 8 genera distributed in 5 families: Megascolecidae, Octochaetidae, Moniligastridae, Glossoscolecidae and Enchytracidae. All the five families were encountered in reserve mix forest; however,only three families (Moniligastridae, Glossoscolecidae and Megascolecidae) were recorded in the plantation forest. Seven species (*Drawida japonica*, *D. nepalensis*, *Dichogaster bolaui*, *Perionyx shillongensis*, *Kanchuria sumerianus, Amynthas corticis,* and Enchytraieds) have been identified from reserve mix forest in addition to only five species (*Drawida* sp., *Eutyphoeus* sp., *Pontoscolex corethrurus, Metaphire anomala* and *M. houlleti*) reported earlier (Haokip and Singh 2012). Thus a total of 12 species were encountered in reserve mix forest and only four in the oak plantation forest. The dominance of species varied with the type of forest. *Drawida* sp. and *Eutyphoeus* sp. dominated the reserve mix forest and *Pontoscolex corethrurus* the oak plantation forest. Earthworm species belonging to different families encountered in different seasons, along with their ecological category are listed in Table 1.

Data presented in Table 2 on the seasonal variation in population densities of various species show that all species exhibited maximum population density during rainy season and gradually decreased in summer and winter. Details of different abiotic factors and nutrient contents (physico-chemical variables) of soils at the study sites (Table 3) were found to play important roles in the population changes of earthworms. Correlation analysis between earthworm species and physico-chemical factors (Tables 4a and 4b) showed positive significant relationships with soil temperature, porosity,

Table 1. Occurrence of earthworms species of different ecological categories in three seasons at the two sites

Species	Ecological category	Summer	Rainy	Winter
Site I. Reserve mix forest				
Family: Moniligastridae				
Drawida japonica (Perrier)	Endogeic	+	++	+
Drawida nepalensis (Michaelsen)	Endogeic	+	++	+
Drawida sp.	Endogeic	++	+++	++
Family: Octochaetidae				
Dichogaster bolaui (Michaelsen)	Endogeic	+	++	+
Eutyphoeus sp.	Endogeic	+	++	+
Family: Megascolecidae				
Amynthas corticis (Kinberg)	Anecic	-	++	+
Metaphire anomala (Beddard)	Anecic	-	++	+
Metaphire houlleti (Perrier)	Anecic	-	++	+
Perionyx shillongensis (Stephenson)	Epigeic	-	+	+
Kanchuria sumerianus (Julka)	Endogeic	-	+	+
Family: Glossoscolecidae				
Pontoscolex corethrurus (Muller)	Endogeic	+	++	+
Family: Enchytracidae (Potworm)	Epigeic	-	+	+
Site II. Oak plantation forest				
Family: Moniligastridae				
Drawida sp.	Endogeic	+	++	+
Family: Megascolecidae				
Amynthas corticis (Kinberg)	Anecic	-	+++	-
Amynthas morissi (Beddard)	Anecic	-	+++	-
Family: Glossoscolecidae				
Pontoscolex corethrurus (Muller)	Endogeic	++	+++	++

- = absent; + = Low population density; ++ = High population density; +++ = High population density

soil moisture, organic carbon, nitrogen, and Phosphorus. All the species recorded showed negative correlation with soil bulk density and soil pH at both the study sites. Earthworms were most abundant in soils with temperature range of 28^0C-34^0 C and 34.2%-40.3% moisture.

The annual species diversity (Shannon-Wiener Index) and species richness (Margalef's index) of earthworm communities of reserve mix forest (2.721 and 2.809 respectively) were comparatively higher than in the oak plantation (1.278 and 0.801 respectively) (Table 4). Hmax' or maximum diversity of earthworm species was also higher in the reserve mix forest ecosystem (3.6) than in oak plantation forest (2.007) as well as Pielou's evenness with a value of 0.756 and 0.636 respectively (Table 5). Sorensen's coefficient of community similarity index of 37.50% and average faunal resemblance of 50% was recorded between the two sites.

Table 5. Spcies diversity of the eartheworms in 0-30 cm soil layer at the two study sites

Sites	Margalef's Index (Da)	Diversity (H')	Hmax'	Evenness (J')
I	2.809	2.721	3.60	0.756
II	0.801	1.278	2.007	0.636

DISCUSSION

All the three ecological categories of earthworms were recorded in this study. Endogeic species were recorded throughout the year at both the study sites and were drastically reduced in number during dry hot summer and dry winter and were in inactive tightly coiled diapauses state. However, most of the epigeics and anecics viz. *M. houlleti*, *M. anomala*, *A. corticis*, *A. morrisi*, *P. shillongensis* and Enchytraieds were not encountered during certain months of summer and winter seasons (Table 4) though Haokip and Singh (2012) reported their presence throughout the year albeit in the surrounding damp areas (kind of wetland that remains moist throughout the year) outside the present study sites. Gates (1961) also reported different behavior of earthworms in different months of the year and observed that some worms disappeared in the winter seasons. Ismail and Murthy (1985) also reported that earthworms avoid much adverse condition by either moving away to moist soils or by aestivating and also observed that availability of earthworms coincides with peak rainfall. Kale and Karmegam (2010) also reported that during second half of January and February earthworms were completely absent. Among the different edaphic factors studied, soil moisture content was found to play the most important role in the fluctuation patterns of the earthworm population. The importance of soil moisture content in relation to population of earthworms in India was reported by Dash and Senapati (1980), Bhadauria

Table 2. Seasonal variation in the population density (×10^2 m^{-2}) of earthworm species in 0-30 cm soil layer at sites I and II (Mean ±S.E.).

Earthworms	Sites	Seasons			
±		Summer	Rainy	Winter	Annual
Drawida sp.	I	77.83 ±13.76	248.17 ±10.18	107.17 ±12.48	433.17 ± 37.20
	II	12.33 ±3.30	79.17 ±12.04	21.17 ±3.42	112.67 ±20.53
Drawida. japonica (Michaelsen)	I	4.17 ±0.87	11.83 ±2.37	3.67 ±0.60	19.66 ±4.1
	II	A	A	A	A
Drawida nepalensis (Michaelsen)	I	7.67 ±1.45	17.67 ±3.27	5.33 ±0.57	30.67 ±5.27
	II	A	A	A	A
Eutyphoeus sp.	I	61.67 ±4.57	194.50 ±12.27	70.33 ±10.20	326.5 ±22.62
	II	A	A	A	A
Pontoscolex corthrurus (Muller)	I	26.17 ±3.45	100.00 ±13.27	24.00 ±5.43	150.17 ±14.78
	II	71.00 ±6.31	270.00 ±29.60	48.67 ±8.84	389.67 ±35.01
Kanchuria sumerianus (Julka)	I	4.17 ±1.17	10.83 ±3.79	2.17 ±0.41	17.17 ±5.16
	II	A	A	A	A
Dichogaster bolaui (Michaelsen)	I	3.67 ±1.76	11.67 ±5.28	4.50 ±0.48	19.83 ±10.01
	II	A	A	A	A
Perionyx shillongensis (Stephenson)	I	A	29.83 ±13.39	A	29.83 ±13.39
	II	A	A	A	A
Amynthas corticis (Kinberg)	I	A	76.33 ±22.87	8.17 ±4.08	84.5 ±26.23
	II	A	151.67 ±4.66	A	151.67 ±6.24
Metaphire anomala (Beddard)	I	A	99.33 ±8.44	16.33 ±8.17	115.67 ±7.72
	II	A	A	A	A
Metaphire houlleti (Perrier)	I	A	96.50 ±3.18	16.00 ±8.00	112.50 ±2.97
	II	A	A	A	A
Enchtraeids	I	A	27.67 ±5.34	2.33 ±1.17	30 ±6.35
	II	A	A	A	A
Amynthas morrisi (Beddard)	I	A	A	A	A
	II	A	271.17 ±11.56	A	271.17 ±11.56

A=Worms absent.

Table 3. Monthly abiotic variables of soils in forest site I and II at 0-10cm depth.

Seasons	Temp. (°C)		Moisture (%)		Bulk Density (g cm^{-3})		Porosity (%)		pH		Organic C (%)		Total N (%)		Phosphorus (%)		Potassium (%)	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Summer	20	27	24	21	1	1	59	51	5	6	2	0.2	0.25	0.20	0.04	0.04	0.06	0.04
Rainy	24	28	32	33	1	1	64	53	5	5	3	0.2	0.32	0.25	0.04	0.04	0.06	0.05
Winter	15	19	20	17	1	1	59	51	5	5	2	0.1	0.23	0.17	0.04	0.04	0.06	0.05

and Ramakrishnan (1989, 1991), Najar and Khan (2011). Blanchart and Julka (1997) have also recorded higher number of earthworm during wet periods. In the present investigation the soil moisture content exhibited high significant positive correlation r = 0.850 (site I), 0.819 (site II), ($P<0.01$) with the total population at both the study sites. Rainfall together with relative humidity during rainy season leads to an increase in earthworm's population. Low rainfall and moisture content in winter season probably decreased the population that was noted

Table 4a. Correlation analysis between total population density (Y) of earthworms (m^{-2}) and soil physico-chemical properties (X) in reserve mix forest (site I).

Variables	r	df	Y	t	P	Variability (%)
Soil Temp. (^{0}C)	0.74	70	-180.004+13.57x	9.21	<0.01	54.8
Soil Moist. (%)	0.85	70	-131.832+8.83x	13.57	<0.01	72.5
Bulk density (g m^{-3})	-0.38	70	1250.52-1088.41x	-3.39	<0.01	14.1
Porosity (%)	0.38	70	-1638.20+28.92x	3.38	<0.01	14
Soil pH	-0.79	70	970.89-159.14x	-10.69	<0.01	61.5
Carbon (%)	0.65	70	-237.42+115.23x	7.19	<0.01	41.6
Nitrogen (%)	0.892	70	-285.69+1384.496x	16.48	<0.01	79.5
Phosphorus (%)	0.828	70	-541.11+14328.03x	12.34	<0.01	68.1
Potassium (%)	-0.211	70	230.84-2035.65x	-1.81	>0.05	4.4

Table 4b. Correlation analysis between total population density (Y) of earthworms (m^{-2}) and soil physico-chemical properties (X) in oak dominated forest (site II).

Variables	r	df	Y	t	P	Variability (%)
Soil Temp. (^{0}C)	0.368	70	-61.84+5.31x	3.32	<0.01	13.6
Soil Moisture (%)	0.819	70	-107.18+7.16x	11.96	<0.01	67.1
Bulk density (g m^{-3})	-0.763	70	2167.74-1668.33x	-9.89	<0.01	58.3
Porosity (%)	0.714	70	-2139.32+42.08x	8.54	<0.01	51.0
Soil pH	-0.761	70	1315.99-209.26x	-9.81	<0.01	57.9
Carbon (%)	0.625	70	-235.60+132.38x	6.70	<0.01	39.1
Nitrogen (%)	0.757	70	-341.14+1823.51x	9.70	<0.01	57.4
Phosphorus (%)	0.664	70	-486.26+12333.05x	7.43	<0.01	44.1
Potassium (%)	-0.221	70	174.31-1898.44x	-1.89	<0.01	4.9

in the present study. Soil temperature was the next major physical factor in determining the population changes of earthworms; however, its effect on earthworm activity seems subject to availability of moisture. The endogeic worms were found inactive/diapause state during cold dry winter season and continues till dry summer season and their activities start with the initiation of warm rainy months whereas epigeics and anecics were not encountered until warm rainy season. Dash (2013) also pointed out that earthworms have developed different adaptive mechanisms starting from avoidance of desiccation to undergo diapauses to avoid water loss and to counter extreme temperature conditions. The optimum temperature for the present earthworms in question ranges from 28^{0}C to 34^{0}C similarly very close optimal temperature of 20^{0}C to 30^{0}C was reported by Lee (1985) and Edwards and Bohlen (1996) for tropical and sub-tropical species. Gunadi et al. (2003) observation of optimal temperature was also in the range of 25^{0}C-30^{0}C. Dash (2013) pointed out that in Indian situations worms operate actively between 0^{0}C and 30^{0}C, however subject to the availability of moisture their numbers decrease when soil temperature is below 4^{0}C or above 25^{0}C. In the present investigation the minimum temperature when the earthworms cease their activities and undergo diapauses state ranged from 14.81^{0}C (dry winter) to 23.97^{0}C (dry summer) which is little higher than the reported values.

Comparatively between the study sites, high temperatures and low rainfall during the months of March to May resulted in the dry condition of the upper soil layers which was more pronounced in the managed oak plantation site due to direct exposure to sunlight and low vegetation and perhaps this conditions had some impact on the lower activities of total earthworms as compared to reserve mix forest which had thick canopy throughout the year. However there was a gradual increase in total earthworm population with the coming up of congenial microclimatic conditions during the rainy seasons. Dry condition and low rainfall condition was also exhibited in the winter season thereby a drastic reduction in population was recorded. Generally the higher temperature in the soils the lower is the tolerance of earthworms species to high water tensions (Nordstrom and Rundgren 1974). Therefore from the present observations and similar other findings by various researchers is suggestive that moisture restriction determines pattern of distribution and activity of earthworms and function of temperature on earthworm activity is subject to availability of moisture for the earthworms of present study.

Soil bulk density and soil porosity did not show much variation within the study sites. Managed oak plantation (site II) was recorded with higher soil bulk density and lower soil porosity (Table 3). This variation of soil bulk density and soil porosity between two study sites, besides different other factors, one factor that can be mentioned probably may be due to the type of soil of the site I which has more clay content, i.e. clay loam soil whereas site II have sandy loam soil. In the present investigation soil bulk density and soil porosity exhibited negative and positive ($r = -0.380, 0.380, P<0.01$) correlation respectively in reserve mix forest whereas in oak plantation site it exhibited higher significant correlation ($r = -763, 714, P<0.01$) with the total population density of earthworms at 0–10cm soil layer. The present observation also conform with the result of Binet et al. (1997), Yeates et al. (1998) and Bithell et al. (2005) where bulk density was observed exhibiting high significant negative and porosity positive correlation with earthworm population changes. Yeates et al. (1998) have reported that the utility of soil bulk density and soil porosity as indicators of earthworm abundance is limited to particular soil types. The sandy loam soil at site I (57% sand, 23% silt and 20% clay) with low bulk density and high porosity had higher population density and species composition whereas site II with clayey loam soil (36% sand, 30% silt and 35% clay) with higher bulk density and low porosity could be responsible for lower population density as well for fewer species. Krishnamoorthy (1989) also stated that sandy loams had a greater species diversity as well as population diversity than the clays. Guild (1948) similarly observed that medium textured soil appear to be more favorable to earthworm than sandy or soils with high clay content. These current findings on the negative effects of soil compaction on earthworms were consistent with other researchers (Edwards and Lofty 1977, Lee 1985, Boström 1986, Rushton 1986, Joschko et al. 1989, Pizl 1992, Sochtig and Larink 1992).

The soil pH of the present study sites ranged from 5.03 to 6.1 showing slightly acidic nature of the soil. The findings of Makeschin (1994) conform to the present finding where he observed a significantly negative correlation between hydrogen ion concentration in soil solution and abundance or biomass of earthworms. In conformation with the present finding Nath and Chaudhuri (2010) also observed the same species of the present study in Tripura rubber plantation revealing significant negative correlation between soil pH and population of earthworms. They also pointed out that worms in Tripura prefer acidic soil (4.2–6.5) viz. *Metaphire houlleti* (4.8–7.0), *Kanchuria sumerianus* (4.8–4.9), *Drawida nepalensis* (4.8–7.0), *Dichogaster bolaui* (5.4–6.4), *Eutyphoeus* sp. (4.8–7.6), *Lennogaster yeicus* (4.8–5) and *Pontoscolex corethrurus* (4.68–7.6). All the worms of this species were encountered in the present investigation and thriving well in average pH ranging from 5.46–5.9. Bouche (1972) further pointed out that since all earthworms have to counteract strong hydrogen ion concentration limiting their occurrence and activity it is more likely that those species occurring in acidic soils are “acid tolerant’’ than “acidophilic”. Therefore the earthworms species found in the present investigation is suggestive of acid tolerant species since higher number and diversity was recorded in reserve mix forest (site I) with lowest pH of 5.46.

The soil organic carbon and soil total nitrogen was comparatively more in reserve mix forest site than oak plantation site. This may be due to the higher accumulation of litter and higher decomposition rate of organic matter in the mix reserve forest (site I) than the oak plantation forest (site II) where the entire trees are pruned periodically and the entire litters are removed by burning of forest floor, correspondingly showed the least soil organic carbon content and nitrogen. The soil organic carbon and nitrogen was recorded maximum during rainy season followed by summer and winter season in both the study sites. High value of organic carbon and nitrogen observed during rainy season may be due to higher decomposition rate of litter and availability of all favorable microclimatic conditions which enhanced the decomposition during rainy season. The higher population density and biomass of earthworms may also be attributed to the higher organic carbon and nitrogen content in reserve mix forest which had a direct influence on the availability of food sources for earthworms.

In the present investigation soil organic carbon content showed significant positive correlationship with total earthworm population (Tables 4a,b) and its significant effects varies at species level at 0–10cm soil layer. Khalaf El-Duweini and Ghabbour (1965) also observed that an increase in organic carbon was associated with increase in worms. Bisht et al. (2003) also reported significant correlation between earthworm biomass and soil carbon. Seastedt et al. (1988) and Scheu and Schaefer (1998) have observed a strong increase in density and biomass of endogeic earthworms in response to labile organic carbon addition in field experiment. Therefore they concluded that endogeic earthworms were limited by carbon availability. Similarly according to Pashanasi et al. (1992), Gonzalez and Zou (1999) observed a significant positive relationship between earthworm abundance and soil organic carbon (SOC) and states that SOC to be a limiting factor. Bhadauria et al. (2012) also reported from their observation that of all soil physico-chemical properties analyzed only SOC was significantly related to total density and biomass and that SOC explained 68% variation in total density. However in contrast to this finding, in the present investigation although the soil organic carbon showed significant correlation with the total earthworm population, at species level the correlation was not consistently significant and the soil total nitrogen always seems to explain higher variation in total density of earthworms as well as at species level. In site I, the soil organic carbon explained 41.6% variation in total density whereas soil nitrogen explained 79.5% variation (Tables 4a, b). In site II as well at species level the finding was consistent that soil nitrogen always showed higher percentage variation in density of worms of the present study. Similarly Russel (1950) opined that earthworms occupy soils with more nitrogen. Soil nitrogen is often considered the critical factor limiting earthworm population in many ecosystems, both temperate (Satchell 1967) and tropical (Lee 1983). Satchell and Lowe 1967 have pointed out that generally nitrogen content of the food resources is of great importance for earthworm's activity. Evans and Guild (1948) have shown that nitrogen rich diets help in rapid growth of earthworms and facilitate more cocoon production than those with little nitrogen available. According to Tripathi and Bhardwaj (2004) the occurrence of most of the species in the sewage soil as compared to other pedoecosystems may be related to high organic carbon and higher nitrogen in the sewage system showing that earthworms prefer to live in soil ecosystems rich in organic matter and nitrogen. Some of the reports from India well support qualitative dependence of earthworm population in soil nitrogen content (Karmegam and Daniel 2000a, b, Senapati and Sahu 1993, Ganihar 1996). Zou (1993) also reported a positive correlation between the abundance of *P. corethrurus* and nitrogen content of plant litter in tropical Hawaii. According to Curry (2004) the nitrogen content of organic matter reflects protein concentrations and is a good indicator of food quality for earthworms and nitrogen availability often is considered the critical factor limiting earthworm populations. The higher species diversity of earthworms in the present study during rainy season in mix reserve forest with higher soil nitrogen content might indicate a definite relation and proportional interdependence between the organic matter and soil nitrogen and earthworm species. According to Piotrowska et al. (2013), earthworms as decomposers require food with relatively high nitrogen content; therefore they may prefer plant residues with low C:N i.e. high nitrogen content and low carbon. In the reserve mix forest, epigeic and anecic species (surface litter or partly decomposed organic matter feeders) were also higher in number. This may be due to the availability of variety of leaf litter as a food source for them. Oak plantation forest ith lesser soil nitrogen content had correspondingly lower population density and diversity. Kale (1998) reported that abundance and diversity is affected by carbon and nitrogen content of the soil. Edwards and Bohlen (1996) also state that earthworms require carbon and nitrogen for their growth and reproduction. It is alsoo noted that the earthworms were encountered highest during rainy season when nitrogen content of the soil was highest than in summer and winter seasons when the nitrogen content of soil was lower.

The other chemical factors like phosphorus showed positive significant correlation with the earthworms recorded in the present study. Similar observation was reported by Bartz et al. (2013) where soil phosphorus contents and total species richness showed significant positive correlation and Marichal et al. (2011) reported earthworm density positively correlated with phosphorus contents in soil. However the soil chemical factors potassium did not seems to play major role with earthworms in the present study. But the combination of many soil factors might have contributed to the overall earthworm composition of selected study sites.

In the present investigation 12 types of earthworms were recorded from reserve mix forest and four species in oak plantation forests ecosystem respectively. The earthworm species diversity in the present study sites is well within the reported range. The number of species in a given earthworm community, which is the simplest measure of species diversity ranged from 1–15 species, and most earthworms communities including those of tropical rainforest had around 3–6 species (Edwards and Bohlen 1996, Fragoso and Lavelle 1992). Singh (1997) reported occurrence of 7–11 species from cultivated, non cultivated, grassland, garden and sewage soils.

The annual species diversity and species richness of earthworm communities of reserve mix forest (2.721) was comparatively higher than oak plantation forest ecosystems (1.278) as it was revealed from Shannon-Wiener Index. According to Fragoso and Levelle (1992), species diversity of earthworms in tropical rain forests ranges from 1.7 to 6.5. Thus in the current study, species diversity of earthworms on the reserve mix forest lies within this reported range, however oak plantation forest is less than that of tropical rain forest. Chaudhuri and Nath (2011) also reported species diversity of earthworms in the mix forest of Tripura (1.76) which lies within this reported range, however, that of the rubber plantation (0.86) is less. Suthar (2011) also reported Shannon diversity indices (H) for earthworm fauna of Thar Desert in India ranged between 1.6203 and 0.5773 in different habitats. The species richness index provides comprehensive evidence of preference of a biological community in any given ecosystem. Diversity index of reserve mix forest in the present study is higher than all the above reported values clearly suggesting that the mix reserve forest to be preferable places for earthworm inhabitations and colonization, however oak plantation site exhibited less index values than some of the above mentioned habitats and in some higher richness values. Ruan et al. (2005) have opined that greater litter accumulation on the ground of forests can lead to a higher biodiversity of macrofauna likely due to the availability of territory space, food and shelter protection from predation by other animals.

Tripathi and Bhardwaj (2004) reported annual species diversity index (H) of earthworms in five pedoecosystems of Jodhpur, and showed species diversity index in grassland to be zero which indicated the dominance by a single species; in wasteland the annual species diversity index of earthworms was recorded 0.670 showing shared dominance in this habitat; garden revealed higher annual species diversity index 1.04 comprising 3 species; 1.05 in cultivated land and 1.06 in sewage all comprising of 3 species. In the present study the annual diversity index (H) was recorded higher than the above reported values indicating that the species diversity and richness is higher in the forests ecosystem irrespective of the type of forest of the present investigation. H max or maximum diversity of earthworm species was also found to be higher in the reserve mix forest (3.60) than the oak plantation forest (2.007) ecosystems.

The evenness (J) of earthworm communities between the two study sites showed that the reserve mix (0.756) exhibited higher value (i.e.,low dominance) than the oak plantation forest (0.636) (i.e., higher dominance). The evenness index was relatively higher for observed habitats of earthworms in arid and semiarid land of Rajasthan ranging from 0.9829 to 0.7612 for different habitats (Suthar 2011) compared to present study sites. The high species diversity and richness of earthworm in site I may be due to less biotic interference, good canopy cover of mature tree throughout the year, good litter fall and litter cover throughout the year of study site probably these factors provided physical habitat and trophic resource for earthworms. The lesser species diversity and richness of earthworm in site II may be due to various biotic interference such as cutting of woods, periodical pruning, removal of litter by burning of forest floor, open canopy as such less organic matter may have cause some of the species unable to thrive in the said sites. May (1979) reported that stable ecosystem have high species diversity as compared to unstable environments. Lee (1985) in conformity with the present investigation reported that diversity is much more in natural systems than in interfered habitats.

The calculation of the Sorensen's (Q/S) and the average faunal resemblance (%) gave the actual similarities between the two study sites. Use of similarity measurements was usually for estimation of the rate and direction of succession and man induced changes in living communities. In the current study the similarity of earthworm species occurrence between two land uses indicate that the species composition of reserve mix forest and oak plantation forest which exhibited only 37.5% similarities and 50% faunal resemblances. Dash (2013) reported that the similarity indices of earthworm species occurrence between different land-uses in

Karnataka, India indicate that the species composition of natural forests is closer to that of coffee plantations, Acacia and cardamom plantations and paddy fields. Grasslands showed least similarity with other land-uses. Similar to the present observation *Pontoscolex corethrurus*, an endogeic species was found in all land-uses (Chandrashekara et al. 2008). Earlier studies by Dash and Patra (1977), Senapati and Dash (1981), Mishra and Dash (1984), Senapati (1993) showed that in pastures and mixed wood forest soils in Orissa, the earthworm species composition were not similar although *Lampito mauritii* was found in all sites (pastures, croplands and forest sites). The similarity of species occurrence of only 37.5% between reserve mix forest and oak plantation forest may be due to the difference in the degree of disturbances or land use type whereby natural habitat condition of reserve forest is preserved due to least biotic disturbance whereas in oak plantation forest, the management practices such as periodical pruning with complete opening of the canopy of the whole forest and complete removal of litters by burning of entire forest floor etc. must have change the structure of the soil environment making it more unfavorable for the similar types of species to occur.

It may be summarized that earthworms population and diversity tends to be higher in the reserve mix forest with least disturbed micro-habitat as compared to oak plantation forest ecosystems with various management practices. Several researchers have also reported that the changes in land use pattern directly affect the composition and population structure of earthworm species in different agro-climatic regions (Blanchart and Julka 1997, Behera et al. 1999, Bhadauria et al. 2000). Several ecological studies confirmed the close relationship between the occurrence of earthworm species and land-use patterns (Lee 1985). The regional earthworm biodiversity and species dispersal pattern is influenced by a variety of biotic and abiotic forces such as soil properties, surface litter inputs, surface vegetation type and its dynamics, land-management history, local or regional climate and human pressure. The presence of a species in a particular habitat and its absence from other habitats shows species specific distribution of earthworms in different pedo-ecosystems. Similar conclusions have been made from species composition of earthworms in different grassland, cultivated and forest soils (Satchell 1983, Julka and Senapati 1986, Singh 1997, Tripathi and Bhardwaj 2004). Distribution of earthworm is usually irregular (Guild 1952, Satchell 1955, Svendsen 1957), the number varying in relation to the type of soil (Evans and Guild 1947) with edaphic factors playing vital role in their distribution. Thus, the present study shows that the biodiversity, distribution and population of earthworms were influenced both by microclimatic factors as well as the degree of disturbance or land use pattern which directly have impact on the soil ecosystem which is the habitat of the earthworms.

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REFERENCES

Anderson, J.M. and. Ingram, J.S.I. 1993. Tropical Soil Biology and Fertility. Second Edition, Centre for Agriculture and Biosciences International Publishing, Wallingford, United Kingdom. 221 pages.

Bartz, M. L. C.; Pasini, A. and Brown, G.G. 2013. Earthworms as soil quality indicators in Brazilian no-tillage systems. Applied Soil Ecology 69: 39-48.

Behera, B.; Giri S.; Dash, M.C.; Nabin.; Sahu, J and Senapati, B.K. 1999. Earthworm bioindicators of forest land use pattern. The Indian Forester 124: 272-281.

Bhadauria, T and Ramakrishnan, P.S. 1989. Earthworm population dynamics and contribution to nutrient cycling during cropping and fallow phases of shiftig agriculture in north-east India. Journal of Applied Ecology 26(2): 505-521.

Bhadauria, T and Ramakrishnan, P.S. 1991. Population dynamics of earthworms and their activity in forest ecosystem of north east India. Journal of Tropical Ecology 7: 305-318.

Bhadauria, T.; Kumar P.; Kumar R.; Maikhuri R.K.; Rao K.S. and Saxena K.G. 2012. Earthworm populations in a traditional village landscape in Central Himalaya, India. Applied Soil Ecology 53: 83-93.

Bhadauria, T.; Ramakrishnan, P.S. and Srivastava, K.N. 2000. Diversity and distribution of endemic and exotic earthworms in natural and regenerating ecosystems in the central Himalayas, India. Soil Biology and Biochemistry 32(14): 2045-2054.

Binet, F.; Hallaire, V. and Curmi, P. 1997. Agricultural practices and the spatial distribution of earthworms in maize fields. Relationships between earthworm abundance, maize plants and soil compaction. Soil Biology and Biochemistry 29: 557-583.

Bisht, R.; Pandey, H.; Bharti, D. and Kaushal, R. 2003. Population dynamics of earthworms (Oligochaeta) in cultivated soils of central Himalayan tarai region. Tropical Ecology 44(2): 229-234.

Bithell, S.L.; Booth, L.H.; Wratten, S.D. and Heppelthwaite, V.J. 2005. Earthworm populations and association with soil parameters in organic and conventional ley pastures. Biological Agriculture and Horticulture 23: 143-159.

Blanchart, E. and Julka, J.M. 1997. Influence of forest disturbance on earthworm (Oligochaeta) communities in the Western Ghats (South India). Soil Biology and Biochemistry 29(3/4): 303-306.

Boström, U. 1986. The effect of soil compaction on earthworms (Lumbricidae) in a heavy clay soil. Swedish Journal of Agricultural Research 16:137-141.

Chandrashekara, U.M.; Balasundaram, M.; Sankaran, K.V.; Varma, R.V.; Senapati, B.K. and Sehgal, M. 2008. Conservation and Sustainable management of Belowground Biodiversity in the Kerala part of Nilgiri Biosphere Reserve- Phase I, Final Technical Report. Kerala Forest Research Institute, Thissur, India. 1198 pages.

Chaudhuri, P.S. and Nath, N. 2011. Community structure of earthworm under rubber plantations and mixed forests in Tripura, India. Journal of Environmental Biology 32: 357-541.

Curry, J.P. 2004. Factors affecting the abundance of earthworms in soils. Pages 91-113, In: Edwards, C.A. (Editor) Earthworm Ecology, second edition. Chemical Rubber Company Press, Boca Raton, Florida, USA.

Dash, M.C. 2013. Tools for Vermitechnology. I.K International Publishing, New Delhi. 182 pages.

Dash, M.C. and Patra, U.C. 1977. Density, biomass and energy budget of a tropical earthworm population from a grassland site in Orissa, India. Revue d' Ecologie et de Biologie du Sol 14(3): 461-471.

Dash, M.C. and Senapati, B.K. 1980. Cocoon morphology, hatching and emergence pattern in tropical earthworms. Pedobiologia 20: 316-324.

Edwards, C.A. and Bohlen, P.J. 1996. Biology and Ecology of Earthworms. Third edition, Chapman and Hall, London. 42 pages.

Edwards, C.A. and Lofty, J.R. 1977. Biology of the Earthworms. Second Edition, Chapman and Hall, London, 333 pages.

Evans, A.V. and Guild, W.J. 1947. Studies on the relationship between earthworms and soil fertility. I. Biological studies in the field. Annals of Applied Biology 34: 307-492.

Evans, A.V. and Guild, W.J. 1948. Studies on the relationship between earthworms and soil fertility. IV. On the life cycles of some British Lumbricidae. Annals of Applied Biology 35: 471-484.

Fragoso, C. and Lavelle, P. 1992. Earthworm communities of tropical rain forests. Soil Biology and Biochemistry 24(12): 1397-1408.

Ganihar, S.R, 1996. Earthworm distribution with special reference to physicochemical parameters. Proceedings of the Indian National Science Academy 62: 11-18.

Gates, G.E. 1961. Ecology of some earthworms with special reference to seasonal activity. American Midland Naturalist 66: 61-86.

Gonzalez, G. and Zou, X. 1999. Plant and litter influences on earthworm abundance and community structure in a wet tropical forest. Biotropica 31(3):486-493.

Guild, W.J. McL. 1948. Studies on the relationship between earthworms and soil fertility III. The effect of soil type on the structure of earthworm populations. Annals of Applied Biology 35: 181-192.

Guild, W.J. Mc. L. 1952. Variations in earthworm numbers within field population. Journal of Animal Ecology 21:169-181.

Gunadi, B.; Edwards, C.V and Blount. 2003. The influence of different moisture levels on the growth, fecundity and survival of *Eisenia fetida* (savigny) in cattle and pig manure solids. Soil Biology 39: 19-24.

Haokip, S.L. and Singh, T.B. 2012. Diversity and distribution of earthworms in a natural reserved and disturbed sub-tropical forest ecosystem of Imphal-West, Manipur, India. International Multidisciplinary Research Journal 2(2): 28-34

Ismail, S.A. and Murthy, V.A. 1985. Distribution of earthworms in Madras. Proceedings of Indian Academy of Sciences (Animal Science) 94: (5).

Joschko, M.; Diestel, H. and Larink, O. 1989. Assessment of earthworm burrowing efficiency in compacted soil with a combination of morphological and soil physical measurements. Biology Fertility of Soils 8: 191-196.

Julka, J.M. and B.K. Senapati. 1986. Earthworms (Oligochaeta: Annelida) of Orissa, India. Records in Zoological Survey of India, Occasional Paper 92: 1- 44.

Kale, R.D. 1998. Earthworm – Cinderella of Organic Farming. Publishers – Prism Book Private Limited, Bangalore, India.

Kale, R.D. and N. Karmegam. 2010. The Role of Earthworms in Tropics with Emphasis on Indian Ecosystem. Applied and Environmental Soil Science 2010: 16 pages

Karmegam, N. and T. Daniel. 2000a. Abundance and population density of three species of earthworms (Annelida: Oligochaeta) in foothills of Sirumalai (Eastern Ghats), South India, Indian Journal of Environment and Ecoplanning 3: 461-466.

Karmegam, N. and T. Daniel. 2000b. Population dynamics of a peregrine earthworm, *Pontoscolex corethrurus* in an undisturbed soil in Sirumalai Hills of Tamil Nadu, South India. Journal of Ecological Research and Bioconservation 1: 9-14.

Khalaf El-Duweini, A. and S.I. Ghabbour. 1965. Population density and biomass of earthworms in different types of Egyptian soils. Journal of Applied Ecology 2: 271-278.

Krishnamoorthy, R.V. 1989. Factors affecting the surface cast production by some earthworms of India tropics. Proceedings of the Indian Academy of Sciences (Animal Science) 98(6): 431-446.

Lee, K.E. 1983. The influence of earthworms and termites on nitrogen cycling. Pages 35-48, In: Lebrun , Ph.; Andre , H.M.; Gregoire-Wibo, C. and Wauthy, G. (Editors) New Trends in Soil Biology. Proceedings of the VIII International Colloquium of Soil Zoology. Dieu-Brichart, Ottignies-Louvain la-Neuve, Belgium.

Lee, K.E. 1985. Earthworms: Their Ecology and Relationships with Soils and Land Use. Academic Press, London, 411pages.

Makeschin, F. 1994. Effects of energy forestry on soils. Biomass Bioenergy 6: 63-79.

Marichal, R.; Mathieu, J.; Couteaux, M.M.; Mora, P.; Roy, J. and Lavelle, P. 2011. Earthworm and microbe response to litter and soils of tropical forest plantations with contrasting C:N:P stoichiometric ratios. Soil biology and Biochemistry 43: 1528-1535.

May, R.M. 1979. The structure and dynamics of ecological communities. Pagees 385-407, In: Anderson, R.M.; Turner, B.D.

and Taylor, L.R. (Editors) Population Dynamics 20th Symposium of British Ecological Society, Blackwells, Oxford.

Mishra, P.C. and Dash, M.C. 1984. Population dynamics and respiratory metabolism of earthworm population in subtropical woodland of western Orissa, India. Tropical Ecology 25: 103-116.

Najar, I.A and Khan, A.B. 2011. Earthworm communities of Kashmir Valley, India. Tropical Ecology 52(2): 151-162.

Nath, S. and Chaudhuri, P.S. 2010. Human-induced biological invasions in rubber (*Hevea brasiliensis*) plantations of Tripura (India)-*Pontoscolex corethrurus* as a case study. Asian Journal of Experimental Biological Sciences 1(2): 360-369.

Nordstrom, S. and Rundgren, S. 1974. Environmental factors and Lumbricid associations in Southern Sweden. Pedobiologia 13: 301-326.

Pashanasi, B.; Melendez, G.; Szott, L. and Lavelle, P. 1992. Effect of inoculation with the endogeic earthworm *Pontoscolex corethrurus* (Glossoscolecidae) on N availability, soil microbial biomass and the growth of three tropical fruit tree seedlings in a pot experiment. Soil Biology and Biochemistry 24: 1655-1659.

Piotrowska, K.; Connolly, J.; Finn, J.; Black, A. and Bolger, T. 2013. Evenness and plant species identity affect earthworm diversity and community structure in grassland soils. Soil Biology and Biochemistry 57: 713-719.

Pizl, V.V. 1992. Effect of soil compaction on (Lumbricidae) in apple orchard soil. Soil Biology and Biochemistry 24: 1573-1575.

Poonia S.R.; Virmani, S.M. and Bhumla, D.R. 1972. Effect of ESP (exchangeable sodium percentage) of soil on the yield, chemical composition and uptake of applied calcium by wheat. Journal Indian Society of Soil Science 20:183-185.

Ruan, H.H.; Li, Y.Q. and Zou, X.M. 2005. Soil communities and plant litter decomposition as influenced by forest debris: variation across tropical riparian and upland sites. Pedobiologia 49: 529-538.

Rushton, S.P. 1986. The effect of soil compaction on *Lumbricus terrestris* L. and its possible implications for populations on land reclaimed from open-cast coal mining. Pedobiologia 29: 85-90.

Russel, E.J. 1950. Soil Conditions and Plant Growth. 8th edition. Longmans, Green and Co., London. 635 pages.

Satchell, J.E. 1955. Some aspects of earthworm ecology. Pages 180-201, In: Kevan, D.K.McE. (Editor) Soil Zoology. Butterworths, London.

Satchell, J.E. 1967. Lumbricidae. pages 259-322, In: Burges, A. and Raw, F. (Editors) Soil Biology. Academic Press, London.

Satchell, J.E. 1983. Earthworm ecology in forest soils. Pages 161-170, In: Satchell, J.E. (Editor) Earthworm Ecology from Darwin to Vermiculture. Chapman and Hall, London.

Satchell, J.E. and Lowe, D.G. 1967. Selection of leaf litter in *Lumbricus terrestris*. pages 102-119, In: Graff, O. and Satchell, J.E. (Editors) Progress in Soil Biology. (Proceedings of the Colloquium on Dynamics of Soil Communities). Vieweg Braunschweig, North Holland, Amsterdam, The Netherland.

Scheu, S. and Schaefer, M. 1998. Bottom-up control on the soil macrofauna community in Beechwood on limestone: manipulation of food resources. Ecology 79: 1573-1585.

Seastedt, T.R.; James, S.W. and Todd, T.C. 1988. Interactions among soil invertebrates, microbes and plant growth in the tallgrass prairie. Agriculture Ecosystems Environment. 24: 219-228.

Senapati, B.K and Dash, M.C. 1981. Effect of grazing on the elements of production in vegetation and Oligochaeta of a tropical pasture. Revue d' Ecolgie et de Biologie du Sol 18: 487-505.

Senapati, B.K. and Sahu, S.K. 1993. Population, biomass and secondary production in earthworms. Pages 57-78, In: Ghosh, A.K. (Editor) Earthworm Resources and Vermiculture. Zoological Survey of India, Calcutta, India.

Senapati, B.K. 1993. Earthworms gut contents and its significance. Pages 97-99, In: Ghosh, A.K. (Editor) Earthworm Resources and Vermiculture. Zoological Survey of India, Kolkata.

Singh, J. 1997. Habitat preferences of selected Indian earthworm species and their efficiency in reduction of organic materials. Soil Biology and Biochemistry 29: 585-588.

Sochtig, W. and Larink, O. 1992. Effect of soil compaction on activity and biomass of endogeic lumbricids in arable soils. Soil Biology and Biochemistry 24: 1595-1599.

Sparling, G.P.; Whale, K.N. and A.J. Ramsay. 1985. Quantifying the contribution from the soil microbial biomass to the extractable levels of fresh and air dried soils, Australian Journal of Soil Research 23:613-621.

Stephenson, J. 1921. Oligochaeta from Manipur, The Laccadive Islands, Mysore, and other parts of India. Indian Oligochaetes XXII: 745-767.

Suthar, S. 2011. Earthworm biodiversity in western and semiarid land of India. Environmentalist 31: 174 -186.

Svendsen, J.A. 1957. The distribution of Lumbricidae in an area of Pennine Moorland (Moor House, Nature Reserve); Journal of Animal Ecology 26: 411-421.

Tian, G.; Brussaard, L. and Kang, B.T. 1993. Biological effects of plant residues with contrasting chemical composition under humid tropical conditions. Forest Ecology and Management 31:211-220.

Tripathi, G. and Bhardwaj, P. 2004. Earthworm diversity and habitat preferences in arid regions of Rajasthan. Zoo's Print Journal 19(7): 1515-1519.

Yang, X. and Chen, J. 2009. Plant litter quality influences the contribution of soil fauna to litter decomposition in humid tropical forests, Southwestern China. Soil Biology and Biochemistry 41: 910-918.

Yeates, G.W.; Shepard, T.G. and Franci, G.S. 1998. Contrasting response to cropping of populations of earthworms and predacious nematodes in four soils. Soil and Tillage Research 48: 255-264.

Zou, X.M. 1993. Three species effects on earthworm density in tropical tree plantations in Hawaii. Biology and Fertility of Soils 15: 35-38.

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