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EARTHWORMS IN THE HIMALAYA AND WESTERN GHATS REGION OF INDIA: A REVIEW

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ABSTRACT

Soil biodiversity is one of the most challenging areas. Our understanding about belowground biodiversity, especially the soil faunal component and its functions in mountainous ecosystems are not as strong as that of other ecosystems and on aboveground biodiversity. Earthworms help faster nutrient release from the organic substrates. This paper provides a review of the available knowledge on earthworm diversity, community structure and abundance in the Himalayas and the Western Ghats, the regions distinguished as global biodiversity hotspots based on the assessment of aboveground diversity.

INTRODUCTION

Mountain regions of the world are fascinating as they cover a wide range of ecological diversity over smaller areas because of elevation effect and settlement of a several local communities maintaining natural ecosystems together with the managed ones, with landscape management practices varying among local communities isolated by terrain and linguistic barriers. In recent times ecotourism to mountainous regions is not only an economic activity but demands conservation of traditional as well as new ecosystems that attract tourists. Sustainable land use and resource management are key requirements for an area to get recognition as a preferred spot of ecotourism. Increasing demand for organic food and persistence of traditional organic agriculture as patches in the matrix of natural ecosystems in marginal mountain areas make them a prospective area of ecotourism. Soil biodiversity is key to sustainable organic farming (Ramkarishnan *et al.,* 2005) and earthworms are the most dominant component of soil biota in terms of biomass and crucial for maintaining soil fertility (Dash, 1978, Senapati and Dash, 1981, Julka and Paliwal, 2005a and b; Dash *et al.,* 2009; Bhadauria *et al.,* 2012; Dash, 2012). This paper is an attempt to review the information available on diversity and functions of earthworms in the Himalaya and Western Ghats region of India, the areas distinguished globally for their highly valuable biodiversity and ecosystem services, and to identify knowledge gaps to be addressed in future research.

Distribution and diversity of earthworms: national survey

INVENTORY India is spread over an area of 3,287,797 km² (2.4% area of the World), covering a wide range of physiographic, climatic and land use/cover types. Among the 15 agro-climatic regions identified in the country, (Fig. 1) four regions viz., Eastern Himalaya, North-east Ranges, Western Ghats and Western Himalayas figure among the global biodiversity hotspots. However, these hotspots identified based on extremely high endemic vascular plant species richness (presence of at least 0.5% or 1500 endemic vascular plant species) and vegetation degradation (loss of at least 70% primary vegetation) may not necessarily have high diversity of other plant and animal taxa (Myers, 2000; Kareiva and Marvier, 2003).

Geological histories, socio-cultural and economic conditions differ within as well as between hotspots. Thus, settled agriculture on terraced slopes constitutes the predominant agricultural land use in the western and central Himalaya and shifting/slash-burn agriculture on natural slopes in the eastern Himalaya and its extension ranges. The Himalayas is a creation of modern plate tectonic forces but not the Western Ghats, an area that has never been submerged under sea. In contrast to high-input commercial agriculture that dominates in the Indo-Gangetic plains, subsistence low-input traditional farming is widespread in the mountain regions (Bhadauria and Ramakrishnan, 2005; Senapati *et al.,* 2005; Chaudhuri *et al.,* 2008).

Zoological Survey of India has been involved with inventorying of soil fauna diversity for a long period of time, with survey efforts focused largely on presence/absence of different taxa in different environments. Nevertheless, the efforts of this organization devoted exclusively for survey and inventorying of the faunal wealth of the country are augmented by many researchers in other research and development institutions. Nine families of earthworms with 69 genera and 418 species have been reported from India. On the basis of available data, the Western Ghats and West Coastal Plains would stand out as the regions with the highest level of earthworm species richness followed by Eastern Himalayan Region, Southern Plateau, Western Himalayan Region, Eastern Coastal Plains and Eastern Ghats, Gangetic Plains, Gujarat plains, Islands, Western dry Regions and transgangetc regions (Julka and Mukherjee, 1984; Julka and Paliwal, 2005a and b; Dash and Dash, 2008). The Western Ghats region is home to 53% species known from India compared to 26% and 12% in the case of the Eastern Himalaya and the Western Himalaya, respectively. Drawida (38 species) is the most species rich genus followed by *Megascolex* (30 species) in the Western Ghats, *Perionyx* (33 species) followed by *Drawida* (14 species) in the Eastern Himalaya, and *Perionyx* and *Amynthas* (4 species in each Genus) in the Western Himalaya. The Western Ghats harbour 193 native species compared to 85 in the Eastern Himalaya and 22 in the Western Himalaya, though the three regions do not differ much in terms of number exotic species (25-26). Among the native peregrine species associated with agroecosystems, *Octochaetona palniensis* is confined to the Western Ghats and *Lennogaster pusillus* and *Eutyphoeus* spp. to the Western Himalaya. Among the exotics associated with agroecosystems, *Drawida japonica* was able to establish only in the Western Himalaya, while *Dichogaster affinis* and *Pontoscolex corethrurus* could establish in Eastern Himalaya and WesternGhats region but not in the Western Himalaya (Table 1).

Earthworm communities and populations

Studies in village landscapes in central/western Himalaya (Bhadauria *et al.*, 2000, Sinha *et al.*, 2003) showed occurrence of three species in pasture soils compared to eight species in other land-uses, with Exotic *Amynthas corticis* being the most common species. Biological invasion was observed in both early and late successional stages.

Bhadauria and Ramakrishnan (2005) found three native species, viz., *Tonoscolex horai*, *Drawida assamensis* and *Perionyx* sp. in the primary forest in north-east India. Conversion of primary forest for slashes and burn agriculture resulted in the loss of two native species and colonization of the disturbed area by another native species viz., *Nelloscolex strigosus* and exotic *Amynthas corticis*. Although richness of native species increased and the native species were able to coexist with the exotic species during secondary succession after abandonment of cultivation, complete restoration of native earthworm species assemblage did not occur. A similar trend was observed in central/western Himalayan region, though there were differences in species found in the western and eastern Himalaya (Bhadauria *et al.,* 2012).

Chaudhuri *et al.* (2008) found that conversion of primary forests to rubber plantations in Tripura led to dominance of the exotic-endogeic *Pontoscolex corethrurus* as well as a change in the functional status of this species, from endogeic in the primary forests to endo-anecic and endo-epigeic in plantations. In general the change in land use pattern or loss of primary forest followed establishment of some exotic species and also replacement of some natives by other native species.

Epigeic and anecic species, such as *Dichogaster bolaui*, *Drawida willsi*, *Perionyx excavatus*, *Perionyx sansibaricus*, *Ramiella* sp. and *Lampito mauritii* are widely distributed and valued for their use in vermitechnology in Western and Eastern

Table 1: Native peregrine and exotic earthworm species associated with agroecosystems in the Himalaya and the Western Ghats region of India (based on Julka and Paliwal, 2005a &b and personal communication with Julka; A, absent; P, present)

Native peregrine species	Western Himalaya	Eastern Himalaya	Western Ghats
Lampito mauritii	A	P	P
Perionyx excavatus	P	P	P
Perionyx sansibaricus	P	A	P
Octochaetona beatrix	P	A	P
Octochaetona surensis			
Octochaetona palniensis	A	A	P
Lennogaster pusillus	P	A	A
Ramiella bishambari	P	A	P
Eytyphoeus incommodus	P	A	A
Eutyphoeus michaelseni	P	A	A
Eytophoeus waltoni	P	A	A
Drawida willsi	A	A	A
Drawida calebi	A	A	A
Drawida nepalensis	P	P	A
Thatonia gracilis	P	A	A
Exotic species			
Dichogaster affinis	A	P	P
Dichogaster bolaui	P	P	P
Amynthas alexandri	P	P	P
Amynthas corticis	P	P	P
Amynthas morrisi	P	P	P
Metaphire houlleti	P	P	P
Metaphire posthuma	P	P	P
Polypheiritima eleongata	A	P	P
Drawida japonica	P	A	A
Pontoscolex corethrurus	A	P	P
Ocnerodrilus occidentalis	P	A	P
Allobophora parva	P	P	P
Aporrectodea cal. trapezoiedes	P	P	P
Aporrectodearosea rosearosea	P	P	P
Eisenia fetida	P	P	P
Octolasion tyrtaeum	P	P	P
Endemic genus/species			
Curgiona	A	A	P
Kotegeharia	A	A	P
Mallehulla	A	A	P
Priodochaeta	A	A	P
Karmiella	A	A	P
Troyia	A	A	P
Comarodrilus	A	A	P
Chaetocotoides	A	A	P
Parryodrilus	A	A	P
Dashiella	A	A	P
Moniligaster	A	A	P
Celeriella	A	A	P
Lampito	A	A	P
Travoscolides	A	A	P
Wahoscolex	A	A	P
Tonoscolex	A	P	A
Kanchuria	A	P	A
Perionyx (4 species)	P	A	A
Eutyphoeus (2 species)	P	A	A
Plutellus (1 species)	P	A	A

Table 2: Density and biomass of earthworms (m^{-2}) in different areas in the Indian mountainous region (blank fields indicate non-availability of data)

Land use/ ecosystems	Diversity	Density (number of individuals m^{-2})	Average/ range of biomass (wet weight, g)	Trends	References
Pine woodland, Meghalaya		9-52	4.4-9.4		Reddy and Alfred, Shilling, (1978)
Mixed woodland, H. P.		30-118		(1984)	Julka and Mukherjee Solan,
Humid Tropical deciduous forest, A. P. (Eastern Ghats)	5 Species: *Amynthas alexandri*, *A. diffringens*, *Metaphire posthuma*, *M. houlleti*, *Dichogaster* sp.	315(28-281 in different micro sites within forest ecosystem)		Two peaks, one during & the other at the end of the rainy season	Reddy (1987)
Shifting agriculture at Nangpoh in North-Eastern India	3 species:*Megascolides antrophytes*, *Drawida assamensis*, *Nelloscolex strigosus*	68		Peak density immediately after rainy season	Mishra and Ramakrishnan, 1988
Shifting agriculture at Shillong in north-eastern India	5 Species:*Amynthas diffringens*, *Drawida assamensis*, *Eutyphoeus festivus*, *Nelloscolex* phase *strigosus*, *Tonoscolex horaii*	4-47 in cropping phase, 50 in fallow	- season except *Amynthas*	Peak density during rainy Ramakrishnan, 1989 *diffringens* , which peaked in winter	Bhadauria and
Pasture Kumaon Himalaya	3 species:*Amynthasdiffringens*, *Amynthas alexandri*, *Eisenia fetida*	139	25	Peak density at the end of rainy season	Kaushal and Bisht, 1994
Cultivated soil Kumaon Himalaya	One speciesAmynthas alexandri	58		Peak density during rainy season	Kaushal *et al.* (1995)
A village landscape in Garhwal Himalaya	8 species: *Amynthas alexandri*, *Bimastos parvus*, *Metaphire anomala, Metaphire birmanica*, *Drawida nepalensis*, *Perionyx excavatus*, *Lennogaster pusilla*, *Octochaetona beatrix*	Traditional agro forestry system: 147; Traditional pure crop system: 132; Moderately degraded natural forest: 63; Rehabilitated Agricultural land : 63; Abandoned agricultural land: 27; Rehabilitated forest land: 8; Highly degraded forest land: 5	Traditional agro forestry system: 266; Traditional pure crop system: 199; Moderately degraded natural forest: 51; Rehabilitated Agricultural land : 21; Abandoned agricultural land: 16; Rehabilitated forest land: 24; Highly degraded forest land: 11	All species except *B. parvus* showed a strong effect of season on . population size, with the highest abundance and biomass values observed during rainy season. Only *D. nepalensis* and *M. birmanica* were a little bit abundant during dry season in traditional agro forestry system	Bhadauria *et al.* (2012)
Village landscape in Kumaon Himalaya	8 Species:*Bimastus parvus*, *Octolasion tyrtaeum*, *Octochaetona beatrix*, *Amynthas corticis*, *Eutyophoeus festivus*, *E. nanianus*, *E. waltonii*, *Drawida* sp.	Climax forest: 526,Mixed forest: 309, 5-year-old pine: 287, 40-year-old pine: 940, grassland :353		Peak density during rainy season	Bhadauria and Ramakrishnan, 2000
Village landscape in Garhwal Himalaya	7 Species:*Amynthas corticis*, *Drawida nepalensis*, *Allobophora parva*, *Eutyphoeus pharpingianus*, *Octochaetona beatrix*, *Perionyx* sp., *Lennogaster pusillus*	108-247 in forests, 89-235 in agro-ecosystems		Abundance in pine forest-higher but diversity lower compared to oak forest	Sinha *et al.* (2003)
Nandadevi Biosphere Reserve in Garhwal Himalaya	8 species: *Lennogaster pusillus*, *Metaphire houlleti*, *M. anomala*, *Ocnerodrilus occidentalis*, *Dendrodrilus rubidus*, *Aporrectodea calliginosa*, *Amynthas corticis*, *Drawida nepalensis*	Lower elevation: Home garden- 100, pine forest:5-10, oak forest: 5, Irrigated agriculture-5, Rainfed agriculture: 5-25 Higher elevationHome garden:10-150, Alpine pasture:5-25, Alpine forest: 10-15	9- 100	Peak density at the end of rainy season	Maikhuri *et al.*, 2008
Rubber plantations in Tripura in the north-eastern Himalaya	20 species:Glossoscolecidae- *Pontoscolex corethrurus*, Octochaetidae- *Eytyphoeus gigas,E.gammiei,E. comillahnus, E assamaensis,E. festivas,Eutyphoeus spp., Dichogaster bolaui, D.affinis, Lenogaster chittagongnensis, Octochaetona beatrix, Megascolecidae-Metaphire houlleti, Perionyx* spp.,*Kanchuria sumerianus*, Kanchuria sp 1 & sp.2, Moniligastridae - *Drawida nepalensis, Drawida* sp-1, *Drawida* sp-2,*Gordiodrilus elegans*	10-262(mean ~ 109)*Pontoscolex corethrurus-dominant72% of total density*, Kanchuria spp-1-*12%*, *Metaphire houlleti-3.6%*	9-100 (mean 43.4) *Pontoscolex corethrurus-* 61.5%Of total biomass		Chaudhuri *et al.* (2008)

Table 2: Density and biomass of earthworms (m^{-2}) in different areas in the Indian mountainous region (blank fields indicate non-availability of data)

Land use/ ecosystems	Diversity	Density (number of individuals m^{-2})	Average/ range of biomass (wet weight, g)	Trends	References
Nilagiri, Biosphere Reserve: , Kerala area in the Western Ghats	Fourteen species: *Dichogaster affinis*, *Drawida modesta*, *D.barwelli impertusa*, *D.ghatensis*, *D. grandis*, *Glyphidrilus annandalei*, *Haplochetalla* sp., *Lampito mauritii*, *Megascolex insignis*, *M. triangularis*, *Octochaetona beatrix*, *Parryodrilus lavellei*, *Plutellus variabilis*, *Pontoscolex corethrurus*	Natural forests: 159; Forest plantations: 350; Palms: 258 Croplands: 640; Fallows: 124			Chandrashekara *et al.* (2008)
Nilgiri Biosphere reserve: Karnataka area in the Western Ghats	13 species: *Drawida somavarapatna*, *Drawida modesta*, *Drawida fakir*, *Drawida pellucida*, *Lampito mauritii*, *Metaphire holoutii*, *Megascolex curgensis*, *Megascolex felisiceta*, *Amynthas corticis*, *Octochaetoides castellanes*, *Pontoscolex corethrurus*, *Dendrodrilus rubidus*, *Cargia narayani*	Natural forests: 477 Forest plantations: 303 Cardamom plantations: 443 Croplands: 595 Fallows: 343			
A segment of Western Ghats		14-825		Earthworms mainly exhibited temporal variability while some other soil organisms were affected more by management practices	Rossi and Blanchart (2005)

Table 3: Ecological category, feeding habit, and habitat and size relationship of eight species of earthworms of rubber plantation in Tripura (Chaudhuri *et al.*, 2008; Chaudhuri and Bhattacharjee, 2009)

Species	Family	Size(mm) L, length; B, breadth	Color	Feeding habit	Distributi on pattern	Ecological category	Soiltemp (°c) (pH:4.4-5.2)	Soilmoisture (g %)v	Soil pH	Soil organic matter(g %)
Pontoscolex corethrurus	Glossoscolecidae	L = 72-100B = 4-5	Lightly pigmented	Geophagous	Exotic peregrine	Topsoil endogeic	19-32	10-29	4.5-4.8	1.7-2.4
DrawidaPapillifer papillifer	Moniligastridae	L = 45-90B = 3-4	Deeply pigmented	Phytogeophagous	Endemic	Epianecic	22-32	10-29	4.5-4.7	1.6-2.4
Drawi daassamensis	Moniligastridae	L = 60-80B = 4-5	Lightly pigmented	Phytogeophagous	Endemic	Topsoil endogeic	21-31	10-29	4.4-5.2	1.5-2.0
Metaphire houlleti	Megascolecidae	L = 100-160B = 3-6	Deeply pigmented dorsally	Phytogeophagous	Endemic peregrine	Epianecic	21-28	14-20	4.4-5.2	1.6-2.0
Eutyphoeus comillahnus	Octochaetidae	L = 70-135B = 2-4	Lightly pigmented	Geophagous	Endemic	Mesohumic endogeic	21-27	17-18	4.5-4.6	1.7-2.0
Dichogaster affinis	Octochaetidae	L = 35-42B = 1-2	Moderately pigmented	Phytophagous	Exotic peregrine	Epigeic	21-28	17-21	4.8-5.2	1.8-2.0
Octochaetona beatrix	Octochaetidae	L = 60-120B = 4-5	Lightly pigmented	Geophagous	Endemic peregrine	Subsoil endogeic	24-28	11..5-14	4.7-4.8	1.6-2.0
Lennogaster chittagongensis	Octochaetidae	L = 40-50B = 1.5-2.5	Lightly pigmented	Phytogeophagous	Endemic peregrine	Topsoil endogeic	24-30	16-18	4.7-4.8	1.5-2.0

Ghats (Dash and Senapati, 1985; Dash and Dash, 2008; Dash *et al.,* 2009). *Haplochetalla* spp is widespread in laterite and red soils of the Western Ghats.

Studies in different land-uses in the state of Karnataka in south India showed species composition of earthworm communities in natural forests closer to that in plantations (coffee, Acacia and cardamom plantations) and paddy fields but radically different from that in grasslands. *Pontoscolex corethrurus*, an endogeic exotic species, was found in all land-uses (Kale *et al.,* 2008, Chandrashekara *et al.,* 2008). Studies carried out in Eastern Ghat region also showed variation in species composition between land uses but a species like *Lampito mauritii* persisted in all land uses (Dash and Patra, 1977; Senapati and Dash, 1981; Mishra and Dash, 1984; Senapati *et al.,* 2005).

Population and biomass

Data available on earthworm population diversity, density, biomass in different mountainous regions of India are summarized in Table 2. Earthworm density and biomass are influenced by a whole range of abiotic and biotic factors. A high level of environmental heterogeneity and variation in land use/management practices in mountains may result in huge variation in biodiversity within an Agroclimatic region. *Metaphire anomala*, *Metaphire houlleti*, *Ocnerodrilus occidentalis*, *Dendrodrilus rubidus* and *Aporrectordea calliginosa* occurred in the Nanda Devi Biosphere Reserve, a relatively cool area with lower degree of anthropogenic pressures due to legal protection but not in Hariyali landscape, a comparatively warmer area faced to more intense human disturbances in the absence of any legal protection. *Allobophora parva*, *Eutyophoeus pharapingianus*, *Octochaetona beatrix* and *Perionyx* spp. occurred in the latter

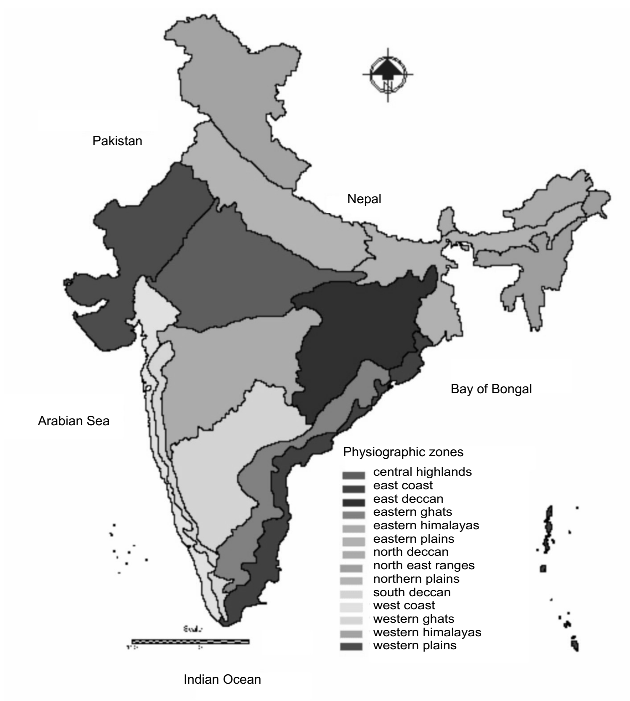

Figure 1: Agroclimatic regions of India (from Julka and Paliwal, 2005)

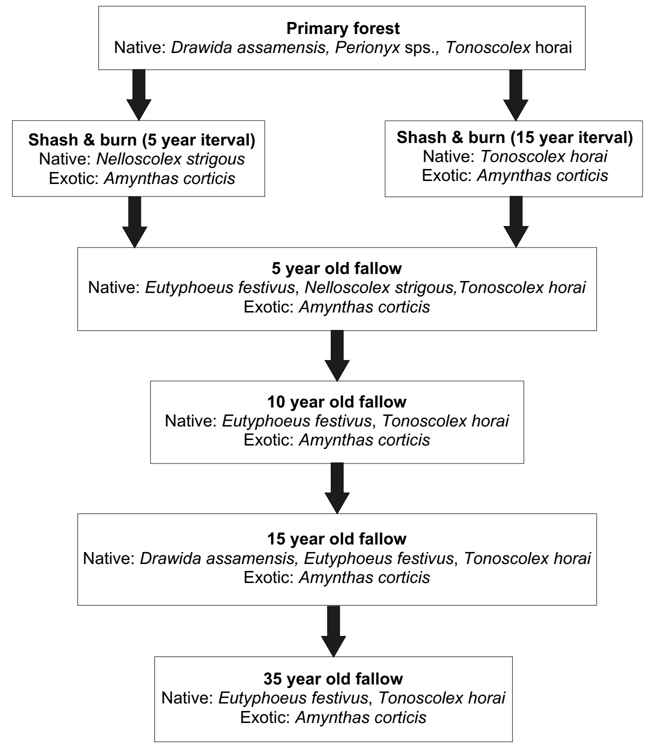

Figure 2: Land use change and earthworm community structure in north-eastern Himalaya (Bhadauria and Ramakrishnan, 2005)

area but not in the former area (Sinha et al., 2003; Maikhuri *et al.,* 2008). In areas with high intensity of agricultural land use, earthworm community comprises *Amynthas diffrigens*, *Amynthas alexandri* and *Eisenia fetida* (Kaushal and Bisht, 1994; Kaushal *et al.,* 1995), species rarely found in traditional landscapes with less intensively land uses. The latter do differ in terms of structure and composition of earthworm communities. *Bimastos parvus* and *Octolasion tyrtaeum* were sampled from a village landscape in Almora district (Bhadauria and Ramakrishnan, 2000) but not from a similar landscape in Chamoli district (Sinha *et al.,* 2003). In shifting agricultural landscapes in the Eastern Himalaya, *Drawida assamensis* and *Nelloscolex strigosus* occurred across an elevation gradient while *Megascolides astrophytes* was confined to lower elevations and *Amynthas diffringens* and *Tonoscolex horaii* to higher elevations (Mishra and Ramakrishnan, 1988; Bhadauria and Ramakrishnan, 1989). Total number of species in cultural landscapes did not vary much (6-8) but certain ecosystem types/patches may be quite poor (e.g., wet paddy fields, Cedrus forests subject to intensive disturbances) or quite rich (e.g., home gardens, rainfed agriculture) in terms of number of species (Maikhuri *et al.,* 2008; Bhadauria *et al.,* 2012).

Earthworms could be a sensitive indicator of environmental quality, e.g., presence of Ramiellona *wilsoni* is indicative of pristine tropical montane forests in Mexico (Negrete-Yankelevich *et al.,* 2007) but necessarily not in all situations. Earthworm population was not significantly influenced by intensity of management in grasslands in Ireland (Curry *et al.,* 2008) and tropical rain forest ecozone in the Western Ghats of India (Rossi and Blanchart, 2005). Density and biomass are likely to be more sensitive to environmental changes and land management practices than species richness and diversity. In

Table 4: Earthworm species richness in Easternghat land uses (Based on Mishra and Dash, 1984; Senapati *et al.,* 2005)

S.no.	Species	Land Uses				
				Shifting Cultivation		
		Natural Forest	Disturbed	8-year old fallow	Cropping phase	Eucalyptus plantation
1.	*Drawida calebi*	+	+	-	-	-
2.	*Drawida willsi*	+	-	-	-	-
3.	*Eutyphoeus incommodes*	+	-	+	+	-
4.	*E.waltoni*	-	-	-	+	-
5.	*Eutyphoeus sps.*	+	-	-	+	-
6.	*Lampito mauritii*	+	+	-	-	+
7.	*Lennogaster dashi*	-	-	-	-	+
8.	*Lennogaster pusillus*	+	-	+	+	-
9.	*Ocnerodrilus occidentalis*	+	+	-	-	-
10.	*Octochaetona surensis*	+	+	-	-	-
11.	*Pellogaster bengalensis*	+	+	+	+	-
12.	*Ramiella bishambari*	+	+	+	-	-

the Nanda Devi Biosphere Reserve, earthworm abundance declined with decline in temperature (*i.e.,* increase in elevation) and was sensitive to both season and land use management, with significant interactions between species, season and management practices. Flooded paddy systems had the lowest and the home gardens the highest species diversity as well as abundance (Maikhuri *et al.,* 2005). Earthworm abundance in the village landscapes at lower elevations was higher (89-940 individuals per m^2) compared to that at higher elevations (5-150 per m^2) (Table 2). In western/central Himalayan region and Tripura in north-eastern Himalaya, endogeic and endogeic-anecic dominate. In rubber plantations in Tripura established after 1962, 15 species are endogeic and only five species are epi-anecic. Further, rubber plantations gave way to exotics like *Pontoscolex corethrurus* (Chaudhuri et *al.,* 2008; Chaudhuri and Bhattacharjee, 2009).

In Nilgiri Biosphere Reserve, 14 species of earthworms were recorded, with 2-8 species occurring in different land use types and total earthworm abundance in the range of 124-560 per m^2. Occurrence of endogeic *Parryodrilus lavelee* and *Pontoscolex corethrurus* in almost all land uses including degraded lands suggests that these species may have a potential for rapid restoration of soil fertility in degraded lands (Chandrashekara *et al.,* 2008). In most studies, population size has been estimated in terms of numerical abundance and not in terms of biomass.

Table 3 gives ecological category, feeding habit, and habitat and size relationship of eight species, out of 20 species of earthworms of rubber plantations raised in undulating areas in Tripura (Chaudhuri *et al.,* 2008, Chaudhuri and Bhattacharjee, 2009). This type of study will be useful for Himalayan and other regions to identify the suitable species for land use management. Functional attributes and ecological strategies of different earthworm species need to be worked out to optimize the contributions of earthworms to ecosystem services and resilience of agroecosytems.

Functional attributes: Bioturbation activity

Bioturbation refers to the biological reworking of soil and sediments, and its importance was first highlighted by Charles Darwin (1881). Bioturbation is now recognized as an archetypal example of 'ecosystem engineering', modifying geochemical gradients, redistributing food resources and microbes in soil column. Bioturbation played a key role in the evolution of metazoan life at the end of the Precambrian Era (Muys *et al.,* 2003). Earthworm casts contain more water soluble aggregates and higher nutrient concentrations than the surrounding soils. Soils with earthworms drain 4 to 10 times faster than soils without earthworms (Guild, 1952, 1955; Low, 1955; Dash and Patra, 1979; Petersen and Luxton, 1982; Bhadauria and Ramakrishnan, 1989; Bhadauria *et al.,* 1997).

Bhadauria and Ramakrishnan (1991) estimated cast production at a rate of 20 tons, 35 tons, 40 tons per hectare per year in a 5-year-old pine forest, a 35-year-old pine forest, and a sacred grove (close to climax vegetation), respectively, in the north-eastern hill region of India. Chaudhuri *et al.* (2008) estimated cast production at a rate of 2.51 ton per ha per year in rubber plantations in Tripura in the north-eastern India. These rates of cast production are substantially lower than the rates of 77-141 tons hectare per year reported in temperate/ tropical ecosystems (Satchell, 1967; Dash and Patra 1979). Estimation of cast production in different land uses would indicate the functional role of earthworms but such studies covering different land-uses and eco-regions in India are lacking.

Land use change and earthworms

Bhadauria and Ramakrishnan (2005) worked on earthworm community structure in relation to land use change in shifting agricultural landscapes in the north-eastern Himalaya (Fig. 2), Chaudhuri *et al.* (2008, 2009) in rubber plantations in Tripura, Chandrashekara *et al.* (2008) in Nilgiri Biosphere, Senapati *et al.* (1994 and 2002) in tea gardens in south Indi and Mishra and Dash (1984) (Table 4), Dash and Senapati (1991); Behera *et al.* (1999) and Senapati *et al.* (2005) in Orissa in south-east India.

Based on these studies, some generalizations can be made. Conversion of natural forests to shifting agriculture and plantations results in some loss of earthworm species richness together with changes in composition of soil fauna community structure and function. Exotic and native species coexist in natural and derived (managed) ecosystems but exotics are less frequent in primary forests. Endopolyhumics in primary forests and Endomesohumics in derived ecosystems (man-managed) dominate the earthworm community structure in north-east India. However in central Himalayas, endomesohumic earthworms dominated irrespective of land use changes from primary forest to grassland and fallows. Land use change from forest to agro ecosystem favoured endomesohumic possibly due to high input of farmyard manure in settled agroecosystems in central/western Himalaya.

Senapati *et al*. (2005) observed proliferation of termite populations following land use intensification in tea plantations and Senapati *et al*. (1994) and Senapati (1997) suggested that termite-earthworm biomass ratio can be used as a sensitive index to land use change. This hypothesis is yet to be tested in wide variety of ecosystems.

CONLUSIONS

Conversion of natural forest results in decline of earthworm species richness and abundance. Organic inputs in the form of manure and crop residues in the derived systems help in restoring earthworm fauna. Termites may proliferate at the expense of earthworms in these derived systems. Periodically inoculation of endogeic and endo-anecic earthworms is likely to restore soil quality in degraded ecosystems. The selection of earthworm species should centre on the naturalized species in a particular site irrespective of whether the species is native or exotic.

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