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Review Article

Ecology and diversity of earthworms in different land use systems of northeast India: A review

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ABSTRACT

In North-Eastern region of India, very few studies on earthworm biodiversity have been done. This review paper integrates these fragmentary studies done in this region till date to understand the total number of reported earthworm species in context of their ecology in different land use systems. Our compilation of data reveals a total of 125 species from 10 families and 28 genera in this region. Highest number of species were reported from Meghalaya (54 species) and lowest (only 9) from Nagaland. The most dominating family with the largest number of species was Megascolecidae followed by Octochaetidae and Moniligastridae. The rare families were Acanthodrilidae, Lumbricidae, Ocnerodrilidae and Eudrilidae. From the entire north-east 39 species were found to be exotic and 86 species native. In terms of community structure, mixed forests were found to harbour maximum earthworm species diversity, the Shannon diversity values ranging from 1.76 to 2.72 whereas the lowest diversity was reported from municipal solid waste deposit site (0.42). Various factors which influence the distribution and abundance of different earthworm species were found to be spatial heterogeneity, habitat and soil characteristics, individual tree species effect, land use history and age of land use system, agricultural intensification, anthropogenic interference and ecological tolerance of the species.

Key words: Earthworm diversity and ecology, Distribution and abundance, Land use systems, North-east India, Regulatory factors, Future research prospects.

INTRODUCTION

The North eastern region (NER) of India comprise eight states viz. Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Tripura and Sikkim covering 25.509 million hectares, which is about 8% of country's geographical area. According to India state of forest report (2021), Govt. of India, more than 64% of the total geographical area is covered with thick and mixed deciduous and semi evergreen forest. Except the Brahmaputra valley covering about 30% land of NER, the rest is hilly and mountainous track with steep slopes. Despite of having such less area coverage it has abundant number of wildlife and plants that form a major part of Indo Burma biodiversity hotspot. The region has a monsoon climate with heavy to very heavy rains, confined within four summer months from June to September. There are three seasons in the area, winter, summer and monsoon season. There is a climatic contrast between the valleys and the mountainous region. The summer temperature in the plains vary between 30 and 33°C, while the hills have a mean summer temperature of around 20°C with a mean minimum of 15°C. The hilly areas of the region receive 2,000 - 3,000 mm of rain, though places like Kohima in Nagaland and Imphal in Manipur, because of their being in the shadow of the mountains, receive less than 2,000 mm of rains.

Earthworms being a major invertebrate fauna of soil ecosystems play many important functional rules in conservation of soil fertility and biodiversity. According to Julka (2014) there are 505 species of earthworms reported from India.Studies on earthworm diversity have been done by various workers in different land use systems of Northeast (NE) especially in the states of Mizoram, Manipur, Meghalaya and Tripura. Some works on Agro forestry (Bhaduria and Ramakrishnan, 1991), Jhum cultivation (Lathanzara *et al* .2011), oak plantations (Haokip and Singh, 2017) have been done in Meghalaya Mizoram and Manipur respectively but a lot more remains to be done. States like Arunachal Pradesh and Nagaland are almost unexplored in this context. Only two major Taxonomic surveys by Prof. J.M Julka, ZSI (Zoological survey of India) India in 1976 and 1981 are till now the lone source of taxonomic information about the earthworm diversity of the state. Reports on earthworm diversity in Assam are available from Rajkhowa *et al* . (2015) and Saikia *et al* . (2021). From Tripura extensive works have been done in different land use systems by Chaudhuri and his coworkers from 2008 to 2020. Figure 1 shows map of NE India based on the GPS coordinates of the areas sampled for earthworm diversity by various workers. Recently a check-list of earthworm species has been reported from NER of India by Tiwari *et al*. (2020) although their studies included Darjeeling and Kalimpong districts of West Bengal. The present paper compiled and reviewed the fragmentary studies on the ecological and biodiversity context of the whole NE India.

Distribution and taxonomic status of earthworms reported from NE India

A total of 125 species of earthworms from 10 families and 28 genera has been reported from NE India (Table 1).

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Table 1. Taxonomic distribution of earthworm species in the different North-eastern states of India.

Sl. No.	State	Area (Sq. Km)	Number of			Remarks
			Families	Genera	Species	
1	Arunachal Pradesh	83743	8	13	52	Largest state in terms of area in NE
2	Assam	78438	8	13	23	Second largest state of NE in terms of area
3	Meghalaya	22429	7	15	54	Highest number of species reported from NE till date
4	Manipur	22327	5	9	17	-
5	Mizoram	21081	3	5	15	-
6	Nagaland	16579	3	4	9	-
7	Tripura	10492	7	14	35	-
8	Sikkim	7096	8	16	29	Smallest state in NE in terms of area
	NE (total area)	**262185**	**10**	**28**	**125**	

Highest number of species has been reported from Meghalaya (54 species). From Arunachal Pradesh, the largest state of NE in terms of area, 52 species of earthworms from 8 families and 13 genera were reported (Table 2). In contrast to that from the 2nd largest state of NE in terms of area in Assam (area-73,438 sq.km), only 23 species were reported from 8 families and 13 genera. The Meghalaya, Manipur and Mizoram having more or less similar area, however, had very uneven reporting in the number of species. While from Meghalaya 54 species of earthworms under 7 families and 15 Genera have been reported, only 17 species belonging to 9 genera and 5 families were recorded from Manipur. Small states like Tripura and Sikkim however presented 35 species (from 7 families and 14 genera) and 29 species (from 8 families and 16 genera) respectively.

The most dominating family with the highest number of species was Megascolecidae followed by Octochaetidae and Moniligastridae. The rare families reported were Acanthodrilidae, Lumbricidae, Ocnerodrilidae and Eudrilidae (Table 2).

The genera *Amynthas*, *Perionyx*, *Drawida* are common to all the NE states. Other mostly reported genera are *Dichogaster*, *Eutyphoeus*, *Metaphire* and *Pontoscolex*. Out of them *Perionyx*, *Eutyphoeus* and *Drawida* are native whereas *Dichogaster*, *Amynthas*, *Metaphire* and *Pontoscolex* are exotic genus (Table 3).

From the entire NE 39 species reported were exotic (31.2%), whereas 86 species (68.8%) were native (Table 4). Most common earthworm species are *A.cortices, D.nepalensis, E.gammiei and P.corethrurus.*

Characterization of different land use systems of NE India

Mixed forests (Manipur, Meghalaya, Tripura)

Earthworm community structures in mixed forests have been studied in Meghalaya, Manipur and Tripura. The mixed forests are natural ecosystems with high plant diversity. In broad leaf mixed forests of Meghalaya only 3 species of earthworms have been reported (Bhadhauria and Ramakrishnan, 1991) whereas, in mixed forests of Manipur and Tripura 12 and 10 species were reported (Table 5). In all these states, endogeics dominated in terms of density, biomass and diversity. Shared dominance between the endogeic and anecic species has also been reported in the mixed forests of Tripura (Chaudhuri and Nath, 2011). The number of exotic earthworm species compared to native species reported were considerably high (Exotic to Native ratio is 0.66 in Tripura and 0.71 in Manipur). In the NE India exotic and native earthworm species coexisted.

Bamboo plantations (Tripura)

Bamboo plantations of Tripura present a picture of semi -natural habitat because of large diversity of other under canopy species which naturally grows in bamboo plantations because of low anthropogenic interference. Works on bamboo plantations has been mainly done by Chakraborty and Chaudhuri 2017, Chaudhuri and Chakraborty 2019 on 5 species of bamboo found abundantly in the state. The plantations in general harbour 11-16 earthworm species (Table 5) and are mostly dominated by endogeic species except *Melocanna baccifera* plantations which is dominated by anecic species. Plantations which have relatively higher anthropogenic interference are dominated by exotic endogeic earthworm especially *Pontoscolex corethrurus,* with high gut assimilation efficiency (Fragoso *et al* ., 1999) whereas, plantations with very low anthropogenic interference have *Drawida assamensis*, a native endogeic worm as the dominant species. The ratios of exotic to native species were much higher in plantations with high anthropogenic interference (Chaudhuri and Chakraborty, 2019). Although, bamboo plantation floors are always covered with bamboo leaf litter, there is remarkably a smaller number of phytophagous epigeic and phytogeophagous anecic species. This is probably due to high lignin content in bamboo leaf which takes a long time for decomposition and thus being less suitable for consumption by earthworm species (Chaudhuri and Chakraborty, 2019).

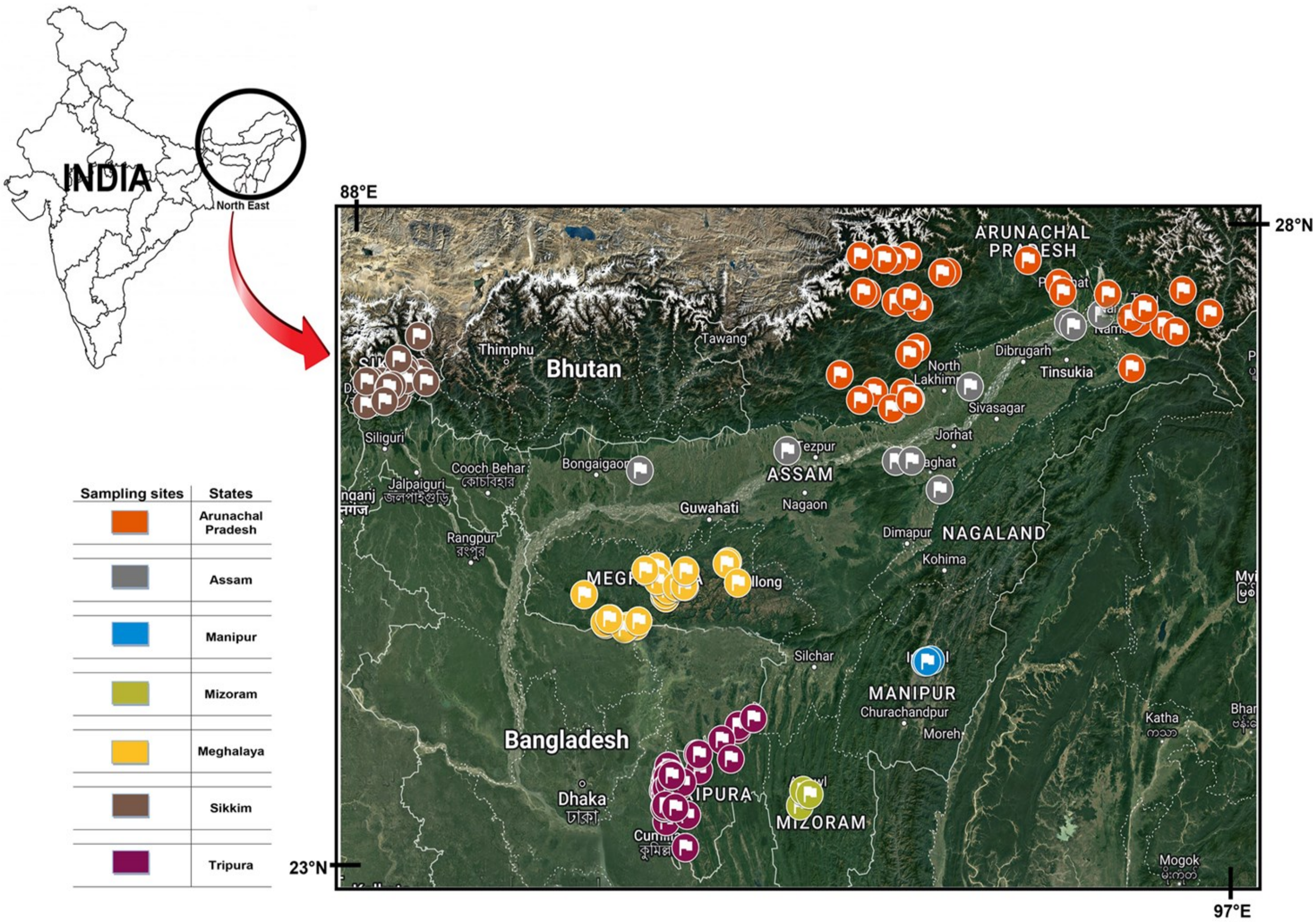

Figure 1. Map of North-east India based on the GPS coordinates of the areas sampled for earthworm diversity

Table 2. Family wise distribution of earthworm species in the different North-eastern states of India.

Earthworm family	Number of Species Found							
	Name of the State							
	ARP	ASS	MNP	MGLY	TRP	MIZ	SIK	NAG
Megascolecidae	22	11	7	34	11	9	12	6
Octochaetidae	5	4	6	6	12	4	1	2
Moniligastridae	10	2	2	7	4	2	1	1
Benhamiidae	4	1	1	4	3	-	4	-
Glossoscolicidae	1	1	1	1	1	-	1	-
Lumbricidae	3	2	-	1	-	-	7	-
Ocnerodrilidae	-	1	-	-	1	-	2	-
Almidae	-	1	-	1	3	-	-	-
Acanthodrilidae	6	-	-	-	-	-	1	-
Eudrilidae	1	-	-	-	-	-	-	-
TOTAL	**52**	**23**	**17**	**54**	**35**	**15**	**29**	**9**

ARP- Arunachal Pradesh, ASS- Assam, MNP-Manipur, MGLY- Meghalaya, TRP- Tripura, SIK- Sikkim, NAG- Nagaland

Table 3. Genera wise distribution of earthworm species in the different North-eastern states of India.

	Earthworm Genus	Number of Species Found								No. of NE states in which found
		Name of the State								
		ARP	ASS	MNP	MGLY	TRP	MIZ	SIK	NAG	
1	*Amynthas**	3	5	4	8	1	6	6	5	**8**
2	*Perionyx*	14	3	2	8	2	2	5	1	**8**
3	*Drawida*	9	2	2	7	4	2	1	1	**8**
4	*Eutyphoeus*	4	3	2	6	9	4	0	2	**7**
5	*Metaphire**	0	2	3	4	4	1	1	0	**6**
6	*Pontoscolex**	1	2	1	1	1	0	1	0	**6**
7	*Dichogaster**	4	1	1	4	3	0	4	0	**6**
8	*Octochaetona*	1	1	1	1	0	0	1	0	**5**
9	*Glyphidrilus*	0	1	0	1	3	0	0	0	**3**
10	*Gordiodrilus*	0	1	0	0	1	0	1	0	**3**
11	*Kanchuria*	0	0	1	8	1	0	0	0	**3**
12	*Lampito*	0	1	0	0	1	0	0	0	**2**
13	*Tonoscolex*	5	0	0	2	0	0	0	0	**2**
14	*Eisenia**	0	1	0	0	0	0	1	0	**2**
15	*Polypheretima**	0	0	0	1	1	0	0	0	**2**
16	*Bimastos**	2	0	0	0	0	0	1	0	**2**
17	*Nelloscolex*	0	0	0	2	1	0	0	0	**2**
18	*Octolasion*	0	1	0	0	0	0	1	0	**2**
19	*Argilophilus**	6	0	0	0	0	0	1	0	**2**
20	*Dendrobaena**	1	0	0	0	0	0	1	0	**2**
21	*Lennogaster*	0	0	0	0	2	0	0	0	**1**
22	*Aporrectodea**	0	0	0	0	0	0	2	0	**1**
23	*Eukerria*	0	0	0	0	0	0	1	0	**1**
24	*Eiseniella*	0	0	0	0	0	0	1	0	**1**
25	*Megascolides*	0	0	0	1	0	0	0	0	**1**
26	*Notoscolex*	0	0	0	1	0	0	0	0	**1**
27	*Eudrilus**	1	0	0	0	0	0	0	0	**1**
28	*Desmogaster*	1	0	0	0	0	0	0	0	**1**
Total		**13**	**13**	**9**	**15**	**14**	**5**	**16**	**4**	

Table 4. Distribution pattern of different earthworm species in North east states of India

Earthworm species		Whether reported (1) or not reported (0)								No. of NE states in which found
		Name of the State								
		ARP	ASS	MNP	MGLY	TRP	MIZ	SIK	NAG	
1	*Amynthas alexandri* *	0	1	0	1	1	1	0	1	**5**
2	*Amynthas corticis**	1	1	1	1	0	1	1	1	**7**
3	*Amynthas diffringens**	1	1	1	1	0	0	1	1	**6**
4	*Amynthas gracilis**	1	0	1	1	0	1	1	1	**6**
5	*Amynthas hawayanus**	0	0	0	0	0	1	1	0	**2**
6	*Amynthas hupeiensis**	0	1	0	0	0	0	0	0	**1**
7	*Amynthas incongruus**	0	0	0	0	0	1	0	0	**1**
8	*Amynthas morrisi**	0	1	1	1	0	0	1	1	**5**
9	*Amynthas papilio**	0	0	0	1	0	0	0	0	**1**
10	*Amynthas papulosus**	0	0	0	1	0	1	0	0	**2**
11	*Amynthas robustus**	0	0	0	1	0	0	1	0	**2**
12	*Aporrectodea rosea rosea**	0	0	0	0	0	0	1	0	**1**
13	*Aporrectodea trapezoides**	0	0	0	1	0	0	1	0	**2**
14	*Argilophilus aborensis**	1	0	0	0	0	0	0	0	**1**
15	*Argilophilus bahli**	1	0	0	0	0	0	0	0	**1**
16	*Argilophilus daminensis**	1	0	0	0	0	0	0	0	**1**
17	*Argilophilus himalayanus**	0	0	0	0	0	0	1	0	**1**
18	*Argilophilus mishmiensis**	1	0	0	0	0	0	0	0	**1**
19	*Argilophilus richikensis**	1	0	0	0	0	0	0	0	**1**
20	*Argilophilus taksingensis**	1	0	0	0	0	0	0	0	**1**
21	*Bimastos parvus**	1	0	0	0	0	0	0	0	**1**
22	*Bimastos rubidus**	1	0	0	0	0	0	1	0	**2**
23	*Dendrobaena rubida**	1	0	0	0	0	0	1	0	**2**
24	*Desmogaster ferina**	1	0	0	0	0	0	0	0	**1**
25	*Dichogaster affiinis**	1	0	0	1	1	0	0	0	**3**
26	*Dichogaster annae**	0	0	0	0	0	0	1	0	**1**
27	*Dichogaster bolaui**	1	0	1	1	1	0	1	0	**5**
28	*Dichogaster modiglianii**	1	0	0	1	1	0	1	0	**4**
29	*Dichogaster saliens**	1	1	0	1	0	0	1	0	**4**
30	*Drawida aruna*	1	0	0	0	0	0	0	0	**1**
31	*Drawida assamensis*	0	0	0	1	1	0	0	0	**2**
32	*Drawida beddardi*	1	0	0	0	0	0	0	0	**1**
33	*Drawida constricta*	1	0	0	0	0	0	0	0	**1**
34	*Drawida decourcyi*	1	0	0	0	0	0	0	0	**1**
35	*Drawida duttai*	1	0	0	0	0	0	0	0	**1**

36	*Drawida japonica*	0	0	1	0	0	0	0	0	**1**
37	*Drawida kempi*	1	0	0	0	0	0	0	0	**1**
38	*Drawida limella*	0	1	0	0	1	0	0	0	**2**
39	*Drawida montana*	0	0	0	1	0	0	0	0	**1**
40	*Drawida nagana*	0	0	0	0	0	0	0	1	**1**
41	*Drawida nepalensis*	1	1	1	1	1	1	1	0	**7**
42	*Drawida papillifer papillif-er*	0	0	0	1	1	0	0	0	**2**
43	*Drawida pellucida pelluci-da*	0	0	0	1	0	0	0	0	**1**
44	*Drawida pellucida stewarti*	1	0	0	1	0	0	0	0	**2**
45	*Drawida rangamatiana*	0	0	0	0	0	1	0	0	**1**
46	*Drawida rosea*	0	0	0	1	0	0	0	0	**1**
47	*Drawida tihunensis*	1	0	0	0	0	0	0	0	**1**
48	*Eisenia fetida**	0	1	0	0	0	0	1	0	**2**
49	*Eiseniella tetraedra tetrae-dra**	0	0	0	0	0	0	1	0	**1**
50	*Eudrilus eugeniaie**	1	0	0	0	0	0	0	0	**1**
51	*Eukerria kuekenthali**	0	0	0	0	0	0	1	0	**1**
52	*Eutyphoeus aborianus*	1	0	0	0	0	0	0	0	**1**
53	*Eutyphoeus assamensis*	0	1	0	0	1	1	0	0	**3**
54	*Eutyphoeus callosus*	0	0	0	1	1	0	0	0	**2**
55	*Eutyphoeus comillahnus*	0	0	0	0	1	0	0	0	**1**
56	*Eutyphoeus festivus*	0	0	0	1	1	0	0	1	**3**
57	*Eutyphoeus gammiei*	1	1	1	1	1	1	0	0	**6**
58	*Eutyphoeus gigas*	0	0	0	0	1	1	0	0	**2**
59	*Eutyphoeus incommodus*	1	0	0	0	0	0	0	0	**1**
60	*Eutyphoeus kempi*	1	1	0	1	0	0	0	0	**3**
61	*Eutyphoeus manipurensis*	0	0	1	0	0	0	0	0	**1**
62	*Eutyphoeus marmoreus*	0	0	0	0	0	0	0	1	**1**
63	*Eutyphoeus mizoramensis*	0	0	0	0	0	1	0	0	**1**
64	*Eutyphoeus nepalensis*	0	0	0	1	0	0	0	0	**1**
65	*Eutyphoeus orientalis*	0	0	0	0	1	0	0	0	**1**
66	*Eutyphoeus scutarius*	0	0	0	0	1	0	0	0	**1**
67	*Eutyphoeus turaensis*	0	0	0	1	1	0	0	0	**2**
68	*Glyphidrilus gangeticus*	0	1	0	0	1	0	0	0	**2**
69	*Glyphidrilus spelaeotes*	0	0	0	1	1	0	0	0	**2**
70	*Glyphidrilus tuberosus*	0	0	0	0	1	0	0	0	**1**
71	*Gordiodrilus elegans*	0	1	0	0	1	0	1	0	**3**
72	*Kanchuria summerianus*	0	0	1	1	1	0	0	0	**3**
73	*Kanchuria antrophyes*	0	0	0	1	0	0	0	0	**1**
74	*Kanchuria octotheca*	0	0	0	1	0	0	0	0	**1**
75	*Kanchuria turaensis*	0	0	0	1	0	0	0	0	**1**
76	*Kanchuria daribokgrensis*	0	0	0	1	0	0	0	0	**1**
77	*Kanchuria karorensis*	0	0	0	1	0	0	0	0	**1**

78	*Kanchuria makhulensis*	0	0	0	1	0	0	0	0	**1**
79	*Kanchuria mohiskulensis*	0	0	0	1	0	0	0	0	**1**
80	*Lampito mauritii*	0	1	0	0	1	0	0	0	**2**
81	*Lennogaster yeicus*	0	0	0	0	1	0	0	0	**1**
82	*Lennogaster chittagongen-sis*	0	0	0	0	1	0	0	0	**1**
83	*Megascolides antrophyes*	0	0	0	1	0	0	0	0	**1**
84	*Metaphire anomala**	0	0	1	0	0	0	0	0	**1**
85	*Metaphire birmanica**	0	0	1	1	0	0	0	0	**2**
86	*Metaphire houlleti**	0	0	1	1	1	1	0	0	**4**
87	*Metaphire peguana**	0	0	0	0	1	0	0	0	**1**
88	*Metaphire planata **	0	1	0	1	1	0	0	0	**3**
89	*Metaphire posthuma**	0	1	0	1	1	0	1	0	**4**
90	*Nelloscolex burkilli*	0	0	0	1	1	0	0	0	**2**
91	*Nelloscolex strigosus*	0	0	0	1	0	0	0	0	**1**
92	*Octochaetona beatrix*	1	0	1	0	1	0	1	0	**4**
93	*Octochaetona surensis*	0	1	0	0	0	0	0	0	**1**
94	*Octolasion tyrtaeum*	0	1	0	0	0	0	1	0	**2**
95	*Perionyx kempi*	1	0	0	0	0	0	0	0	**1**
96	*Perionyx annandalei*	0	1	0	0	0	0	0	0	**1**
97	*Perionyx annulatus*	1	0	0	0	0	0	0	0	**1**
98	*Perionyx daflaensis*	1	0	0	0	0	0	0	0	**1**
99	*Perionyx daminensis*	1	0	0	0	0	0	0	0	**1**
100	*Perionyx depressus*	1	0	0	0	0	0	0	0	**1**
101	*Perionyx excavatus*	1	1	1	1	1	1	1	0	**7**
102	*Perionyx fossus*	0	0	0	1	0	0	0	0	**1**
103	*Perionyx foveatus*	1	0	0	1	0	0	0	0	**2**
104	*Perionyx gravelyi*	1	0	0	0	0	0	0	0	**1**
105	*Perionyx himalayanus*	0	0	0	0	0	0	1	0	**1**
106	*Perionyx horai*	0	0	0	1	0	0	0	0	**1**
107	*Perionyx jorpokriensis*	0	0	0	0	0	0	1	0	**1**
108	*Perionyx koboensis*	1	0	0	0	0	0	0	0	**1**
109	*Perionyx macintoshi*	1	0	0	1	1	1	0	0	**4**
110	*Perionyx modestus*	1	0	0	1	0	0	0	0	**2**
111	*Perionyx pulvinnatus*	0	1	0	0	0	0	0	0	**1**
112	*Perionyx rufulus*	0	0	0	0	0	0	0	1	**1**
113	*Perionyx shillongensis*	0	0	1	1	0	0	0	0	**2**
114	*Perionyx sikkimensis*	0	0	0	0	0	0	1	0	**1**
115	*Perionyx turaensis*	1	0	0	1	0	0	0	0	**2**
116	*Perionyx variegatus*	1	0	0	0	0	0	1	0	**2**
117	*Perionyx vidakensis*	1	0	0	0	0	0	0	0	**1**
118	*Polypheretima elongata*	0	0	0	1	1	0	0	0	**2**
119	*Pontoscolex corethrurus*	1	1	1	1	1	0	1	0	**6**
120	*Tonoscolex striatus*	1	0	0	1	0	0	0	0	**2**
121	*Tonoscolex horai*	0	0	0	1	0	0	0	0	**1**
122	*Tonoscolex indicus*	1	0	0	0	0	0	0	0	**1**
123	*Tonoscolex kabakensis*	1	0	0	0	0	0	0	0	**1**
124	*Tonoscolex michaelseni*	1	0	0	0	0	0	0	0	**1**
125	*Tonoscolex oneilli*	1	0	0	0	0	0	0	0	**1**
	TOTAL	**52**	**23**	**17**	**54**	**35**	**15**	**29**	**9**	

ARP- Arunachal Pradesh, ASS- Assam, MNP-Manipur, MGLY- Meghalaya, TRP- Tripura, SIK- Sikkim, NAG- Nagaland; *Exotic species =39

Agro forestry systems (Mizoram)

Agro forestry systems are land use systems where woody perennials are grown on the same land management unit as agricultural crops. Agroforestry systems of Mizoram harboured plants like *Leucaena leucocephala*, pine apple and a tree species- *Citrus reticulate*. The soil was slightly acidic with brown to dark brown colouration having clay to clay loam texture. Only 5 species of earthworms (Table 5) viz. *Perionyx excavatus* (epigeic), *Metaphire houlleti* (anecic), *Eutyphoeus mizoramensis* (endogeic), *Drawida* sp. and *Perionyx macintoshi* were reported (Lalthanzara *et. al.,* 2011).

Tea plantations (Tripura)

The largest producer of tea in India is Assam. Tea is also grown in Tripura (5th producer) and in some pockets in rest of all the NE states. These plants thrive well in hot and humid climate with high rainfall in well drained, deep, friable loam soils. There is moderate canopy cover of trees and the plantation floor remains covered with partly decomposed tea leaf litter along with different weeds. In managed plantations anthropogenic practices includes leaf plucking, weeding and annual pruning of the tea bushes. Unfortunately no work on earthworm community composition and ecology has been reported from any of the NE states except Tripura where substantial works have been done by Jamatia and Chaudhuri (2017a, 2017b). Fifteen species of earthworms have been reported from tea plantations of Tripura(Table 5). Interestingly unmanaged tea plantations showed greater species diversity than managed plantations. Although both managed and unmanaged plantations had dominance of endogeic species of earthworms, in unmanaged plantations with very low anthropogenic interference, the most dominant earthworm species was *D. assamensis* and in managed plantations with high anthropogenic interference the most dominant species was an exotic species (*Pontoscolex corethrurus*). The ratio of exotic to native species was very high (0.85) in the managed plantations compared to unmanaged plantations (0.50).

Jhum cultivation (Mizoram and Meghalaya)

Slash and burn agriculture (locally called Jhum cultivation) is a type of shifting agriculture practiced by the tribal population of the NE India which involves slashing of vegetation followed by burning of dried felled vegetation. This land is then used for growing crops. Some works on earthworm community structure in Jhum fellows has been reported from Meghalaya and Mizoram. Mishra and Ramakrishnan (1988) reported presence of 3 species of earthworms from Jhum fellows of different age groups. The 0-year fellow had only one species of earthworm, *Drawida assamensis*. The 5-year fallow had 3species of earthworms, whereas, 15 year fallow had only 1 species of earthworm. Zodinpuii *et al* (2019), reported presence of 9 species of earthworms in jhum cultivation of Mizoram (Table 5). According to the authors, traditional shifting cultivation adversely affects earthworm density and diversity. The destructive effects of shifting cultivation on earthworms are mainly attributed to habitat disturbances, reduced food availability and changes in soil physicochemical properties. However, the spatial distribution pattern of an earthworm species is not significantly affected by shifting cultivation according to the authors. The genus *Drawida* was most versatile in terms of spatial distribution.

Rubber (Tripura)

Tripura is the second largest producer of natural rubber in India only after Kerala. Rubber plantation is characterized by deciduous litter fall almost throughout the year and soils with horizontal distribution of extensive network of root system. Extensive works on earthworm ecology have been done by Chaudhuri *et al* . (2008, 2013).

The authors reported 10 species of earthworms (Chaudhuri and Nath, 2011) from rubber plantations of Tripura (Table 5) which are mainly dominated by endogeic earthworm species. *Pontoscolex corethrurus* was the dominant species representing 72% density of the total earthworm population (Chaudhuri *et al .,* 2008). With increase in the age of rubber plantations both the densities and biomass of earthworms increased dramatically (Chaudhuri *et al .,* 2013). According to the authors high contents of polyphenol, flavonoid and lignin in younger plantations (3-10years) in rubber plantations through their effects on food intake, resulted to low biomass values whereas in older plantations (above 10 years) decrease in these contents led to increase in the biomass of the earthworms. Afforestation of wasteland or fallows through rubber plantation in Tripura played a major role in determining the abundance and community characteristics of earthworms and the establishment of the exotic earthworm, *Pontoscolex corethrurus* in areas previously inhabited by other endogeic earthworm species (Nath and Chaudhuri, 2010). Factors contributing to invasion of *P. corethrurus* in rubber plantations include anthropogenic disturbances, individual tree species effect, competitive interaction between the exotic and the endemic species and their reproductive success.

Pineapple (Meghalaya, Tripura)

Pineapples are grown in acidic, sandy loam soils with good drainage and sufficient sunlight. Research work on pineapple plantations has been reported from Meghalaya and Tripura. Dey and Chaudhuri (2014) reported 11 earthworm species from the pineapple plantations of Tripura (Table 5), whereas, Tiwari *et al* . (1992) reported occurrence of only 5 species of earthworms from East Khasi hills of Meghalaya. Due to the presence of high contents of organic acids and fibers, pineapple leaves takes a very long time to degrade. So, the top soils of pineapple plantation never contain a rich nutrient pool. Endogeic *D. assamensis* was the dominant species with its highest biomass, density, relative abundance and frequency. According to the authors (Dey and Chaudhuri, 2014), this was due to individual plant species effect i.e., as *Ananas comosus* (pineapple) favours *D. assamensis*, a native endogeic species over other earthworm species. Interestingly, with increase in plantation age, fruit yield becomes drastically reduced leading to sudden decline in human interference with the increase in diversity of earthworm species.

Paddy (Tripura)

Paddy is the staple food of most of the NE states and its cultivation accounts for more than 80% of the total cultivable land. Due to its periodic submergence in water, paddy plantations have typical hydromorphic clay -rich acidic soils which are quite different from the other terrestrial land use systems. In Tripura manual tillage with limited application of fertilizers is usually practiced in the state as most of the farmers are poor with limited or no mechanization of agricultural tools. Dhar and

Chaudhuri (2020a) reported 7 species (*Glyphidrilus* sp., *Drawida assamensis*, *Drawida papillifer papillifer*, *Drawida* sp. *Metaphire houlleti*, *Perionyx excavatus* and *Pontoscolex corethrurus*) of earthworms from the paddy plantations of Tripura. *Glyphidrilus*, a native endogeic species dominates (RA 55.72%) the paddy plantations. The ratio of exotic to native species is 0.28 which is quite low compared to many terrestrial systems.

Flower (Tripura)

Tripura has, about 108 ha, including 4.6 ha protected and 103.40 ha open field cultivation of flower till 2009-10 (De and Singh, 2016). Floriculture in the state is done in sandy loam soils having slightly acidic pH and rich organic matter. Dhar and Chaudhuri (2020b) reported 7 species earthworms (Table 5) among which 2 were exotic and 5 were native. The most dominant species was an exotic anecic species, *M. houlleti* (42.86%). In the soils of the flower agro-ecosystems, anecic earthworms were the dominant functional group contributing 73% and 89% of earthworm density and biomass respectively. Complete absence of epigeic earthworms in the flower garden was due to periodic application of chemical fertilizers and weedicides which prohibit their surface dwelling activities (Dhar and Chaudhuri, 2020b).

Banana (Tripura)

Banana plants grow in well drained, acidic red laterite soils of Tripura. The plantation soils are well drained, fertile, moisture retentive containing plenty of organic matter.Twelve earthworm species (Table 5) were reported from the banana plantations of Tripura (Dhar and Chaudhuri, 2020b). The banana plantations are dominated by endogeic species, *P corethrurus* (RA 41.22%). The exotic to native ratio is 0.50 (Dhar and Chaudhuri, 2020b).

Pasture (Tripura)

Pastures constitute only 1% of the total land area in NE India. A pasture ecosystem consists of a variety of herbaceous vegetation along with other plant species from various families like Fabaceae (*Desmodium*, *Mimosa*), Lamiaceae (*Clerodendrum infortunatum*) and Cyperaceae (*Cyprus rotendrus*) etc. The soils are usually poor in organic matter having pH less than 6. Earthworms are known to play the role of major decomposers in pastures. Debbarma and Chaudhuri (2019) reported 11 species of earthworms from pastures of West Tripura (Table 5). The most dominant earthworm species was *L. mauritii*. Out of 11recorded species 3 were exotics and the rests were natives.

Oak plantations (Manipur)

Oak stands usually occur in higher altitudes of temperate Himalayas in acidic soils. Although an important plant species in mountain vegetation of NE, fewer studies have been done on earthworm community structure of oak plantations of NE India.Haokip and Singh (2017) reported only 4 species of earthworms in the managed oak plantations of Manipur (Table 5). Out of 4 species, two were endogeic and two anecic. Three earthworm species were exotic (*Pontoscolex corethrurus, Amynthas cortices* and *A. morrissi*) and only one native (*Drawida* sp.). *P. corethrurus* dominated the oak plantations. The higher number of exotics than natives in oak plantations is really an exception as compared to other land use systems of NE where although in some land use systems (rubber,tea) exotics are dominant but the numbers of native earthworm species are always higher than the exotics. According to Haokip and Singh (2017), high anthropogenic interference like pruning of trees, removal of forest floor litter by burning in the managed oak plantations lead to lesser soil nitrogen with lesser earthworm diversity.

Waste deposit sites (Tripura)

Studies on earthworm community structure in waste deposit sites in Tripura were done recently by Debnath and Chaudhuri (2019) and Debnath (2021). Four types of waste deposit sites studied in Tripura were municipal solid waste deposit site (MSD), sawdust heaps, poultry wastes and cow dung deposit sites. Community compositions of each of these waste deposit sites were substantially different from each other. Municipal solid waste deposit sites were dominated by *L. mauritii* which had very high relative abundance (88.2%).Seven earthworm species were reported from MSD (Table 5) out of which 4 were exotic (*M.posthuma*, *M. houlleti*, *D. bolaui*, *P. corethrurus*) and rest three native (*L. mauritii*, *P. excavatus*, *O. beatrix*). Among the waste deposit sites studied, sawdust heaps had the highest species diversity i.e. 12 species and the most dominant species was an exotic geophagous species *M. posthuma* (Table 5). Here also the exotic to native species ratio was high (0.71).Poultry wastes also had 11 earthworm species where dominance was shared by an epigeic species *D. bolaui* and the anecic species *L. mauritii* (Table 5). Here 4 of the 11 species were exotic. Eleven species of earthworms were also reported from cow dung deposit sites, the most dominant species being *P. excavatus*, a native epigeic species.

Earthworm density and biomass in different land use systems of NE and their relation with various diversity indices

In terms of community diversity, mixed forest seems to be most diverse ecosystem. Mixed forests in Manipur, Mizoram and Tripura showed very high Shannon diversity (H)indices ranging from 1.76 to 2.72. All the systems have very high evenness indices with many species sharing dominance among them (Bhaduria and Ramakrishnan, 1991; Chaudhuri and Nath, 2011) (Table 5) Semi-natural habitats like bamboo plantations (*Bambusa balcooa*, *B. cacharensis, B. bambos, B. polymorpha, Melocanna baccifera*) and pastures, Shannon diversity was of intermediate range (1.08 to 1.67). Among the pure monoculture systems highest diversity was found in unmanaged tea plantations of Tripura (0.89) and lowest in paddy plantations of Tripura (0.46). The land use systems which showed very low Shannon diversity were flower, paddy and municipal waste deposit sites (Table 5). Among different studied waste deposit sites, highest species diversity (number of species) and Shannon diversity was reported in saw dust heaps (12 species, H 1.64) and lowest in municipal solid waste deposit sites (7 species, H 0.42). Density and diversity are inversely related to each other. Ecosystems with high diversity and high evenness have low density of earthworms although many other factors can contribute to it and the operationally significant factors which regulate diversity, density and evenness in a community vary from one to another. For example in a natural mixed forest or a semi-natural habitat like bamboo plantations, spatial heterogeneity or microhabitat diversity may be a very important factor whereas in a

Table 5. Species diversity, population and community characteristics of earthworms in different land use systems of North-East India.

Land use System	No. of Species found	Density (ind. m^{-2})	Bio-mass (g. m^{-2})	Shan-non diversi-ty	Simpson domi-nance	Even-ness	Most dominant species (functional catego-ry)	Relative Abundance (%)	Reference
Broad leaf mixed forest (Meghalaya)	3	145	-	-	-	-	*T. horaii*	57.5	Bhadauria and Rama-krishnan, (1991)
							D. as-samensis	12.8	
							Perionyx sp.	12.2	
Natural mixed forest (Manipur)	12	-	-	2.72	-	0.75	-	-	Haokip and Singh, (2017)
Natural forest (Mizoram)	11	1353.6	-	2.23	0.10	0.93	-	-	Zodinpuii *et. al.*,(2019)
Jhum cultiva-tion (Mizoram)	9	857.6	-	2.07	0.14	0.88	-	-	Zodinpuii *et. al.*,(2019)
Mixed forest (Tripura)	10	69.01	45.24	1.76	0.20	0.83	*P. corethrurus*	27.98	Chaudhuri and Nath, (2011)
							Kanchuria sp.	15.61	
							M. houlleti	12.52	
							D. papil-lifer papil-lifer	12.67	
							D. as-samensis	17.31	
Bambusa cacharensis (Tripura)	10	73.82	31.26	1.67	0.22	0.73	*D. as-samensis*	32.68	Chaudhuri and Chakraborty ,(2019)
Sawdust heaps (Tripura)	12	95.4	112.4	1.64	0.25	0.71	*M. posthu-ma*	37	Debnath, (2021), Ph.D. thesis
							P. elonga-ta	25.3	
							P. corethrurus	14.01	
							D. bolaui	10.18	
Pasture (Tripura)	11	128.94	63.76	1.51	0.30	0.55	*L. mauritii*	34.14	Debbarma and Chaudhuri, (2019)
Bambusa bambos (Tripura)	11	117.14	36.66	1.46	0.31	0.61	*D. as-samensis*	39.93	Chaudhuri and Chakraborty , (2019)
Poultry waste (Tripura)	11	88.01	61.2	1.43	0.36	0.47	*L. mauritii*	27.3	Debnath, (2021), Ph.D. thesis
							D. bolaui	27.3	
							P. corethrurus	11.6	

Bambusa polymorpha (Tripura)	16	175.09	75.69	1.28	0.37	0.43	*P. corethrurus*	40.07	Chaudhuri and Chakraborty, (2019)
Melocanna baccifera (Tripura)	10	108.68	36.65	1.27	0.36	0.61	*M. houlleti*	36.59	Chaudhuri and Chakraborty, (2019)
Oak plantation (Manipur)	4	-	-	1.27	-	0.63	-	-	Haokip and Singh,(2017)
Cow dung deposit site (Tripura)	11	156.3	80.4	1.16	0.42	0.43	*P. excavatus* *L. mauritii*	59.01 12.8	Debnath, (2021), Ph.D. thesis
Bambusa balcooa (Tripura)	12	96.57	36.71	1.08	0.49	0.47	*P. corethrurus*	73.24	Chaudhuri and Chakraborty, (2019)
Tea (*unmanaged plantation*) (Tripura)	15	183.82	79.02	0.89	0.37	0.66	*D. assamensis*	40.50	Jamatia and Chaudhuri, (2017b)
Rubber plantation (Tripura)	10	115.41	45.91	0.86	0.62	0.41	*P. corethrurus*	76.53	Chaudhuri and Nath,(2011)
Banana (Tripura)	12	153.78	76.32	0.78	0.23	0.42	*P. corethrurus*	41.22	Dhar and Chaudhuri, (2020b)
Pineapple plantation (Tripura)	11	158.66	41.99	0.67	0.70	0.28	*D. assamensis*	82.52	Dey and Chaudhuri, (2014)
Tea (*managed plantation*) (Tripura)	13	205.79	54.32	0.66	0.73	0.36	*P. corethrurus*	56.63	Jamatia and Chaudhuri, (2017b)
Flower (Tripura)	7	185.85	91.78	0.60	0.32	0.66	*M. houlleti*	42.86	Dhar and Chaudhuri, (2020b)
Paddy (Tripura)	7	163.48	56.35	0.46	0.60	0.14	*Glyphidrilus* sp.	55.72	Dhar and Chaudhuri, (2020a)
Municipal waste deposit site (Tripura)	7	63.3	44.4	0.42	0.79	0.03	*L. mauritii*	88.2	Debnath, (2021), Ph.D. thesis
Agro forestry (Mizoram)	5	3-243	1.92-677.64	-	-	-	*Drawida* sp.	-	Lalthanzara *et. al.,*(2011)
Pine forest (Meghalaya)	3	120	-	-	-	-	*A.diffrigens* *T.horaii*	32.2 59.4	Bhadhauria and Ramakrishna, (1991)
Jhum cultivation (Meghalaya)	1-3	67.5	-	-	-	-	-	-	Mishra and Ramakrishna, (1988)

- Not reported

Monoculture plantation, level of anthropogenic interference may play the most important role in regulating community diversity. In specialized habitats like MSD site, the chemical nature of the waste usually determines the type of earthworm species, their density and diversity. The functional categories of earthworms (epigeic, endogeic, anecic) inhabiting a land use ecosystem is usually determined by the physicochemical properties of the soil in which they live which may in turn be influenced by other factors like litter chemistry and presence of fine and decayed roots in the soil. One interesting observation was that a good number of earthworm species found in different land use systems of different NE states were common, whereas many earthworm species reported by ZSI from the virgin ecosystems like remote forests of Arunachal Pradesh are not found in other land use systems infringed by human activities. This indicates that these species are more sensitive to disturbance and can't thrive in those habitats colonized by humans.

Species diversity and its regulatory factors in different land use systems of NE India

Out of 20 land use systems of NE India from which earthworms were reported, high species diversity was reported from rubber plantations (10 species), bamboo plantations (16 species), mixed forests (12 species) and pasture (11 species) (Table 5). The agro ecosystems showing low species diversity are pine plantation (3 species), agro forestry (5 species), oak plantation (4 species) and paddy plantation (7 species).These nine land use systems are dominated by exotic earthworm species and the rest are dominated by native species. Ecosystems like mixed forests and poultry waste heaps show shared dominance between native and exotic species (Table 5).

Various factors which influence the distribution and abundance of different earthworm species are-

Sampling effort/extent of work done

Very less intensive studies have been done on most of the agro ecosystems of NE India except for Tripura where extensive works have been done in agro ecosystems like rubber, tea and bamboo etc. Due to greater sampling efforts in these plantations (in Tripura), it is very likely that more species were reported in these systems compared to other systems where such system wise studies are very less or totally lacking. That sampling effort has a great relationship with species richness in pineapple and mixed fruit plantations have been determined by Dey and Chaudhuri (2013).

Habitat/ spatial heterogeneity

In bamboo plantations and mixed forests of Tripura, the species diversity of earthworm is high. One of major reasons for it is the spatial heterogeneity with more microhabitat diversity. According to Chaudhuri and Chakraborty (2019), the Shannon diversity (H) in various bamboo species of Tripura ranges from 1.08-1.67 which approaches to polyculture conditions. Mixed forests of Tripura also show Shannon's index of 1.76 (Chaudhuri and Nath, 2011).

Anthropogenic interference

Studies from rubber plantations (Nath and Chaudhuri, 2010), tea plantations (Jamatia and Chaudhuri, 2017b) and bamboo plantations (Chaudhuri and Chakraborty, 2019) of Tripura show that more anthropogenic interference in habitats leads to higher dominance of exotic species and loss of diversity in most of the habitats. The invasive status of *Pontoscolex corethrurus,* an exotic Brazilian earthworm has also been established in many ecosystems of the world (Fragoso *et al .,* 1999; Hendrix *et al .,* 1999; Hendrix and Bohlen, 2002). Research works in rubber and bamboo plantations clearly indicate that increase in the exotic species coupled with higher dominance indices and greater relative abundance of this species and very high anthropogenic disturbance in these habitats had led to lesser species diversity of native species in these habitats. Chaudhuri *et.al* (2013) reported that with increase in the age of rubber plantation density and biomass of earthworms increase. In the pineapple plantations of Tripura an increase in the number of earthworm species has been reported by Dey and Chaudhuri (2012) (7 species in 1-5 year plantation whereas 11 species in 30-35 year old plantations with increase in the age of plantations. According to the authors with the increase in plantation age, fruit yield becomes drastically reduced which led to sudden decline in human interference and a consequent increase in the number of earthworm species.

Individual tree/plant species effect

From some plantations 'individual plant species effect' has been reported. For example, dominance of *D. assamensis*, a native species, reported from the pineapple plantations of Tripura was due to acidic nature of the soil in the plantations and acidophilic nature of the species. Likewise, dominance of *P. corethrurus* in the rubber plantations of Tripura has been linked with rubber plant, both the species *P. corethrurus* and Rubber being native to Brazil.

Habitat and soil characteristics

Paddy plantations in Tripura has much less species diversity (7 species) compared to many other agro-ecosystems like rubber, tea and bamboo. Survival of earthworm species in semi-aquatic habitats requires specialized adaptations for the concerned earthworm species often not found in the terrestrial species. Thus *Glyphidrilus* being a semi-aquatic species was the most dominant earthworm species in the paddy plantations. This species showed some interesting adaptations such as presence of 'wings' (an expanded epidermal structure) at clitellar region which is a vascularized organ evolved for respiratory function in an aquatic habitat (Dhar and Chaudhuri, 2020a). Another interesting behavioral adaptation in the same species was placement of their quadrangular posterior body end above the surface of the wet paddy soil especially during afternoon and evening to form U-shaped channels which ensure water and air circulation down the borrows. Interestingly, in the paddy plantations of Tripura there was complete absence of the earthworms of Octochaetidae family. Although soils in India are dominated by endogeic species of earthworms, functional status of their ecological categories change with variations in land use systems. For example,rubber, pineapple, tea, paddy, banana, oak plantations show dominance of endogeics whereas flower garden, pasture and MSD sites showed dominance of anecic earthworm species. Four of 5 bamboo species showed dominance of endogeic worms, whereas, mixed forests of Tripura had shared dominance of both endogeic and anecic species. Dominance of endogeic earthworms in tropical ecosystems is due to the fact that tropical soils are nutrient poor due to rapid turnover of nutrients and oxidation of soil carbon due to heat where endogeic species survive well (Kale, 1998).

Since the amount of organic matter is limiting in tropical soils, endogeic earthworms generally persist as they only ingest large amount of soil with poor nutrient content to meet their energydemand. Reasons for dominance of anecic species in flower garden, pasture, solid waste deposit sites and *M.buccifera* bamboo plantations are diverse. In flower gardens high availability of easily decomposable leaf bases and flower petals forms a rich food base for phytogeophagous anecic earthworms, whereas, in pastures anecic worms like *Lampito mauritii* dominate due to detritus and nematode feeding preference, greater polytrophic adaptation and higher tolerance to changing microhabitats (Debbarma and Chaudhuri, 2019). Dominance of anecic earthworms in solid waste deposit sites was certainly due to very high organic matter content in the habitats which is not favourable for endogeic species (Debnath and Chaudhuri, 2019).

Land use history

Most of the land use systems of Tripura like rubber, bamboo, tea plantations show coexistence of native species with the exotic species. This is unlike many Central American countries like Mexico where natives have been replaced by exotic species. Most of the agro-ecosystems of Tripura like rubber and tea are relatively new and has retained many of the original native species. This is especially true for those native species with wide range of ecological tolerances like *Drawida assamensis.*

Agricultural intensification

Earthworm community composition also dependson the amount of agricultural intensification. Usually, lesser the intensification, greater the diversity of species in the agro-system. For example paddy plantations in Tripura harbour only 7 earthworm species because of its intense agricultural activities and semi-aquatic habitat. Similarly unmanaged tea plantations of Tripura were reported to have more earthworm species than managed plantations as the latter had more intense agricultural practices with higher anthropogenic interference. Studies by Zodinpuii *et. al.* (2019) on shifting cultivation (Jhum) in a hilly terrain of Mizoram clearly indicate that traditional shifting cultivation adversely affects earthworm density and diversity due to habitat disturbances, reduced food availability and changes in the soil physicochemical properties.

Age of the land use system

Age of the land use system and change in the physiology of the vegetation, anthropogenic influences and interferences with aging of the land use system has an important bearing on the earthworm community composition. Works on rubber, pineapple and Jhum fallows of NE India clearly indicate this. Rubber plantations in Tripura are not very old and were done as part of wasteland reclamation by the govt. of Tripura. Considering the fact that rubber is a monoculture, the earthworm species diversity as reported in the state along with higher diversity of native species than exotic ones point out to the fact that in most of the cases the original earthworm communities are retained in the plantations although there have been infringement of the exotic species especially *P. corethrurus*. Both in rubber and pineapple plantations of Tripura there was increase in the density and biomass of earthworm species with increase in the age of the plantations. Interestingly in the rubber plantations, biomass and densities of the exotic species were higher in the younger plantations which decreased with increase in the age of the plantations whereas for the native species the case was just the reverse. Their biomasses and densities increased with an increase in the age of the plantations. In fact, with the increase in plantation age, rubber/fruit (pineapple) yield declines drastically leading to gradual decrease in human activities with concomitant increase in both diversity and density of the native species. Earlier Mishra and Ramakrishnan (1988), Bhadauria and Ramakrishnan (1991) also recorded an increase in earthworm diversity with the increase in the age of the plantations in pine, forest ecosystems and Jhum fallows of Meghalaya. However once a climax community is firmly established and stabilized, it appears that diversity may slightly decrease and is labeled. In such a community perhaps only 'habitat specialists' can thrive well. Thus the 'intermediate disturbance' hypothesis given by Stiling (2001) seems to work out in these ecosystems.

Ecological tolerance of the species

The earthworm species which are reported from most of the land use systems of NE India are *Pontoscolex corethrurus*, *Metaphire houlleti*, *Drawida assamensis*, *Drawida papillifer papillifer* and *Perionyx excavatus*. Two of the former species are exotic and rest three species are native ones. All these species show wide range of ecological tolerance to various edaphic factors (Table 6).

From the entire NE *Pontoscolex corethrurus*, has been reported from almost 13 land use systems, *Metaphire houlleti* from 13 systems, *Drawida assamensis* from 11 systems, *Drawida papillifer papillifer* from 10 systems and *Perionyx excavatus* from 6 land use systems (Table 7). *Pontoscolex* has been reported from temperatures as low as 17ºC from nursery stocks of Assam (Rajkhowa *et al .,* 2014) to temperatures as high as 29ºC in the paddy plantations of Tripura (Dhar and Chaudhuri, 2020a).

Drawida is a genus which has been reported from almost all the land use systems of NE states of India. Different species of *Drawida* dominate agro forestry and Jhum cultivations of Mizoram. Unmanaged tea plantations, pineapple plantations and two species of bamboo (*B. cacharensis* and *B. bambos*) plantations show the dominance of native endogeic *Drawida assamensis*. Dey and Chaudhuri (2014) attributed the dominance of *D. assamensis* to its acidophilic nature which is favourable for its growth and reproduction in acidic soil of pineapple plantations.

Species wise density variations and relationship with edaphic factors in different land use systems

Table 7 shows species wise population densities in various land use systems and table 6 their relation with various edaphic factors. Data regarding species wise distribution of various population characteristics (like density, frequency, relative abundance) and relationship with edaphic factors is being sparingly reported except for some detailed analysis in some land use systems of Tripura by Chaudhuri and his co-workers (Chaudhuri *et al .,* 2008; Dey and Chaudhuri, 2014;Jamatia and Chaudhuri, 2017a; Chakraborty and Chaudhuri, 2017;Debbarma and Chaudhuri, 2019; Dhar and Chaudhuri, 2020). It reveals that most of the earthworms were reported from sandy loam and clay loam soil (Table 6). Most of the species were reported from soil temperature ranging from 20ºC-30ºC, moisture 15-40 g%, pH 4.47-7.6 and organic matter content from

1.13- 3 g%. The most common species reported from almost all the land use systems were *D. assamensis*, *M. houlleti* and *P. corethrurus* (Table 7).

All these species show very wide range of tolerance to various edaphic factors. In general the genus *Drawida* is very common in NE India with at least one species from each state. In particular, *D. assamensis* has been reported from almost all land use systems of Tripura except in municipal solid wastes. The metallic content was probably toxic for the species which however was in significant numbers in tea, paddy, banana, fruit, bamboo, pastures and even in cow dung heaps. An extremely high density of the species (131ind/m^2) has been reported from pineapple plantations of Tripura. According to Dey and Chaudhuri (2014) this is probably due to the acidophilic nature of the species which prefer the acidic soils of pineapple plantations to soils of other land use systems. *P. corethrurus*, which acquired invasive status in many tropical ecosystems is also found in many land use systems of NE such as rubber plantations (88.32 ind/m^2), banana plantations (76.63 ind/m^2) of Tripura and oak plantations (112.67 ind/m^2) of Manipur. The semi-aquatic species *Glyphidrilus sp.* has been reported to have very high density (88.68ind/m^2 ref) from paddy plantations (Dhar and Chaudhuri, 2020). Since this species is a 'habitat specialist' with narrow range of ecological tolerance, it thrives well in semi aquatic habitat. High densities of *Lampito mauritii* have been reported from municipal solid waste sites and cow dung heaps (Table 7). Other species which are reported from these waste deposit sites in high densities are *D. bolaui*, *M.posthuma* and *P. excavatus*. This indicates that the above-mentioned species (*Lampito mauritii*, *D. bolaui*, *M. posthuma*, *P. excavatus*) may play an important role in solid waste management (Debnath and Chaudhuri, 2019). According to Ismail (1993), a combination of epigeic earthworm *P. excavatus* and anecic *L.mauritii* act well for efficient organic waste management.

Most of the other species (Table 7) show low density mostly owing to narrow ecological tolerances (Table 6). For a far greater number of species as reported from NE, their required soil ecological factors are not known. Most of the earthworm species reported on the basis of taxonomic surveys in remote hilly terrain are not found in the studied land use systems as these edaphic factors probably do not meet the ecological requirement of those species.

Endemic and rare earthworms of NE India

Very little studies on earthworm diversity and taxonomy have been done on the states of Arunachal, Assam and Nagaland. Most of the species recorded from Assam by Rajkhowa *et al* . (2014) have been reported from either Meghalaya or Tripura. Most of the studies done much earlier in Arunachal Pradesh and Sikkim were by ZSI (Julka, 1976, 1977;Julka and Halder,1977; Halder, 2003) were system independent taxonomic surveys in the hitherto unexplored terrenes (forests and riverbanks) of these states. Consequently, most of the species discovered are rare and is not found in the agro ecosystems of the more explored states like Tripura and Meghalaya. From the studies of the land use systems of Tripura, Meghalaya, Mizoram, Manipur and Assam, following generalizations can be made:

1. Many species of *Eutyphoeus* like *E. comillahnus*, *E.orientalis*, *E.scutarius*, *E.turaensis* and *E.gammiei* have only been reported from Tripura. *Eutyphoeus comillahnus* is a native endogeic species but is widely distributed in diverse habitats of Tripura. *E. comillahnus* is a unique species which is found only in Tripura of India. Although its biomass is extremely low compared to some common native species, among the different land use systems, maximum density and biomass of the species were reported from pastures of Tripura (Debbarma and Chaudhuri, 2019, table 7). In terms of tolerance to various edaphic factors, this species shows intermediate values (Table 6). *E. turaensis* and *E.orientalis* are however extremely rare species reported only in very few land use systems (Pasture, tea,bamboo) of Tripura and have extremely narrow range of ecological tolerance to various edaphic factors (Table 6). Some other species of *Eutyphoeus* like *E. gigas*, *E.assamensis*, *E.festivus* and *E.callosus* have been reported from Tripura, Mizoram and Meghalaya. Most of them are reported from 2-3 landuse systems only. *Eutyphoeus mizoramensis* has been reported only from agroforestry systems of Mizoram (Julka *et al* ., 2005). Three new species of *Eutyphoeus* i.e. *E. kempi* and *E. nepalensis* from Meghalaya (Thakur *et al* ., 2020) and *E.marmoreus* from Nagaland (Thyug, 2019) have recently been reported.

2. *Lennogaster chittagongensis* and *L.yeicus* are two species reported only from Tripura in NE which have very low density, frequency and relative abundance. *Lennogaster chittagongensis* has been reported only from unmanaged tea plantations, *Bambusa polymorpha* and *Bambusa bambos* plantations and rubber plantations of Tripura in the entire NE whereas *L. yeicus* has been reported from tea plantations, *B. cacharensis* and *B. polymorpha* and rubber plantations of the state. Both the species seem to appear in semi-natural habitats like bamboo plantations, unmanaged tea gardens or newly established rubber gardens.

3. Although *M. houlleti* is a common species in NE, *M. anomala* has been reported from mixed sub-tropical forests of Manipur only while *M. planata* and *M. peguana* from pastures and around cow dung pits of Tripura only.

4. *Kanchuria* is a genus which has been only reported from various land use systems of Meghalaya, Manipur and Tripura. *Kanchuria* sp1 is a new species reported first from rubber gardens of Tripura but latter on reported from various diverse plantations of Tripura such as tea, bamboo, mixed forest,pineapple plantations, mixed fruit plantations, pastures and even cow dung heaps of Tripura (Table6). Second highest density, highest biomass and frequency of this species have been reported from mixed forests of Tripura by Chaudhuri and Nath (2011). Other rare reported species are *Kanchuria summerianus*, *K. octotheca* and *K. turaensis*.*K. summerianus* has been reported from Tripura, Manipur and Meghalaya from rubber, pineapple and reserve mixed forests. Kharkongor (2018) reported *K. octotheca* and *K. turaensis* from Meghalaya only in NE. Lone *et al* . (2020), described 4 new species of Kanchuria – *Kanchuria daribokgrensis, Kanchuria karorensis, Kanchuria makhulensis* and *Kanchuria mohiskulensis* from reserve forests (Garo and Khasi hills) of Meghalaya which are new to science.

5. Although *Amynthas alexandri* is relatively a common species reported from many land use systems of NE, other species of *Amynthas* has been reported mostly from forest ecosystems and river banks. *Amynthas diffrigens* has been reported from Pine forests of

Table 6. Earthworm species reported from different land use systems of north-east India and the range of edaphic variables in which they appear.

Earthworm species	Soil types in which mostly found	Average soil temperature range in which it appears (ºC)	Average soil moisture range in which it appears (g %)	Average pH range in which it appears	Average organic matter range in which it appears (g %)	Land use systems in which reported
A. alexandri	SnL, CL, SiL, SCL	20.00-27.73	10-36.6	4.47-7.00	0.5-2.5	T, B, MFr, MF, Sc, P, Ps,R
D.assamensis	S, SCL, CL, SiL, SnL	11-33	12-46.84	4.47-6.71	1.21-6.28	T,B,MF,R,Ps,CWP ,MFr,P,Pdy,Sc
D. papillifer papillifer	SnL,SCL, CL,SiL	25.4-27.73	15.22-26.44	4.47-5.52	1.23-2.51	T,B,R,MF.Pdy,MFr,P,Ps
D.nepalensis	SiL,SnL, CL	18.6-26.3	10-40	4.41-5.83	0.5-2.5	MFr,P,Ps,B,MF,Sc
E.comillahnus	SnL, SCL	25.64- 30	12.92-40	4.5-6.4	0.5-2.7	T, B, R, MF,Ps, Mfr, P, CWP
E. orientalis	S, SCL	25.68-27.73	15.62-19.59	4.4-5.3	1.63-2.5	T, B
E. scutarius	SnL, SCL	25.58-28.00	15.62-40	4.47-7.00	0.5-3.14	T,R,B, MFr, P,Ps
E. turaensis	CL, SiL	20-27	10-40	4.8-7.0	1.8-1.9	R,Ps
E. gigas	SnL, CL	22.0-27.73	17.51-40	4.51-7.0	0.5-2.51	T, B, R, MF ,P, Mfr, Ps, Sc
D.bolaui	SnL, SCL	24-30	13.09-55	4.47-7.19	0.94-11.45	T, CWP, MF, B, R, Ps, MSW
O.beatrix	SnL,SCL	25.64-31.20	15.62-46.25	4.47-7.43	1.30-2.51	T,B,R,Ps, CWP,MSW
Glyphidrilus sp.	CL	28.13	37.76	4.95	1.56	Pdy
Kanchuria sp.	S,SnL, SCL, CL	25.64-27.73	15.62-23.84	4.47-5.33	1.36-2.51	T,B,R,MF
L.mauritii	SnL, LC, SiL	20.8- 28.4	14.79-32.12	5.8-7.62	1.13-9.23	Bnp,FP,Ps,MSW, CWP,MFr,B,As
L .chittagongensis	S,SnL, SCL,CL	24.81-29.55	15.62-45.34	4.47-7.77	1.63-7.74	T,B,R,CWP
L. yeicus	S,SnL, SCL, CL	25.68-27.73	15.34-17.51	4.47-5.36	1.63-2.11	T, B ,R
M. houlleti	S,SCL,SnL,CL,SCL , SiL	11-33	10-55	4.47-7.6	0.5-8.03	Sc,MF,T,B,R,Ps,CWP,MSW,MFr,P,Pdy,OF,Agf
M. posthuma	SnL,SiL, LS, CL	22.8-30	10-40	5.02-7.6	1.36-8.5	B,Ps,CWP,MSW, MFr,P
P.excavatus	CL,SiL	20.8-29.87	18.41-40.20	5.07-7.02	1.16-8.43	B,CWP,MSW,MFr ,Pdy,Agf,MF,Sc,As
P.corethrurus	S,SnL, SCL, CL,SiL	17.00-29.70	15.04-33.77	4.47-7.03	0.07-3.07	OF,T,B,R,MF,Ps, MSW,CWP,MFr,P, Pdy,MF,Ns

S- Sandy soil, SnL- Sandy loam, SiL- Silty loam, CL- Clay loam, SCL- Sandy clay loam, LC- Loamy clay, Ls- Loamy sand, T= Tea, B= Bamboo, MF= Mixed forest, R= Rubber plantation, MFr= Mixed fruit, P= Pineapple, CWP= cow dung pits, Ps= pasture, MSW= Municipal solid waste, Sc= Sifting cultivation, Pdy= Paddy cultivation Bnp- Banana plantation, FP- Flower plantation, As- Agricultural system, OF-Oak forest, Agf- Agroforestry, Ns- Nursury stock.

Table 7. Species wise earthworm population densities in various land use systems of Northeast India
-not reported/species density not reported

Earthworm species	Earthworm density in different land use systems (ind/m^2)														
	T	**R**	**P**	**Pdy**	**FP**	**BNP**	**MFr**	**OF**	**B**	**Ps**	**Sc**	**AgF**	**MF**	**MSW**	**CWP**
A. alexandri	0.36	-	-	-		0.62	0.13	-	0.70	-	-	-	-	-	-
D.assamensis	14.34	3.41	130.93	14.28	6.4	17.31	46.27	-	13.14	20.27	-	-	4.66		24.00
D. papillifer papillifer	6.55	1.16	4.93	9.2	4.63	19.52	11.87	-	6.39	11.87	-	-	3.78	-	-
D.nepalensis	-	-	0.67	-	--	-	2.40	-	0.08	-	-	-	30.67	-	-
E.comillahnus	0.36	0.92	0.40	-	-	5.66	1.33		1.07	7.09		-	1.45	-	-
E. orientalis	0.07	-	-	-	-	-	-	-	0.16	-	-	-	-	-	-
E. scutarius	3.27	0.64	0.27	-	-	-	1.07	-	-	-	-	-	-	-	-
E. turaensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. gigas	0.37	1.12	0.27	-	-	-	1.33	-	0.57	-	-	-	2.40	-	-
E.gammiei	0.95	-	0.13	-	-	-	0.67	-	-	-	-	-	-	-	19.5
D.bolaui	0.14	-	-	-	-	-	-	-	0.12	0.51	-	-	19.83	59.8	67.6
O.beatrix	2.81	0.13	-	-	9.78	12.91	-	-	1.28	4.05	-	-	-	16	16
Glyphidrilus sp.	-	-	-	88.68	-	-	-	-	-	0.14	-	-	-	-	-
Kanchuria sp.	1.74	5.39	1.20	-		0.86	0.93	-	0.95	7.75	-	-	11.12	-	16
L.mauritii	-	-	-	-	37.2	7.79	1.20	-	0.28	44.31	-	-	-	82.3	76.7
L.chittagongensis	0.21	-	-	-		5.83	-	-	0.37	-	-	-	-	-	24
L. yeicus	0.64	-	-	-	-	-	-	-	0.41	-	-	-	-	-	-
M. houlleti	11.6	1.86	3.07	0.74	56.43	14.43	5.33	51.08	10.5	11.66			14.13	16	40.08
M. posthuma	-		0.53			2.77	1.20		1.77					39.5	54.2
P.excavatus	-	-	-	0.33	-	1.17	1.07	-	0.12	-	-	-	-	30.51	126
P.corethrurus	21.73	88.32	16.53	0.33	8.28	76.63	18.67	112.67	15.38	15.06			19.30	16	37.30

T= Tea, B= Bamboo, MF= Mixed forest, R= Rubber plantation, MFr= Mixed fruit, P= Pineapple, CWP= cow dung pits, Ps= pasture, MSW= Municipal solid waste, Sc= Shifting cultivation, Pdy= Paddy cultivation Bnp- Banana plantation, FP- Flower plantation, OF-Oak forest, Agf- Agroforestry.

Meghalaya and Agricultural systems of Assam. *Amynthas morrisi* and *Amynthas corticis* have been reported from oak plantations of Manipur. The latter species has also been reported in shifting cultivation of Mizoram by Zodinpuii *et al* . (2019). Vabeiryureilai *et al* . (2020) however opined about the richness of the genus *Amynthas* in the NE region. They confirmed the presence of 10 species of this genus including three species i.e. *Amynthas hawayanus*,*Amynthas hupeiensis* and *Amynthas incongruous* newly reported from this region.

6. Six species of *Tonoscolex* have been reported from NE India. Three of the 6 species (*Tonoscolex oneilli*, *Tonoscolex indicus* and *Tonoscolex kabakensis*) reported were from Arunachal in virgin forests or soils of bamboo forests.

7. Only two species of *Nelloscolex* viz. *Nelloscolex strigosus* and *Nelloscolex burkilli* has been reported from entire NE India. *Nelloscolex strigosus* has been reported from 5 year fallow land after slash and burn cultivations and pineapple plantations from Meghalaya whereas the other species has been reported from forest soil in Meghalaya and from rubber plantations of Tripura.

8. As many as 23 species of *Perionyx* has been reported from NE. Although *Perionyx excavatus* is common native species reported from various land use systems, most of the other species were reported from virgin forests of Arunachal or Meghalaya. *Perionyx macintoshi* has been reported from agro forestry, natural forests and shifting cultivation of Mizoram and from the rubber plantations of Tripura.

9. Three species of *Glyphidrilus* (*Glyphidrilus gangeticus*, *Glyphidrilus spelaeotes* and *Glyphidrilus* sp.)have been reported from the semi-aquatic habitats of Tripura (Paddy soil, pond soil, sewage systems) in NE which are not found in other land use systems.

10. Five species of *Plutellus* (*Plutellus mishmiensis*, *P. bahli*, *P. daminensis*, *P. richikensis* and *P.taksingensis*) have only been reported from forests ecosystems of Arunachal Pradesh.

11. *Gordiodrilus elegans* of Ocnerodrilidae family has been reported from Tripura (Mixed forest, Rubber), Assam (upland soil) and Sikkim (Tiwari *et al* ., 2020).

12. Few species from Lumbricidae like *Dendrobaena rubida*, *Aporrectodea trapezo*ids have been also reported from Arunachal and Meghalaya.

Impact of change in land use patterns on earthworm community structures in North-East India

Being mostly a hilly terrain, the main type of agriculture in NE India has been the slash and burn or jhum cultivation being traditionally practiced from antiquity by the natives of the land. Paddy being the staple food of the region (Debnath *et.al,* 2017) was mainly grown by this method traditionally. The conventional methods of paddy cultivation came much later. Apart from this, the main cash crops of this region are tea and rubber (especially in Tripura). The Tea, as a crop was first introduced by Robert Bruce in 1823 when it was discovered as a wild bush growing in upper Brahmaputra valley and the beverage is now cultivated and consumed in all the NE states. Rubber plantations were introduced in Tripura in 1969 by the forest department to check soil degradation due to slash and burn agriculture practiced by the local tribal people and also as a part of their rehabilitation programme(Chaudhuri *et.al*, 2008). Pineapple, an important fruit crop, originally introduced in India by Portuguese in 1548 (Bartholomew *et al* ., 2003), is also widely cultivated in the hill slopes of Tripura, Assam, Manipur, Meghalaya and Nagaland. Another naturally growing commercially viable product of the region is bamboo. As many 90 species of bamboos naturally grows in the NE region of India (Loushambam *et.al.,* 2017). Bamboo plantation in NE got a boost with the establishment of National bamboo mission in 2006-2007.

Slash and burn agriculture and introduction of cash and fruit crops (Tea, rubber, pineapple) led to significant changes in the land use pattern of the region and subsequent changes in the earthworm communities and population structures which however is not extensively documented because of the lack of intensive and in-depth ecological studies in the region. Review of research literature (Tiwari *et.al* 1992, Chaudhuri and Nath 2011, Dey and Chaudhuri 2014, Chaudhuri *et.al* 2016, Jamatia and Chaudhuri 2017b, Zodenpuii*et.al* 2019, Chaudhuri and Chakraborty 2019, Chaudhuri and Jamatia2021) however indicates a few but significant findings. Zodenpuii *et.al* (2019) in Mizoram reported that jhum cultivation sites had a significantly lower index of earthworm diversity and evenness but a higher index of dominance then the natural forests. There was a dramatic fall in the overall mean earthworm density in the jhum cultivation sites compared to the control natural forest sites. The introduction of rubber in the fallow lands of Tripura mainly intended to reduce soil erosion, however led to invasion of an exotic species of earthworm (*P.corethrurus*) with significant increase in the its density and biomass and significant decrease in density and biomass of the native species of earthworms residing there (Chaudhuri and Nath, 2011). Monoculture conditions and intensification of anthropogenic interference often leads to increase in dominance of few non-native species and decrease in overall diversity of the system. This observation corroborates well with the findings of Chaudhuri and Chakraborty (2019) in the bamboo plantations of West Tripura also. Among the five studied species of bamboo highest earthworm diversity was found in *Bambusa cacharensis* (local name *Bom*) with lowest anthropogenic practices in contrast with those of *Bambusa balcooa* (*Barak*) plantations which had the lowest earthworm diversity with highest anthropogenic interferences. Presence of highest number (5) of exotic species including high density of *P.corethrurus* in *B.balcooa* led to lowest earthworm diversity in these plantations compared to the other bamboo plantations. Jamatia and Chaudhuri(2017b)also reported 13 species of earthworms from the managed (high anthropogenic interference) tea plantations as compared to 15 species from the non-managed (low anthropogenic interference) tea plantations of Tripura. Significantly higher index of dominance and lower diversity index were observed in the managed tea plantations compared to those of non-managed tea plantations.

In the pineapple plantations of West Tripura and East Khasi hills of Meghalaya, Dey and Chaudhuri (2014) and Tiwari *et.al* (1992) however reported dominance of *Drawida assamensis*, a native endogeic earthworm species. The mean earthworm population density was significantly higher and biomass significantly lower than in the adjacent mixed fruit plantations. Both in pineapple plantations (Chaudhuri *et.al*. 2016)and tea plantations (Chaudhuri and Jamatia 2021) a significant increase in earthworm population density along with .increase in crop yield occurred following application of increased doses of vermicompost in the cultivation sites. This clearly indicates that the practice of organic farming leads to the conservation of earthworm population under field conditions. As the age of the plantations increase with concomitant increase or decrease of human activities, there is subsequent increase or decrease in earthworm diversity as has been seen in most of the land use systems (Chaudhuri *et.al* 2013, Dey and Chaudhuri 2014). However, unlike many countries of Central America and Mexico, many of the native species of earthworms co-exist with the exotic species in the various land use systems of NE. This may be due to the fact that the land use systems introduced like tea, rubber or pineapple in the NE are relatively new i.e. not so old and thus the original native earthworm species were retained along with the exotics in these land use systems

CONCLUSION

From this review, it becomes amply clear that the reported earthworm diversity of the north-east India is a gross underestimation of the actual species richness of the region. Except for states like Tripura and Meghalaya where some substantial studies have been done on earthworm ecology in different land use systems, the same is lacking in most of the other states of NE. One time taxonomic surveys or expeditions conducted by ZSI in some of the NE states are more than 40 years old and no new studies have been initiated. Even with so little field studies in states like Arunachal Pradesh a highest number of 52 species have been reported which is almost equals to number of species being reported from Meghalaya, a state having a total area about one-fourth of it. Having such a large area of the former (Arunachal) with high diversity of habitats in it, it is most likely that much more species are there yet to be discovered and reported. States like Assam and Nagaland has also remained practically unexplored in this context. The lack of trained field taxonomists and the harsh terrain of these states are the main hurdles for finding of more new species. Recently modern techniques of taxonomic delimitation like bar-coding using CO1 mitochondrial DNA has been initiated by some workers like Lone *et al* . (2020) and Lanthanzara *et al* . (personal communication), which has led to demarcation of some new species. It should be noteworthy that although integrated techniques (using the traditional and modern approaches like DNA barcoding etc.) of species delimitation are best for precise taxonomic studies but dearth of field morpho-taxonomists and ecologists in earthworm ecology in India should be a matter of grave concern. Nevertheless, NE India is a treasure trove in context of earthworm diversity. Even with the present estimates NE earthworm diversity represents 25-27% of earthworm diversity of the whole Indian subcontinent. Hence, massive explorations are required in this region to understand its true earthworm diversity status. Also land use system specific studies are much more required as most of the generalizations in this review are based on studies mainly from Tripura, Meghalaya and Mizoram and thus may not completely reveal the whole picture of earthworm ecology and species diversity of the region.

CONFLICT OF INTEREST

The authors declare no conflict of interest in this work.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Sourabh Chakraborty, BiplabDebbarma and Priyasankar Chaudhuri. The first draft of the manuscript was written by Sourabh Chakraborty and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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