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Seasonal distribution and abundance of earthworms (Annelida: Oligochaeta) in relation to the edaphic factors around Udupi Power Corporation Limited (UPCL), Udupi District, southwestern coast of India

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Abstract: Seasonal distribution and abundance of four species of earthworms belonging to three families—Rhinodrilidae (*Pontoscolex corethrurus*), Megascolecidae (*Megascolex konkanensis* and *Metaphire houlleti*) and Octochaetidae (*Karmiella karnatakensis*)—were studied in three habitats (residential, agricultural and forest) along with edaphic factors around Udupi Power Corporation Limited (UPCL), Karnataka, India between September 2014 and August 2016. Among the four species, *P. corethrurus* was collected throughout the year and was most abundant in residential habitats such as colacasia garden, coconut and banana pits. *M. konkanensis* was collected from coconut plantations, banana plantations and forest soil during monsoon and post-monsoon periods. *M. houlleti* was collected from manure heaps, coconut and banana pits of residential habitat, coconut plantations and forest soil. *K. karnatakensis* was collected from garden soil in residential habitat during the post-monsoon period, coconut plantations and soil mixed with forest leaf litter during monsoon and post-monsoon periods. The soil temperature differ significantly during different seasons in residential (P= 0.01) and agricultural (P=0.03) habitats whereas moisture shows highly significant difference in agricultural habitat (P=0.00037) during different seasons. *P. corethrurus* showed positive correlation with organic carbon during pre-monsoon and C/N ratio during monsoon in the residential habitat. It shows negative correlation with pH during the monsoon period. *M. houlleti* showed positive correlation with organic carbon in residential habitat during the pre-monsoon and in forest habitat during monsoon periods. *M. konkanensis* showed positive correlation with electrical conductivity in agricultural habitats during monsoon period. *K. karnatakensis* showed positive correlation with moisture during monsoon and with C/N ratio during post-monsoon period in forest habitats.

Keywords: Earthworm distribution, edaphic factors, Megascolecidae, Octochaetidae, Rhinodrilidae, Udupi Power Corporation Limited (UPCL).

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INTRODUCTION

India is a vast country with great diversity of plants and animals supported with tropical and sub-tropical climates. Soil faunal population is very important in many agro ecosystems; because the soil organisms promote soil fertility (Lee 1985; Werner & Dindal 1989). The major soil organisms include earthworms, centipedes, millipedes and microorganisms. Of these, earthworms are considered as one of the major soil invertebrates belonging to the phylum Annelida and class Oligochaeta. Oligochaetes are mainly divided into megadriles and microdriles. Megadriles live in both terrestrial and aquatic systems whereas microdriles prefer only aquatic systems. Globally, there are about 4,400 different species of earthworms (Reynolds & Wetzel 2017) and from India 505 species of earthworms (Julka 2014; Ahmed & Julka 2017; Narayanan et al. 2017) have been reported.

Diversity and distribution of earthworms have been studied from different parts of the world, viz., Bulgaria (Mihailova 1964; Stojanovic et al. 2012), Thrace (Mihailova 1966), Myanmar (Gates 1972; Reynolds 2009), Australia (Jamieson & Wampler 1979; Blakemore 2000; Blakemore & Paoletti 2006), Argentina (Mischis & Brigada 1985; Mischis 1992, 1993; Mischis & Righi 1999; Laura & Ines 2001), Turkey (Omodeo & Rota 1991), Australia, Japan and India (Blakemore 1994, 2004, 2006), Bangladesh (Reynolds 1994; Reynolds et al. 1995b; Das & Reynolds 2003), northern Neotropical region (Fragoso et al. 1995), Belize (Reynolds et al. 1995a), Mexico (Fragoso & Reynolds 1997), New Zealand (Springett et al. 1998), Faisalabad (Ghafoor & Qureshi 1999), Taiwan (Tsai et al. 2000, 2004), Gujranwala (Rana et al. 2002), north-west of the Iberian Peninsula (Monrey et al. 2003), central Terai region (Bisht et al. 2003), Philippines (James 2004), Taiwan (Tsai et al. 2004), Singapore (Shen & Yeo 2005), southern and eastern Uruguay (Grosso et al. 2006), Mexico (Huerta et al. 2007), North America (Reynolds & Wetzel 2008), northwestern England (Chamberlain & Butt 2008), Nicaragua (Sherlock et al. 2011), Hawaii (Reynolds 2015), Bermuda (Reynolds & Fragoso 2004), South America (Christoffersen 2008a,b, 2010; De-Assis et al. 2017), Guadeloupe Islands of West Indies (Csuzdi & Pavlicek 2009), Serbia and Bulgaria (Stojanovie et al. 2013), and Thailand (Chanbun et al. 2017).

The reports on Indian oligochaetes include, Karnataka (Kale & Krishnamoorthy 1978), southern India (Julka 1983), woodlands of Karnataka (Krishnamurthy & Ramachandra 1988), Kumaun Himalayan pasture soil (Kaushal & Bisht 1994), Western Ghats (Blanchart & Julka 1997), central Himalaya (Bhadauria et al. 2000), Tamil Nadu (Gobi & Vijayalashmi 2004; Kathireswari et al. 2005, 2008), Chennai (Begum & Ismail 2004), Rajasthan (Tripathi & Bharadwaj 2004), western Himalaya (Paliwal & Julka 2005), Pondicherry (Sathianarayan & Khan 2006), northern Indian states (Dhiman & Battish 2006), Tripura (Chaudhuri et al. 2008), Uttarakhand (Joshi & Aga 2009), southern Karnataka (Kale & Karmegam 2010), Garhwal Himalaya (Joshi et al. 2010), Kashmir Valley (Ishtiya & Anisha 2011), Dakshina Kannada District of Karnataka (Siddaraju et al. 2010), Jammu, northeastern India (Rajkhowa et al. 2014), and Kerala (Narayanan et al. 2016).

Earthworms feed on organic matter and litter. They enrich soil fertility by adding nutrients to the soil through their burrowing activities and are recognized as ecological engineers due to their strong interaction with soil functioning in the ecosystem (Jones et al. 1994; Lavelle et al. 1994). Earthworm casts are highly rich in organic matter compared to the non-ingested surrounding soil. The effect of earthworms on the dynamics of soil organic matter depends on the time and space (Mora et al. 2005). Earthworms are known to increase the transfer of organic carbon and nitrogen into soil through their gut microbial activities and they facilitate the stabilization and accumulation of soil organic matter (Desjardins et al. 2003). The cycling process of C and N in agro- ecosystems depends on the cropping system and management practices (Fonte et al. 2007). The earthworm species and their interactions also affect the nitrogen mineralization (Brown et al. 1999). They also increase the soil pH and promote the microbial activity in the soil. In addition, other nutrients such as N, P, K and Ca derived from earthworm urine and mucus are also involved in soil fertility (Parmelec et al. 1998).

Understanding the soil factors which control the abundance of earthworms and their strong interaction in maintaining the soil ecosystem functioning has gained widespread attention in recent years. Several studies have shown that a number of factors control the earthworm's density and distribution (Fonte et al. 2009). Huerta et al. (2007) have observed high earthworm abundance in soil with high organic matter in tropical rain forests. Management practices, however, alter the earthworm population density by altering the aggregation of soil organic matter (Fonte et al. 2009).

Most of the studies focussed on diversity and distribution of earthworms in natural habitats and agro ecosystems. A few studies have reported bio-indicator activities for earthworms for heavy metal pollutions in various habitats (Hook 1974; Spiegel 2002; Hobbelen et al. 2006; Suther et al. 2008). The present study records the seasonal occurrence and distribution of four species of earthworms in relation to the edaphic factors around Udupi Power Corporation Limited (UPCL), Udupi District of Karnataka, southwestern coast of India.

STUDY AREA

Udupi Power Corporation Limited (UPCL) (14.22305556^{0}N & 76.21138889^{0}E) is an important coal based thermal power plant, established in 2008. It is located to the north of Mangaluru, west of Belman and adjacent to the north-east of Padubidri in the village of Yellur, Udupi District, Karnataka, India and it is situated roughly 7–8 km from the coast (Arabian Sea), very close to the Shambhavi River. The study area covers the radius of about 10km around UPCL and the villages included are Bellibettu, Kaup, Kuthyaru, Mudarangadi, Nadsal, Nandikur, Padabettu, Yellur and Tenka-Yermal. The geographical coordinates in each habitat were noted using a Garmin eTrex GPS and a Google map was constructed using Google Earth (Image 1). The annual rainfall in Udupi District ranged from 3,184–3,575 mm. The elevation ranges from 5–51 m in the study area. The average soil temperature ranged between 26.5–29.2 ^{0}C. Soil texture varies from fine clay to loamy. The sampling sites were broadly divided into residential, agricultural and forest habitats. In the residential habitat, the major plants include: *Cocus nucifera* (Coconut), *Areca catechu* (Areca Nut), *Musa* spp. (Banana), *Psidium guajava* (Common Guava) and *Carica papaya* (Papaya). In the agricultural habitat, the major crops include, *Oryza sativa* (Paddy), *Cocus nucifera*, *Areca catechu*, *Musa* spp. and in the forest habitat the tree species include: *Tectona grandis* (Teak), *Millettia pinnata* (Indian Beech), *Mangifera indica* (Mango), *Borassus flabellifera* (Palmira), *Artocarpus heterophyllus* (Jack Fruit), *Alstonia scholaris* (Saptaparna), *Tamarindus indica* (Tamarind) and *Manikara zapota* (Sapodilla).

METHODS

Studies on distribution and abundance of earthworms (*Pontoscolex corethrurus, Megascolex konkanensis, Metaphire houlleti* and *Karmiella karnatakensis*) was carried out in residential, agricultural and forest habitats around Udupi Power Corporation Limited (UPCL) during pre-monsoon (February–May), monsoon (June–September) and post-monsoon (October–January) periods of September 2014 to August 2016. Sampling points were identified and soil was excavated from 30x30x30cm quadrants in each site in the selected villages. Available earthworms were collected by hand sorting method and brought to the laboratory along with soil samples in polythene bags. Specimens were washed with tap water and anesthetized in 30% ethyl alcohol, straightened and preserved in 5% formalin. Species were identified based on standard taxonomic keys of Julka (1988) and Blakemore (2006).

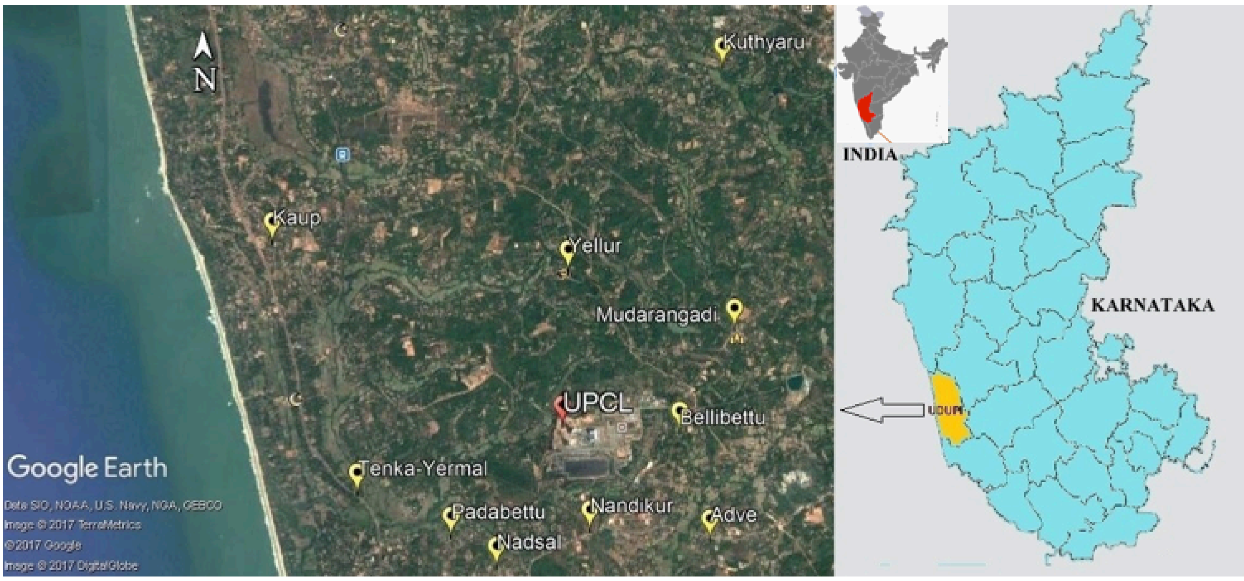

Image 1. Location map of Udupi Power Corporation Limited (UPCL) and sampling sites.

Soil analysis

In the earthworm sampled habitats such as residential and agricultural (in all seasons) and forest habitat (monsoon and post-monsoon seasons), edaphic factors were analysed by using standard protocols (Jackson 1973). Soil temperature was measured by using a digital thermometer (TP 101 model) at the depth of 10cm. Moisture content was determined gravimetrically on a wet weight basis by oven drying method (105^{0}C, 12 hours). The air dried soil sample was sieved and subjected to the following analysis. The pH (1:2.5) was detected using digital pH meter (Systronics model EQ 610). Electrical conductivity (EC) was measured using conductivity meter (Systronics model EQ 660A). Organic Carbon (OC) content was determined using Walkley-Black chromic acid wet oxidation method. Nitrogen (N) content was estimated by Micro Kjeldahl method. The available Phosphorous (P) content was measured by Bray's method for acidic soil samples (pH<6.5) and Olsen's method for alkaline soil samples (pH>6.5) using Near Infra-Red (NIR) spectrophotometer. The Potassium (K) was measured by Flame photometer method using neutral normal ammonium acetate as an extractant.

Statistical analysis

The seasonal abundance of earthworms in relation to edaphic factors was analysed using Karl Pearson's Correlation method. To compare the means of two different groups, independent student t-test and for comparison of more than two group's one way ANOVA test was used. Statistical analysis was done using SPSS version 16.

RESULTS AND DISCUSSION

The present study records, the distribution pattern and abundance of four species of earthworms belonging to three families, viz., Rhinodrilidae (*P. corethrurus*), Megascolecidae (*M. konkanensis* and *M. houlleti*), and Octochaetidae (*K. karnatakensis*) (Table 1; Figs. 1–3). Among these species *P. corethrurus* was observed during all the seasons in the soil of colacasia gardens, coconut and banana pits of residential habitats, paddy fields and coconut plantations. More abundance was observed during the monsoons in the residential habitats (62.0±14.85) and less abundance during the post-monsoons in agricultural habitats (3.0±2.60). The species, however, was not recorded in forest habitats in any of the seasons. *M. konkanensis* was recorded from coconut gardens and banana plantations in maximum numbers (51.0±10.82) during the monsoons and minimum in forest habitats (15.0±7.53) during post-monsoons. *M. houlleti* was recorded throughout the year except in the forest habitats during pre-monsoons. The maximum was recorded from coconut gardens, garden soil and manure heaps in the residential habitats (51.0±0.82) during the monsoon period; however, fewer numbers were recorded in agricultural habitats (1.0±1.8, 2.0±1.41, 3.0±2.19). *K. karnatakensis* was recorded from all the selected habitats during monsoon and post-monsoon periods except in residential habitats during the monsoon period and in all the habitats during the pre-monsoon period. The maximum number was observed in forest habitats (42.0±3.22) during the monsoon period and minimum number was observed in agricultural (3.0±2.75) and residential (3.0±2.92) habitats during monsoon and post-monsoon periods respectively.

1. *Pontoscolex corethrurus* (Fr. Muller, 1857) (Image 2)

Distribution: Bellibettu (coconut and banana pits of residential habitats); Kaup (colacasia garden); Mudarangadi (banana pits of residential habitats), Padabettu (paddy field) and Tenka-Yarmal (coconut pits of residential habitats) villages.

Recorded periods: All the seasons.

Previous records: Bangladesh (Reynolds 1994; Reynolds et al. 1995b; Das & Reynolds 2003), Mexico (Fragoso & Reynolds 1997), Taiwan (Tsai et al. 2004),

Table 1. Seasonal distribution and abundance of earthworm species (Mean±SD) (n=6).

Seasons	Pre-monsoon			Monsoon			Post-monsoon		
Habitats / Species	Residential habitat	Agricultural habitat	Forest Habitat	Residential habitat	Agricultural habitat	Forest habitat	Residential Habitat	Agricultural habitat	Forest habitat
P. corethrurus	41.0±4.93	11.0±3.16	-	62.0±14.85	45.0±10.77	-	7.0±2.62	3.0±2.60	-
M. konkanensis	-	-	-	-	51.0±10.82	-	-	-	15.0±7.53
M. houlleti	13.0±4.81	1.0±1.8	-	51.0±10.82	2.0±1.41	22.0±5.83	18.0±7.18	3.0±2.19	9.0±4.09
K. karnatakensis	-	-	-	-	3.0±2.75	42.0±3.22	3.0±2.92	13.0±5.09	13.0±6.19

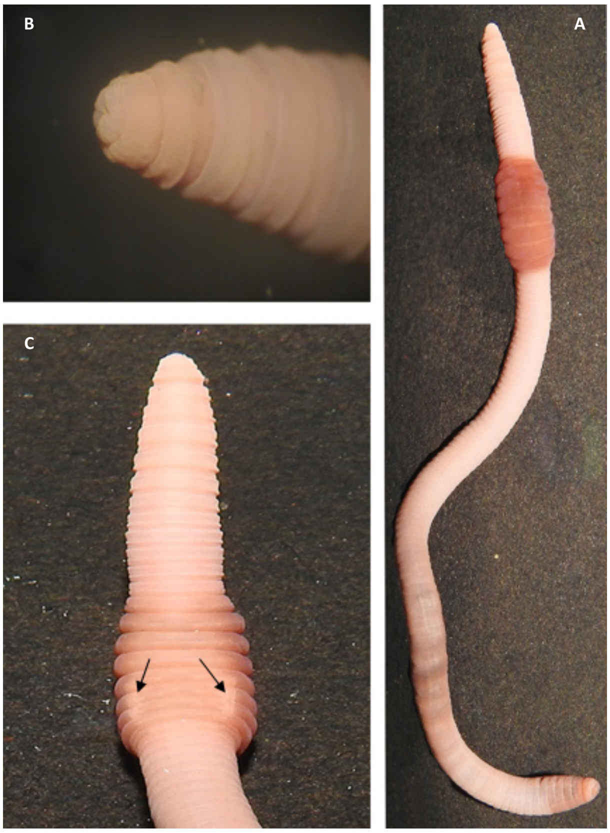

Image 2. *Pontoscolex corethrurus*
A - external morphology; B - prostomium region; C - genital pore region

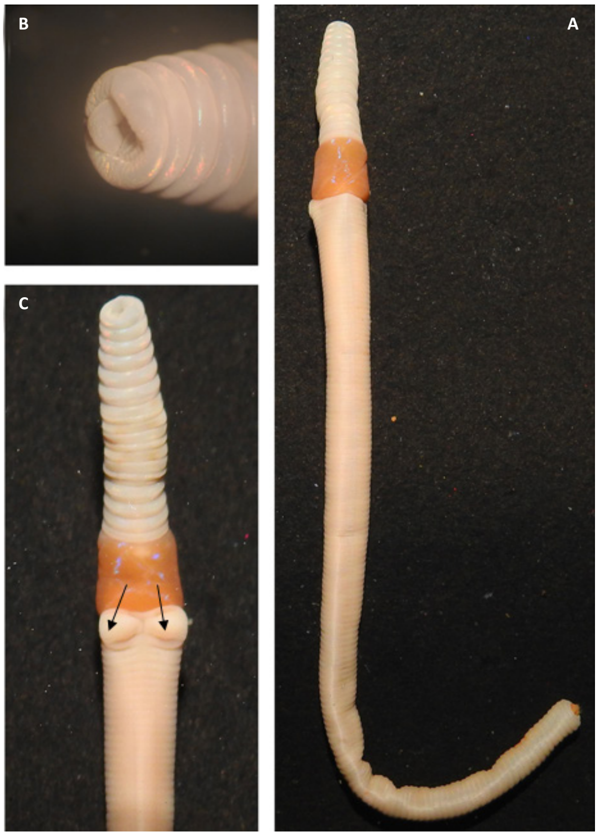

Image 3. *Megascolex konkanensis*
A - external morphology; B - prostomium region; C - genital pore region

Rajasthan (Tripathi & Bharadwaj 2004), Singapore (Shen & Yeo 2005), Tamil Nadu, southern India (Kathireswari et al. 2005, 2008; Blakemore 2006), Puducherry (Sathianarayan & Khan 2006), Tripura, India (Chaudari et al. 2008), Myanmar (Gates 1972; Reynolds 2009), Dakshina Kannada, southwestern coast of Karnataka (Siddaraju et al. 2010), southern Karnataka (Kale & Karmegam 2010), Nicaragua (Sherlock et al. 2011), Western Ghats of Karnataka, India (Biradar et al. 2013), Assam, northeastern India (Rajkhowa et al. 2014), and Kerala, India (Narayanan et al. 2016).

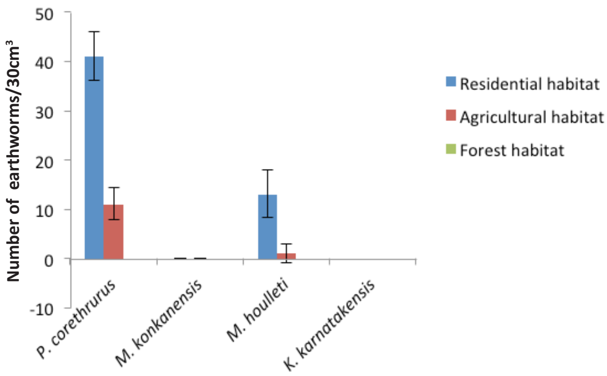

Figure 1. Abundance of earthworm species in selected habitats (pre-monsoon).

2. *Megascolex konkanensis* Fedarb, 1898 (Image 3).

Distribution: Adve (Banana plantation); Kuthyaru (coconut plantation); Nandikur (forest soil) and Yellur (banana plantation) villages.

Recorded periods: Monsoon and post-monsoon.

Previous records: Southern India (Stephenson 1923; Rao 1979; Oommen 1998; Blakemore 2006; Reynolds et al. 2010), Dakshina Kannada, southwestern coast of Karnataka (Siddaraju et al. 2010) and Western Ghats of Karnataka, India (Biradar et al. 2013).

3. *Metaphire houlleti* (Perrier, 1872) (Image 4).

Distribution: Adve (banana pits in residential habitat); Bellibettu (forest soil, manure heaps, coconut and banana pits of residential habitats) and Nadsal (coconut plantations) villages.

Recorded periods: Monsoon and post-monsoon.

Previous records: Belize (Reynolds et al. 1995a),

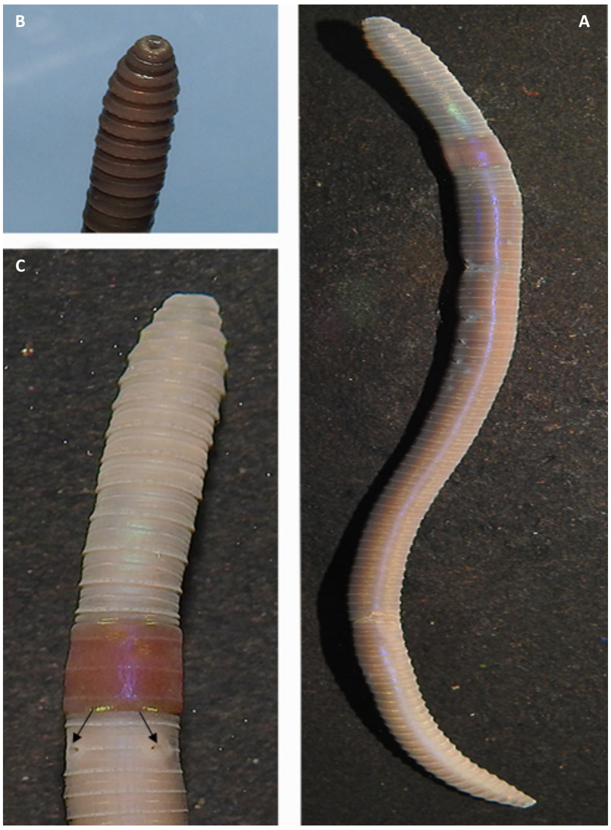

Image 4. *Metaphire houlleti*
A - external morphology; B - prostomium region; C - genital pore region

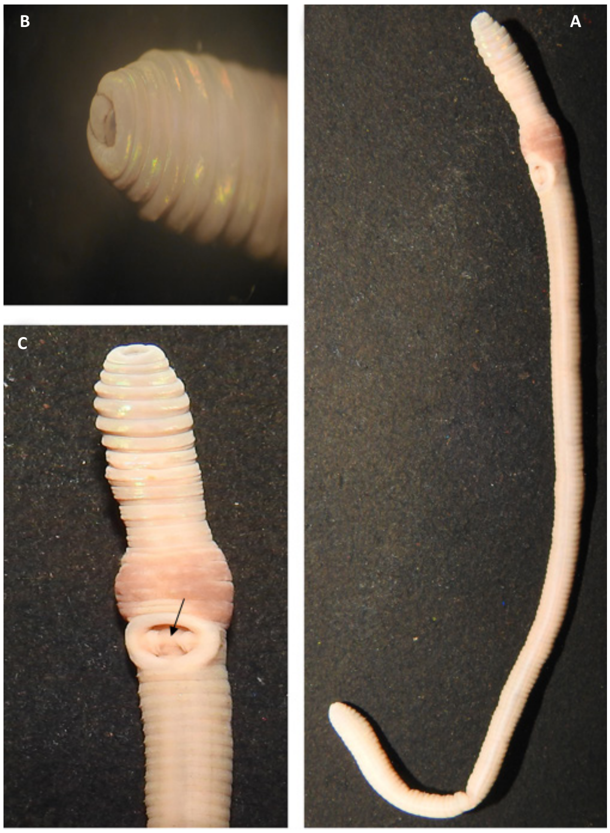

Image 5. *Karmiella karnatakensis*
A - external morphology; B - prostomium region; C - genital pore region

Bangladesh (Das & Reynolds 2003), Taiwan (Shen et al. 2005), Tamil Nadu (Kathireswari et al. 2005), western Himalaya states (Paliwal & Julka 2005), Australia, Japan and India (Blakemore 1994, 2004, 2006), northern Indian states (Dhiman & Battish 2006), North America (Reynolds & Wetzel 2008), Tripura, India (Chaudari et al. 2008), Guadeloupe Islands of West Indies (Csuzdi & Pavlicek 2009), Garhwal Himalaya (Joshi et al. 2010), southern Karnataka (Kale & Karmegam 2010) and Dakshina Kannada, southwestern coast of Karnataka (Siddaraju et al. 2010).

4. *Karmiella karnatakensis* Julka, 1983 (Image 5)

Distribution: Bellibettu (garden soil of residential and forest habitats); Nandikur (coconut plantations) villages.

Recorded periods: Monsoon and post-monsoon.

Previous records: Tirthahalli, Kotegehara, Moodabidri, Bhagamandala, Sakleshpur of Karnataka State, India (Julka 1988).

Edaphic factors

As shown in the Table 2 the edaphic factors such as soil temperature (T), pH, moisture content (MC), electrical conductivity (EC), organic carbon (OC), nitrogen (N), carbon and nitrogen ratio (C/N), phosphorous (P) and potassium (K) show the variation range during the study period in selected habitats. The range of parameters during pre-monsoon in the residential habitat include, T (27.0–30.2 ^{0}C); pH (5.98–7.63); MC (20.19–41.19 %); EC (0.15– 0.49mS cm^{-1}); OC (2.87–6.60 %); N (0.14–0.38 %); C/N ratio (9.23–25.38%); P (99.0–513.0 kg/ha) and K (92.51–609.28 kg/ha). In agricultural habitat, T (28.2–30.2 ^{0}C); pH (5.53–6.51); MC (24.11–27.97 %); EC (0.19–0.36mS cm^{-1}); OC (4.8–5.7 %); N (0.40 to 0.44%); C/N ratio (10.90 to 14.25 %); P (13.0 to 149.0 kg/ha) and K (76.6–204.73 kg/ha). During monsoon, in residential habitat, T (24.0–28.0 ^{0}C); pH (4.32–7.52); MC (34.26–64.83%); EC (0.21–0.90mS cm^{-1}); OC (2.7–6.32 %); N (0.21–0.48 %); C/N ratio (10.36–27.63 %); P (37.0–480.0 %) and K (50.70–635.60 %). In agricultural habitat, T (24.5–27.6 ^{0}C); pH (5.17–7.37); MC (35.73–51.04 %); EC (0.12–0.38mS cm^{-1}); OC (2.0–7.02 %); N (0.17–0.48 %); C/N ratio (7.4–20.17 %); P (11.0–175.0 kg/ha) and K (22.1–348.54 kg/ha) and in forest habitat, T (24.0–27.6 ^{0}C); pH (4.85–7.62); MC (24.33–60.17 %); EC (0.12–0.68mS cm^{-1}); OC (3.68–7.11 %); N (0.21–0.49

Table 2. Soil characteristics of different habitats in three seasons (Mean±SD) (n=6).

Habitats	Seasons	Temperature (⁰C)	pH	MC (%)	EC (mS cm^{-1})	OC (%)	N (%)	C/N	P (kg/ha)	K (kg/ha)
Residential habitat	Pre-monsoon	28.6±1.58	6.93±0.63	28.06±8.59	0.27±0.11	4.33±1.29	0.27±0.09	17.46±6.63	213.0±155	292.16±213
	Monsoon	26.5±1.07	6.61±1.13	45.79±11.1	0.39±0.20	4.72±1.32	0.29±0.08	16.64±6.09	145.0±129	184±189
	Post-monsoon	27.4±0.89	6.98±0.61	35.53±7.32	0.23±0.09	4.43±1.42	0.35±0.06	12.87±4.39	94.0±92	300.91±253
	P value	**0.01***	0.43	0.06	0.17	0.82	0.32	0.40	0.32	0.45
Agricultural habitat	Pre-monsoon	29.2±1.41	6.02±0.69	26.04±2.72	0.27±0.12	5.25±0.63	0.42±0.02	12.57±2.36	81.0±96.16	140.36±91
	Monsoon	26.4±1.19	5.99±0.67	42.95±5.06	0.24±0.09	4.11±1.83	0.27±0.10	15.13±3.83	83.0±54.81	159.9±93
	Post-monsoon	27.4±1.07	6.10±1.24	33.32±2.32	0.24±0.13	4.79±0.75	028±0.01	16.68±2.60	52.0±33.71	193.78±69
	P value	**0.03***	0.97	**0.00037****	0.94	0.58	0.14	0.419	0.65	0.73
Forest habitat	Pre-monsoon	-	-	-	-	-	-	-	-	-
	Monsoon	26.6±1.23	5.79±0.86	43.48±10.99	0.25±0.19	5.33±1.23	0.32±0.11	19.97±13.8	145.0±195	190.0± 270.06
	Post-monsoon	27.5±0.70	5.92±0.03	34.28±0.59	0.17±0.07	5.14±0.24	0.13±0.02	38.40±4.24	18.0±12.02	136.43±73
	P value	0.41	0.84	0.29	0.57	0.83	0.07	0.11	0.41	0.79

**P<0.05 (indicates statistically high significant difference), *P<0.01 (indicates statistically significant difference).

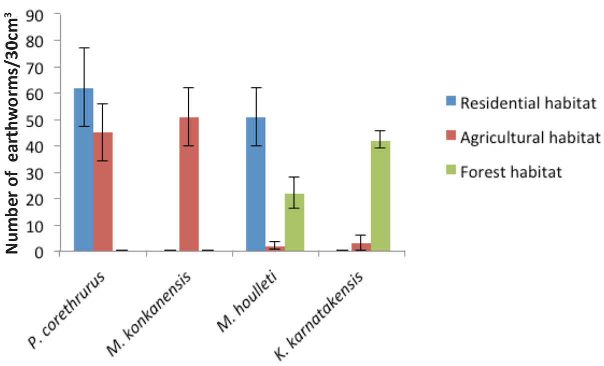

Figure 2. Abundance of earthworm species in selected habitats (monsoon).

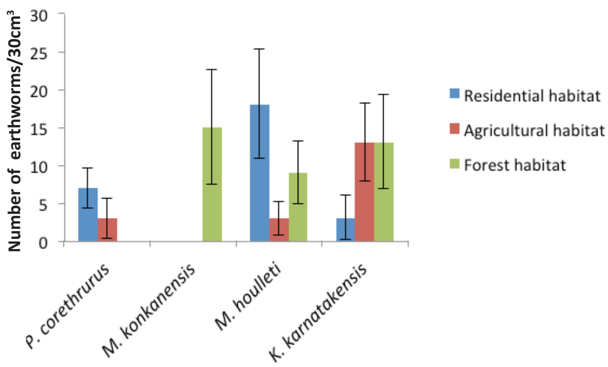

Figure 3. Abundance of earthworm species in selected habitats (post-monsoon).

%); C/N ratio (10.65–50.78 %); P (8.0–499.0 kg/ha) and K (38.75–798.78 kg/ha). During post-monsoon, in residential habitat, T (26.0–28.0 ⁰C); pH (6.21–6.75); MC (20.19–41.19 %); EC (0.15–0.49mS cm^{-1}); OC (2.87–6.60 %); N (0.14–0.38 %); C/N ratio (9.23–25.38 %); P (99.0–513.0 kg/ha) and K (92.51–609.28 kg/ha). In agricultural habitat, T (26.5–28.5 ⁰C); pH (4.94–7.86); MC (30.14–35.21 %); EC (0.12–0.36mS cm^{-1}); OC (4.28–5.91 %); N (0.27–0.30 %); C/N ratio (14.26–20.37 %); P (13.0–94.0 kg/ha) and K (94.64–251.88 kg/ha) and in forest habitat, T (27.0–28.0 ⁰C); pH (5.90–5.95); MC (33.86–34.70 %); EC (0.12–0.22mS cm^{-1}); OC (4.97–5.31 %); N (0.12–0.15 %); C/N ratio(35.40–41.41 %); P (9.0–26.0 kg/ha) and K (85.05–187.82 kg/ha). The soil temperature showed significant difference in residential (P=0.01) and in agricultural (P=0.03) habitats in all the seasons. Whereas, moisture content (P= 0.00037) is found to be highly significant in all the seasons. In forest habitats, no significant difference was found between any of the edaphic factors during monsoon and post-monsoon periods. The other parameters such as pH, electrical conductivity, organic carbon, nitrogen, C/N ratio, available phosphorous and potassium also showed no significant difference during different seasons in the study area.

Correlation between the seasonal abundance of earthworm species with edaphic factors

The correlation analysis of abundance of different species of earthworms in relation to edaphic factors in different seasons has revealed that, during pre-monsoon, the abundance of *P. corethrurus* (r= 0.882; P=0.02) and *M. houlleti* (r=0.814; P=0.049) were positively correlated with organic carbon and are statistically significant in the residential habitats. During monsoons, *P. corethrurus* showed positive correlation with C/N ratio (r=0.732; P=0.01) and is statistically significant, whereas it shows negative correlation with pH (r=-0.755; P=0.007) and is statistically highly significant in the residential habitats. *M. konkanensis* showed positive correlation with electrical conductivity (r=0.925; P=0.00034) and is statistically highly significant in the agricultural habitat. In the forest habitat, *K. karnatakensis* showed statistically highly significant negative correlation with temperature (r=-0.803; P=0.029) and positive correlation with moisture content (r=0.770, P=0.043). Whereas, *M. houlleti* showed positive correlation with organic carbon (r=0.882; P=0.009) and is highly significant. During post-monsoons, *K. karnatakensis* showed positive correlation with C/N ratio (r=0.879; P=0.049) and is statistically significant in the residential habitats.

Diversity, distribution and abundance of earthworm species

Diversity, distribution and abundance of soil organisms are influenced by many soil factors. Understanding the factors which control the earthworm's diversity and population density is a vital process to maintain the soil ecosystem. Earthworms are important soil dwelling organisms and are found in a wide range of soil representing 60–80 % of the total soil biomass and they prefer soil which is rich in organic matter. Diversity is affected due to the loss of their native habitats (Lavelle et al. 1994; Bhadauria et al. 2000). Various studies have reported earlier the distribution of earthworms in relation to habitats (Fonte et al. 2009). In the earlier reports, *P. corethrurus* was recorded from habitats such as manure heaps, garden soil, cultivated land, coconut and rubber plantations (Julka 2008); nursery stock of Assam (Rajkhowa et al. 2014), human disturbed forests of Kerala state (Narayanan et al. 2016), moist soil and cow dung slurry pits of Dakshina Kannada, Karnataka (Siddaraju et al. 2010). In the present study *P. corethrurus was* found to be more widely spread and was the dominant earthworm species in the study area. The highest population density was observed during the monsoons followed by post-monsoon period and the same observation was made by Blanchart & Julka (1997) and Joshi & Aga (2009). This aneciec earthworm *M. konkanensis* an endemic species was reported earlier from forest leaf litter in different parts of South India (Oommen 1998; Kathireswari et al. 2005). Siddaraju et al. (2010) recorded this species from banana and cashew plantations in Dakshina Kannada district of Karnataka. Siddaraju et al. (2010) have recorded the same species from manure heaps, coconut, rubber and cocoa plantations in Dakshina Kannada, Karnataka. The present study also records the co-existence of *P. corethrurus* and *M. houlleti* in banana and coconut pits of residential habitats. Julka (1988) has reported *K. karnatakensis* from Bhagamandala, Kotegehara, Moodabidri, Sakleshpur and Tirthahalli in Karnataka.

Earthworm abundance in relation to edaphic factors

The species density was observed where there was the highest litter degradation in the study area. It indicates that moisture content and food availability in the habitats influence the distribution of earthworms. It has been observed that, the species abundance in residential habitats throughout the year is probably due to ideal soil moisture and rich organic matters as it was reported earlier by Ghosh (1993). Soil temperature gradually increases from monsoon to pre-monsoon periods and there is not much variation in temperature between habitats. Soil pH (5.79 to 6.93) did not show much difference between the habitats in different seasons. Iordachf & Borza (2010) opined that earthworm abundance decreased with increasing soil pH. In the present study, *P. corethrurus* shows negative correlation with pH (r=-0.755; P=0.007) in the residential habitats during the monsoon period. *M. konkanensis* showed the positive correlation with electrical conductivity (r=0.925; P= 0.00034) in the agricultural habitats during the monsoon period. Whereas, *K. karnatakensis* showed negative correlation with temperature (r=-0.803; P=0.029) and positive correlation with moisture (r=0.770; P=0.043) in the forest habitats. Organic carbon is very essential for the normal growth and development of earthworms, which is obtained from litter, grit and micro-organisms present in the soil. All the soil had high levels of organic carbon (>2.5%) in the selected habitats during different seasons. Wherever there is high moisture content and decaying organic matter available easily to the worms, the rate of decomposition activity is recorded to be more as it was observed in the study area (Edwards & Bohlen 1996; Joshi & Aga 2009). Hendrix et al. (1992) reported that earthworm population density is positively correlated with organic carbon. In the present study also a similar result was observed in the residential habitats with *P. corethrurus* (r=0.882; P=0.02) and with *M. houlleti* (r=0.814; P=0.049) during the pre-monsoon and in forest habitats (r=0.882; P=0.009) during the monsoon period with *M. houlleti* (Joshi et al. 2010). Nitrogen content in the soil is due to the accumulation and decomposition of leaf litter and debris of the plants. Banana plants add more nitrogen to the soil after death and decay by decomposition processes. Nitrogen showed no significant relationship with the distribution of the species. Only *P. corethrurus* (r=0.732; P=0.01) and *K. karnatakensis* (r=0.879; P=0.049) showed a positive correlation with C/N ratio in the residential habitats during monsoon and post-monsoon periods respectively. In all the soils, the available phosphorous content was high (52.75 to 213 kg/ha) in all the seasons, except in forest habitats (17.5 kg/ha) during the post monsoon period. The available potassium content was medium (136.43 to 193.73 kg/ha) in all the soil samples, whereas in residential habitats it shows high during pre-monsoon (292.16 kg/ha) and post monsoon (300.91 kg/ha) periods. In the present study, that the species didn't show the relation with P and K. Phosphorous content in the soil may be due to the addition of fertilizers in higher doses and also from litter (Singh et al. 2016). Potassium content in the soil might be attributed to release of more K from organic residue and application of K containing fertilizers.

Many reports have shown that industrial discharge deposits on surrounding areas enters the food chain. These discharges mainly contain toxic substances such as organic and inorganic deposits as well as toxic metals and affects the health of mankind as well as the quality of the soil and its productivity (Chhonka et al. 2000; Ho et al. 2012). Most earthworm species are very sensitive to the alteration in the soil nutrients; though some species may survive in altered environments (Suther et al. 2008). The present study clearly indicates that there is a species specific relation with the nutrient availability in the soil. Bio indicator activities of the earthworm species are being studied to know the impact of industrial discharge on earthworm species in the study area.

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National Biodiversity Authority