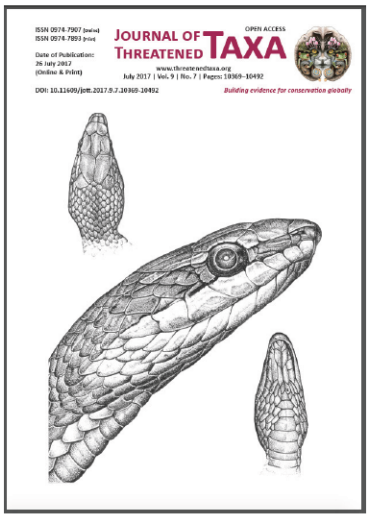

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COMMUNICATION

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Influence of seasonal and edaphic factors on the diversity of scolopendromorph centipedes (Chilopoda: Scolopendromorpha) and general observations on their ecology from Kerala, India

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Abstract: Scolopendromorph centipedes (Chilopoda: Scolopendromorpha) are a diverse group of invertebrate communities, which play significant, but often poorly acknowledged or understood roles in the delivery of soil ecosystem services. In the present paper we analyze the impact of seasonal and edaphic factors on the species diversity of scolopendromorph centipedes based on the field studies conducted in three selected sites. The study sites included a protected forest ecosystem, an undisturbed isolated hillock and a residential plot at Kozhikode District, Kerala, India. The study was performed from April 2011 to November 2012. Overall 486 individuals belonging to 18 species under the families Cryptopidae and Scolopendridae were collected. The range of Shannon-Wiener diversity was 0.89–2.58 and Simpson diversity was 1.91–13.69. Species diversity is also influenced by variations in seasons and various physico–chemical properties of soil in the study area. General observations on parental care, moulting, hibernation and ectoparasitism were also included.

Keywords: Centipedes, diversity, ecology, edaphic factors, seasons, Scolopendromorpha.

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Author Contribution: DB surveied, collected and carried out taxonomic studies of Scolopendrid centipedes under PMS supervision.

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INTRODUCTION

Soil organisms are the main mediators of soil functioning at different scales, which can be pictured as having a hierarchical relationship of eating and being eaten. Soil organisms are nick-named "ecosystem engineers", since they control, either directly or indirectly, the availability of resources to other species (Jones et al. 1997). They physically modify, maintain and create new habitats for other organisms, thus creating higher habitat diversity, which may in turn increase species diversity (Lavelle & Spain 2001). Scolopendromorph centipedes belong to the category of soil macro fauna i.e., "an invertebrate group found in terrestrial soil samples which has more than 90% of its specimens (individuals) visible to the naked eye" (IBOY 2000). As predators, they regulate herbivores; act as ecosystem engineers, litter transformers, decomposers and micro regulators (Moreira et al. 2008).

The order Scolopendromorpha includes centipedes with 21, 23, 39 and 43 body segments (Chagas-Jr et al. 2008; Minelli et al. 2009). Currently, 90 valid species of Scolopendromorph centipedes belonging to eight genera of Scolopendridae and three genera of Cryptopidae are known from India against 687 species under 17 genera known globally (Khanna 2008; Dhanya et al. 2012). Scolopendromorph centipedes represent a diverse group of invertebrate community which play significant, but often poorly acknowledged or understood roles in the delivery of soil ecosystem services. Despite having a rich fauna of scolopendrid centipedes, detailed studies on their taxonomy and ecology are still in an infantile stage in India. The aim of the present study is to understand the diversity of Scolopendromorpha in selected habitats of Kerala and to analyze the impact of seasonal and edaphic factors on their diversity.

MATERIALS AND METHODS

Study area

The study was undertaken at three different sites (Fig. 1; Images 1–3), site 1—Protected forest Ecosystem: Urakkauzhy, Kakkayam at Malabar Wildlife Sanctuary, Kozhikode District, Kerala (11.54460833 N & 75.92583333 E, elevation 720.3m); site 2—undisturbed & isolated hilly area: Narayamkulam, Kozhikode District, Kerala (11.50749444 N & 75.80666667 E, 134m) and Site 3—Residential land: Kuttothparambu, Kozhikode District, Kerala (11.44972222 N & 75.95833333 E, 36.4m).

Image 1. Site 1—Protected forest ecosystem: Urakkauzhy, Kakkayam at Malabar Wildlife Sanctuary

Image 2. Site 2—undisturbed & isolated hilly area: Narayamkulam, Kozhikode District

Image 3. Site 3—Residential land: Kuttothparambu, Kozhikode District

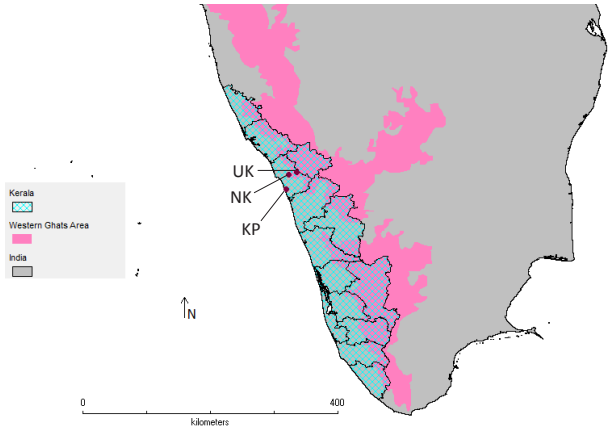

Figure 1. Study areas for ecological studies
Site 1: Protected forest ecosystem: Urakkauzhy (UK); Site 2 - undisturbed & isolated hilly area: Narayamkulam (NK); Site 3 - Residential land: Kuttothparambu (KP)

Methods

The collection methods included active sampling in daytime from vegetation, ground collection and litter sampling and ethyl acetate was utilized for narcotizing the animal. Specimens collected from the field were fixed in 70% ethanol or 2% formalin. Scolopendromorphs especially the slender cryptopids examined in Petri dishes containing ethylene glycol monophenol ether before microscopic examinations for clearing the specimens (Pereira 2000). For taxonomic identification of Scolopendridae, keys by Jangi & Dass (1984), Lewis (2010), illustrated key by Sureshan et al. (2006) were followed. For Cryptopidae, keys by Attems (1930), Dhanya et al. (2012) were used for identification of species.

After a pilot study in selected sites (50m x 50m each), five quadrates (10m x 10m each) were laid for the random sampling. Monthly observations were made during April 2011 to November 2012 and the number of species and individuals were recorded. Soil sampling and analysis were carried out in three seasons (pre-monsoon, monsoon and post-Monsoon) across the sites.

In these study sites, Shannon mean, Shannon exponential mean and Simpson index were calculated as a measure of diversity within the habitat (alpha diversity or point diversity). The similarity indices (Chao shared estimate, Jaccard classic, Sorenson classic, Chao-Jaccard-est abundance-based, Chao-Sorenson-est abundance-based and Morisita Horn) were used to compare the diversity across study sites. For the analysis of the data MS–Excel 2007, PAST 1.89 software package (Hammer et al. 2001), EstimateS Version 8.2.0 (Colwell 2009) and SPSS were utilized.

Soil Temperature, Soil pH, Soil Electrical Conductivity (EC), Organic Carbon (OC), Available P, K, Ca and Mg were also analyzed during different seasons to study the influence of such parameters in diversity of Scolopendromorpha.

RESULTS

Diversity and Composition

Altogether 18 species (13 from site 1, 11 from site 2 and 3 from site 1) were reported which included representatives of two families and eight genera from the study sites (Table 1). The species composition of each study sites is as follows.

Species diversity within the habitat

In the present study, diversity of scolopendromorph centipedes from three different ecosystems was analyzed. The values of diversity indices (Table 2) indicated that Site 1 was more relatively diverse than the other two sites. The forest Site 1 possesses more diversity than Site 2 (undisturbed & abandoned agricultural land) and Site 3 (residential area). The habitat quality may be the most vital factor determining the presence of species at a given biota. In this study also Site 1 being a forest it harbors more species.

Shared species and similarity between diversity and abundance

The analysis for comparing the similarity in diversity of ecosystems revealed that Site 1 and 2 are more similar and possess a maximum number of shared species (Table 3). The similarity indices (Jaccard, Sorenson and Morisita Horn) indices also showed the same results indicating the higher level of similarity between Site 1 and 2. The high diversity in Site 2 being an unprotected and isolated hilly ecosystem indicates the significance of "conservation efforts outside protected areas". It supports the opinion that areas outside existing conservation reserves, harboring significant levels of biodiversity need to be targeted for long term conservation (Raman & Mudappa 2003). Besides, Site 2 (Narayamkulam) is a hillock adjacent to (about 30.9km away) Malabar Wildlife Sanctuary where site 1 was located. The maximum number of shared species (7) between these two sites also support the assumption that once it was a pristine forest which later transformed to a rather abandoned and isolated hillock area.

Table 1. Species composition in three ecosystems

	Family	Species recorded	Study sites		
			Site 1	Site 2	Site 3
1	Cryptopidae	*Cryptops malabarensis* Dhanya et al., 2012	R	R	NR
2		*Cryptops* sp 1	R	R	NR
3		Cryptops sp 2	NR	NR	R
4		*Paracryptops* sps 1	R	R	NR
5	Scolopendridae	*Scolopendra morsitans* Linnaeus, 1758	NR	R	NR
6		*Digitipes barnabasi* Jangi & Dass, 1984	R	R	NR
7		*Digitipes coonoorensis* Jangi & Dass, 1984	R	R	NR
8		*Digitipes pruthi* Jangi & Dass, 1984	NR	R	NR
9		*Digitipes* sp 1	R	NR	NR
10		*Digitipes* sp 2	R	NR	NR
11		*Rhysida immarginata immarginata* (Porat, 1876)	NR	NR	NR
12		*Rhysida longipes longipes* (Newport, 1845)	NR	R	R
13		*Asanada sukhensis* Jangi & Dass, 1984	NR	R	NR
14		*Cormocephalus dentipes* Pocock, 1891	R	R	NR
15		*Cormocephalus nigrificatus* Verhoeff, 1937	R	NR	NR
16		*Otostigmus politus politus* Karsch, 1881	NR	NR	NR
17		*Otostigmus* sp 1	R	NR	NR
18		*Ethmostigmus rubrieps platycepahlus* Newport, 1845	R	NR	NR

Site 1 - Malabar Wildlife Sanctuary; Site 2 - Narayamkulam undisturbed & isolated hilly area; Site 3 - Kuttothparambu residential area.
R = Recoreded from site; NR = not recorded from site

Table 2. Comparison of diversity indices within three ecosystems

Diversity Indices	Mean ± SD			Range		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Number of species	13	11	3			
Shannon Mean	2.42 ±0.16	2.23±0.17	1.14±0.16	2.12–2.58	1.9–2.42	0.89–1.38
Shannon Exponential Mean	11.29±1.64	9.41±1.53	3.17±0.52	8.27–13.2	6.71–11.2	2.44–3.97
Simpson Mean	9.83±3.17	8.32±2.65	3.03±1.07	4.87–13.69	4.32–11.53	1.91–5.08

Site 1 - Malabar Wildlife Sanctuary; Site 2 - Narayamkulam undisturbed & isolated hilly area; Site 3 - Kuttothparambu residential area

DISCUSSION

Impact of seasonal fluctuations in diversity index

Seasons (premonsoon, monsoon and postmonsoon) in Kerala were observed to have an imperative impact on the diversity of scolopendromorph centipedes. Species richness varied significantly between sites and seasons (p=0.05) (Figs. 2–4). The highest Simpson mean value was recorded during the month of October (9.82) at post monsoon period in Site 1 (Malabar Wildlife Sanctuary). The minimum value in the index was recorded in the month of March (1.91) at pre-monsoon period in Site3 (Kuttothparambu). The same trend has been observed in cases of Shannon exponential mean and Simpson mean. As monsoon period is defined as the reproductive active time for the scolopendromorph centipede (Lewis 1972, 1981) then there is a chance of increasing the number of organisms in the post- monsoon time.

In the discussion of the life histories of Nigerian centipedes Lewis (1972) made out an observation that *S. amazonica* (= *Scolopendra morsitans* Linnaeus, 1758) (Bücherl, 1946) in order to avoid the dry season it took refuge in cow dung and R. *nuda togoensis* Kraepelin, 1903 and *E. trigonopodus* Leach, 1817, which are virtually absent from superficial habitats may enter deep crevices in soil. In accordance with this observation, the present study also pointed out the decreasing pattern of Indices in premonsoon period (mainly in the summer

Table 3. Shared species analysis between three ecosystems

First sample	Second sample	Shared species observed	Chao shared estimated	Jaccard classic	Sorensen classic	Chao jaccard raw abundance based	Chao sorensen raw abundance based	Morisita horn
Site 1	Site 2	7	7	0.412	0.583	0.746	0.854	0.545
Site 1	Site 3	1	0	0.067	0.125	0.059	0.111	0.067
Site 2	Site 3	2	0	0.167	0.286	0.442	0.613	0.389

Site 1 - Malabar Wildlife Sanctuary; Site 2 - Narayamkulam undisturbed & isolated hilly area; Site 3 - Kuttothparambu residential area

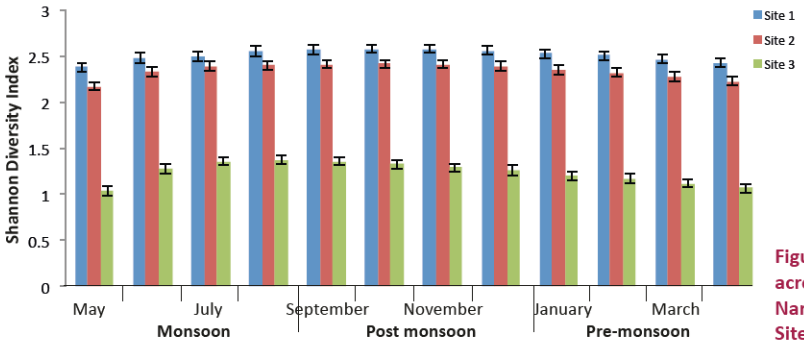

Figure 2. Mean seasonal variations of Shannon Index across Site 1 - Malabar Wildlife Sanctuary; Site 2 - Narayamkulam undisturbed & isolated hilly area; Site 3 - Kuttothparambu residential area

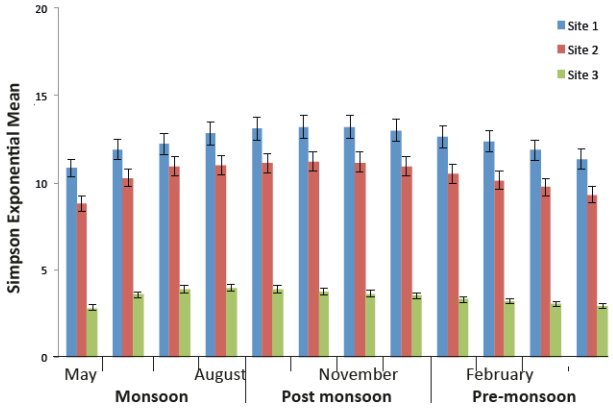

Figure 3. Mean seasonal variations of Shannon Exponential Mean across Site 1, 2 & 3

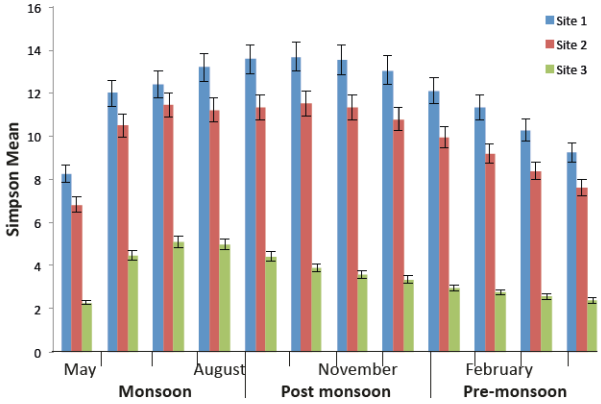

Figure 4. Mean seasonal variations of Simpson Mean across Site 1, 2 &3

months of March and April); it may also be due to the centipedes' behavioral tendency to avoid desiccation. In the month of December and January very less number of individuals were observed at Site 1 and 2. Even in termite soil and leaf litter of Site 1 where there is a more probable chance of finding centipedes, no specimens were observed. In the same months the activities of associated soil fauna were also negligible.

Seasonal influence on the soil properties in study area

Seasonal trend in the physico-chemical properties is given in Table 4.

Soil temperature

In general, soil temperature reported in three study sites showed variations across the seasons (Table 4). The least average temperature was observed in Site 1 during monsoon and the highest recorded at Site 3 during post–monsoon. The high rainfall in the higher altitude areas of Malabar Wildlife Sanctuary where Site 1 is located could be the reason for the lowest soil temperature reported. Being a residential area, Site 3 recorded the higher values during the dry seasons of premonsoon. Shannon diversity index also showed the same trend as soil temperature so it can be predicted

Table 4. Mean Index and Soil Physico-Chemical properties of three sites across 3 seasons

Sites	Season	Shannon Diversity Index	Temperature	pH	EC(ds/m)	OC%	P(mg/kg)	K(mg/kg)	Ca(mg/kg)	Mg(mg/kg)
Site 1	PrM	2.48	22.75	6.09	0.17	3.2	41.5	104	411.5	138.5
Site 1	M	2.47	18	4.6	0.07	2.46	34.5	184.5	509.4	93.4
Site 1	PsM	2.57	18.25	5.32	0.7	1.92	26.5	84.5	93	22
Site 2	PrM	2.29	25.75	5.52	0.07	3.7	41.45	223.5	616	179
Site 2	M	2.32	24	5.53	0.05	3.8	34.45	128	248.9	71
Site 2	PsM	2.39	25.25	4.76	0.8	3.15	27.2	53.5	162	28
Site 3	PrM	1.14	27	5.51	0.07	3.1	42.9	134.5	811.5	211.5
Site 3	M	1.26	24.25	4.9	0.11	2.26	36.5	138.5	812.2	79.3
Site 3	PsM	1.31	25.75	4.91	0.1	3.12	27.2	131	192	49

Site 1 - Malabar Wildlife Sanctuary; Site 2 - Narayamkulam undisturbed & isolated hilly area; Site 3 - Kuttothparambu residential area.
PrM - Pre Monsoon; M - Monsoon; PsM - Post Monsoon

that the temperature influences the diversity pattern.

The same observations were reported in the following studies earlier. Abrahamsen' (1971) studied the effect of temperature and moisture content on soil fauna and observed that temperature and moisture content of the soil play a critical role in the distribution and diversity of soil organisms. Jabin et al. (2004) conducted the litter accumulation treatments for studying the effect of change in mean temperature on soil biota and revealed that the abundance of centipedes varied in accordance with temperature differences.

Soil pH

In general, the average pH of soil from three sites during three seasons recorded in the range of slightly acidic i.e., 4.6–6.09 (Table 4). The seasonal trend in Shannon diversity index also showed the same pattern as the seasonal trend of soil pH (Fig. 2). A similar observation was reported from Jabin et al. (2004) in which the author discussed that the arthropods with a calcareous exoskeleton demonstrated the highest correlations within the soil fauna, as they were positively correlated to pH-value.

Soil organic carbon

Increased Organic Carbon (OC) in premonsoon (3.2%) in site 1 may be attributed to higher level of leaf fall in the forest area which may lead to increase in soil OC content; similarly excessive soil erosion due to rainfall can be a reason for lower level OC during monsoons (Table 4). Kirby & Potvin (2007) find a correlation between biodiversity and organic carbon in soils and suggested that increase in biodiversity as the reason for excessive organic carbon in forests. The excessive mulching of soil due to leaf litter may create a different microclimate on pre-monsoon, than the litter free monsoon season during which there is decreased oxidation of humus formed in summer. The seasonal trend in Shannon Diversity Index also showed the same pattern as the seasonal trend of soil OC. The present study also revealed that there is comparatively high OC and lower diversity at Site 3 than Site 1 and 2.

Soil chemical properties

In general, the seasonal trend in Shannon diversity index also showed the same pattern as the seasonal trend of soil chemical parameters. The available Phosphorus will be lower in natural forests (Site 1) because there is no use of artificial fertilizers there.

Influence of soil properties on Shannon diversity index

Important abiotic factors that observed influencing the diversity and richness of scolopendromorph are temperature, pH, OC, EC, chemical parameters and seasonal fluctuations.

In the three sites (1, 2 and 3) temperature seemed to have a significant influence on diversity index and showed a positive correlation of r = 0.754 (Site 1) and r = 0.966 (Site 2) and r = 0.551 (Site 3). In the case of pH, index at Site 1 showed a positive correlation r =954, while it was very insignificant in Site 2 and 3. The EC diversity in three sites showed a negligible correlation only (r = 0.037 (Site 1) and r = 0.204 (Site 2) and r = 0.340 (Site 3). In the case of OC and K, however, site 3 showed a high correlation of r = 0.864 (OC) and r = 0.840 (K) where in site 2 and 3 it showed a very negligible correlation. Across three of the sites K showed high correlation r = 0.840 (Site 3) and r = 0.500 (Site 1) and a low correlation r = 0.190 (Site 2). Ca and Mg seem to be less correlated with diversity and showed lower correlation values.

Table 5. Relative abundance of Scolopendromorpha across altitudinal gradient

Altitude Gradient (m asl)	Number of species	Relative abundance
10–200	18	47.37%
200–400	6	15.79%
400–600	8	21.05%
600–800	15	39.47%
800–1000	6	15.79%
1000–1200	8	21.05%
1200–1400	3	7.89%
1400 and above	6	15.79%

From these observations it can be presumed that, in soil ecosystems temperature plays a significant role in the diversity of scolopendromorph centipedes. Besides, scolopendromorph likely prefer alkaline soils and shows a high diversity in alkaline rich soils. EC of soils seemed to be not influencing the scolopendromorphs. While OC, K and Ca influence these organisms, the contents of Mg and P seems to be less influencing. Jabin et al. (2004) in studies on influence of soil attributes to the distribution pattern of soil arthropods in temperate deciduous forests reported that arthropods with a calcareous exoskeleton showed the highest correlations within the soil fauna, as they were positively correlated to pH-value and (Ca+Mg+K)/Al molar ratio. In the present study at Site 1 the forest habitat a positive correlation of diversity with pH is reported, the cases of Ca and K also showed similar effects. But the correlation of Mg is reported against their observations. In another investigation by (Shakir & Ahmed 2015) on influence of blend of meteorological and edaphic factors on soil arthropod abundance observed that soil temperature and soil organic matter showed significant positive correlation with abundance, which supports the present findings. They also discussed that soil moisture and pH showed no significant correlations, which is applicable to the reported observations also.

General observations on Scolopendromorpha ecology distribution across altitude gradient

Apart from these, it is also observed that in high altitude area (1,500–1,700 m) scolopendromorph centipedes were represented less in number and diversity but geophilomorph centipedes were in plenty. And in the highest altitude in some forest patches like Sholas only lithobiomorph centipedes were observed indicating a possible influence of climatic along with altitudinal variations on centipede diversity. Regarding the distribution of Scolopendromorpha across altitude gradients, the study areas of Kerala State are categorized into eight altitudinal gradients. The results showed that the altitudinal zone of 100–200 m has the highest number of species accumulations (18 species) and the zone of 1,200–1,400 m possess the lowest number of species (3 species) (Table 5).

Parental care

Egg laying and brooding behavior of Indian scolopendromorph centipedes is not well documented, but there are short communications on the parental care of the species *Cormocephalus dentipes* Pocock, 1891 by Tilak & Roy (1988), Jangi & Dass (1984), Yadav (1994) and Khanna (19 July 2011 pers. comm.). During the present study, two such notable observations on parental care were noticed and recorded. It included the observations on two species, in *Rhysida immarginata* (Porat, 1876) and *Digitipes barnabasi* Jangi & Dass, 1984. The parental care of *R. immarginata* was observed in an unprotected and isolated hilly area adjoining a moist deciduous forest patch on a laterite hill at foothills of Western Ghats. The centipede was observed about 5cm below the soil surface, which was ploughed for Ginger cultivation. The soil temperature at the time of observation was 26^{0}C and the soil pH was 4.2. At the time of observation, the mother centipede was found coiled around the ball like clutch of embryonic stadia, with the ventral surface touching the clutch, and dorsal surface exposed. The same posture of mother centipede typical for Scolopendromorpha was also reported by earlier workers in the order Craterostigmomorpha (found only in Tasmania and New Zealand) and in placodesmatic geophilomorphs (Edgecombe et al. 2010). The clutches consisting of about 34 embryonic stadia were clustered together and each stadium was transparent, pale white in colour and coiled (Image 4). On disturbance, the female recoiled and moved away from the clutch, thus scattering the stadia apart. When forcefully reintroduced into the scattered clutch, the female did not care for the hatchlings and tried to burrow into the soil by to–and–from movements of trunk appendages. After about an hour the centipede searched for the hatchlings and tried to settle it together using the trunk appendages. Then, it again coiled around the partly settled clutch in a rather loose way using its mouthparts and anterior appendages, only to abandon the hatchlings after an hour most.

Besides, an individual of *D. barnabasi* in brooding (Image 5) was also observed during faunistic surveys at

Image 4. *Rhysida immarginata* in parental care

Image 5. *Digitipes barnabasi* in parental care

Image 6. Stadium

Image 7. Moulted individual

Kappalamudu, Kottayam District, Kerala on July 2011 (post monsoon time). The centipede was observed in a rubber plantation adjoining a moist deciduous forest patch on a hillock, about 5cm below the soil surface, which was exposed for faunistic collection. At the time of observation, the mother centipede was found coiled around the ball like clutch of embryonic stadia, with the ventral surface touching the clutch, and dorsal surface exposed. The clutches consisting of about 34 embryonic stadia were clustered together and each stadium was transparent, pale white in colour and coiled (Image 6). The disturbance in soil detached some of the stadia, which were collected for study. A similar observation was also recorded from the Site 1 at Malabar Wildlife Sanctuary, where an adult *Rhysida* sp. with 18 numbers of stadia were observed in the month of September 2011 (post monsoon) after prolonged rainy days. The brooding was observed in between stones and when disturbed for clear observation mother escaped leaving back the stadia. It was also noticed that in the month of September most of the specimens observed in all the study area were mainly sub adults.

Moulting and hibernation

During the present study some of the specimens were collected in their moulting stages but it was difficult to identify them due to the vague taxonomic characters (Image 7). Microscopic examination of such specimens revealed that they might be in a condition similar to Stage B (in which the cuticle begins to harden) in moulting procedure as reported by Rajulu (1973). Interestingly an 'almost hibernation' behavior was observed in *Digitipes*

Image 8. *Cormocephalus* sp. in hibernation inside a coconut trunk

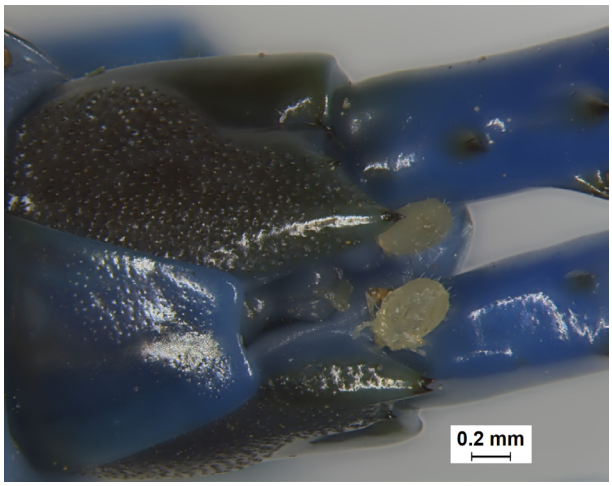

Image 9. Ectoparasitism of acari on *Digitipes barnabasi*

and *Cormocephalus* species in high altitude habitats especially in winter and summer seasons. In the field, these individuals were in an inert condition beneath the soil (Image 8). Even after disturbance, they didn't turn up and no movement was observed for a prolonged time. It could be an adaptive measure to tide over the adverse climatic conditions like water scarcity and low temperature.

Ectoparasitism of acari

Like in other arthropods, centipedes are also frequently found to have mites attached to them. The six-legged larvae of trombidiids and resting stage (hypopus) of several species of Tyrogliphidae are found as ectoparasites on centipedes (Lewis 2002). Interestingly during the microscopic examinations of a specimen of *Digitipes coonoorensis* Jangi & Dass, 1984 the ectoparasitism by Acari mites was observed. The specimen was an adult one, and the mites of about 2–3 mm in size and whitish in colour and oval in appearance were found attached with the soft tissues near genital organs and spiracles (Image 9).

CONCLUSION

In summary, pre-monsoon, monsoon and post monsoon seasons in Kerala observed to be have an imperative impact on the diversity of scolopendromorph centipedes. Species richness varied significantly between sites and seasons (p=0.05). The results based on comparison of alpha diversity within three different habitats pointed out that the forest area was relatively more diverse than the other two sites. The analysis for comparing the similarity in diversity of ecosystems revealed that the forest and the undisturbed isolated non-protected area are more similar and possess maximum number of shared species. This result pointed out the significance of conserving the diversity outside the protected areas too. The ecological studies based on soil analysis of the selected areas revealed that abiotic factors such as temperature, pH, OC, EC, chemical parameters may influence the diversity of Scolopendromorpha. Further studies including more parameters are warranted to reveal the ecology of Scolopendromorpha in detail.

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