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Diversity of Millipedes (Myriapoda: Diplopoda) at Southern Western Ghats of Tirunelveli District, Tamil Nadu

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ABSTRACT

The present study was conducted with the prime objective to document the diversity of millipedes at Southern Western Ghats of Tirunelveli district, Tamil Nadu. A total of 1615 individuals of ten species of millipedes belonging to 3 families have been recorded in the surveys carried out from December 2018 to December 2020. Among three families Pachybolidae and Arthrosphaeridae were dominant with 4 species recorded in each and other family Paradoxosomatidae with two species recorded. During surveys, *Anoplodesmus saussurii* is the most common species and *Eucentrobolus maindroni* and *Arthrosphaera hendersoni* were rarely sighted. The millipede abundance was increasing and maximum during October, November and December of 2019 and 2020, declining gradually from the month of January. It was observed that the abundance of millipedes increased during the post-monsoon season (Oct-Nov). The millipede abundance was correlated with meteorological parameters such as temperature, rainfall and humidity. It resulted as millipede prefer conducive rainy season, high humidity relatively with low temperature. This is the first scientific report from the study area and it is the baseline data for further studies.

Keywords: *Millipede, Diversity, Southern Western Ghats, Abundance, Temperature.*

INTRODUCTION

Millipedes are arthropods from the class Diplopoda that consists of more than 12,000 species. Their distribution extends to all continents except Antarctica with a preference for burrowing in dark areas of warm, humid climates such as the tropics (Lofgren *et al.,* 2021). Millipedes (Myriapoda, Diplopoda) are a group of insects often called 1,000-legged worms or rain worms (Gray, 2009). It belongs to the class Diplopoda, a highly diverse group of terrestrial organisms and the third-largest class of terrestrial Arthropoda with over 12,000 species and an estimated 80,000 yet to be described in 145 families and 16 orders (Shelley, 2002). Among insects, the millipedes are the largest macro arthropods also known as "indicators of environmental alteration or conditions" (Seeber *et al.,* 2008). Other than these millipedes have an important role in ecology especially in the food chain as a "decomposer". They are the major saprophagous in temperate and tropical ecosystems (Lawrence, 1984; Blower, 1985; Lawrence and Samways, 2003) distributed throughout the world (Kime, 2000). Prince (1988)

stated this millipede are detritivores invertebrates in enriching the decomposition of dead plant material is to stimulate microbial activity. They involve in the redistribution of organic material and release of chemical elements mainly nitrogen which is the important nutrient that plants absorb easily in the soil (Chezhian and Prabakaran, 2016) and improve the nutrients and organic matter of soil (Seeber *et al.,* 2008). Millipedes mechanically fragment plant litters and release some elements which facilitate the soil mineralization (Wallwork, 1976; Hopkin and Read, 1992; Dangerfield and Milner 1996). Even though only 10% of the total decomposition of plant litter within an ecosystem takes place through millipedes, their feeding enhances microbial activities, resulting in the breakdown of litter up to 90% (Anderson and Bignall, 1980).

In India, the millipede comprises 270+ nominate species or subspecies in at least 90 genera, 25 families and 11 orders (Golovatch and Wesener, 2016). Even though their diversity, phylogeny, and morphology are less explored than other arthropod groups (Sierwald and Bond, 2007). In India the documentation of millipedes is fragmented and paucity, South India has some number documentation which is the pioneer in the millipede diversity and most of the records are from Western Ghats (Mary bai 2001; Ashwini & Sridhar, 2008; Kadamannaya, & Sridhar, 2009; Sridhar & Ambarish, 2013; Choudhari *et al.,* 2014; Golovatch, 2021) and from Eastern Ghats (Periasamy Alagesan *et al.,* 2013; Chezhian & Prabakaran, 2016), this documentations from the Gujarat, Karnataka, Kerela and Tamil Nadu. Surveys in peninsular India revealed the occurrence of about 46 species of family Arthrosphaera (Pocock,1899; Attems, 1936; Chowdaiah, 1969; Achar, 1980; 1986; Janardanan and Ramachandran, 1983; Ashwini and Sridhar, 2008). 35 species of Arthrosphaera endemic to India and Sri Lanka, 27 species are known from southern India (Attems, 1936; Pocock, 1899). Attems (1936) stated that the diplopod fauna of India consists of a high number (92 genera) of the order Sphaerotheriida (giant pill millipedes) and the majority of them are endemic in distribution. In India, millipedes inhabit mainly the regions with high rainfall in the Western Ghats and the Eastern Ghats forests (Maharashtra, Karnataka, Kerala, Tamil Nadu and Andhra Pradesh). South India has a good number of millipede records due to the presence of the Eastern Ghats and the biogeographic region or biodiversity hotspot known as "The Western Ghats". It is situated along the west coast with north to south distance of 1490 km, minimum width of 48 km and maximum width of 210 km covering a total area of 136800 km^2 (CEPF,2007) with long ecological history (Chandran,1997). The Western Ghats are rich in biodiversity which is geographically divided into northern, central, Nilgiris and southern Western Ghats. In this Southern Western Ghats is the rainforest ecoregion with high endemism. This region represents rainforest above 1000m elevation of the mountain range along the west coast of the Indian subcontinent. The population dynamics of millipedes are significantly contributed by the various metrological parameters such as rainfall, temperature and moisture (Kadamannaya *et al.,* 2009) and they are conservative and sensitive to water deficit, soil texture, and litter thickness (Kime, 2000), the spread of diplopoda fauna depends in the combination of several factors where the values of temperature, rain and moisture have an important role in their proliferation, particularly

in their active period during the year (Hajdar and Mihallaq, 2010). Ausden *et al.* (2001) reported that humidity is one of the principal characteristics that influence the distribution of soil macro arthropods, it prefers humid climates such as the tropics (Trevor Lofgran *et al.,* 2021). In fact, the sampling season was also the most important factor, affecting the population density of the millipede (Smith *et al*., 2006). Millipedes are sensitive to a narrow change in edaphic factors (Kime and Golovatch, 2000). The environmental changes commonly affect the millipede mainly high temperature. It is also a biological indicator; it shows variation in environment and climatic conditions (Brunner, 2001). This alteration in edaphic and weather parameters causes variation in the millipede population. In addition, human interference, mainly the use of forest products and agricultural activities, has tremendously influenced the ecosystem of Western Ghats (Ashwini and Sridhar, 2008). No detailed account on the distribution of Arthrosphaera and none of the sampling sites is available from the Western Ghats and adjacent biomes (Ashwini and Sridhar, 2008). The present study was conducted to document the diversity of millipedes in relation to metrological parameters in southern Western Ghats of Tirunelveli district, Tamil Nadu.

MATERIAL AND METHODS

Study Area:

The study area Southern Western Ghats region of Tirunelveli district, Tamil Nadu is the part of the Western Ghats with an area of about 6,823 sq. km. It lies between 8.7153^0 N latitude and 77.4702^0 E longitudes. The area receives good rainfall during the northeast monsoon. During the study period, the area's annual rainfall ranges from 968mm to 1400mm, the temperature ranges from 17^0 C to 31^0C with a relative humidity of 81%-87%. The Tambraparani, Chittar, Manimuttar, Virasuli, Sarangani Kundar, and Vaippar are the major river flows in this region. The study area is the dense forest predominantly covered by trees, shrubs, herbs and plants with very few anthropogenic interventions. Totally ten sites were randomly selected, they are 1. Courtallam 2. Papanasam 3. Manimutharu 4. Kalakkad 5. Ambasamudram 6. Manjolai 7. Kannikatti 8. Mundanthurai 9. Kuthiraivetti 10. Karayar (Fig.1). All these sites are mixed with various types of forests such as evergreen, dry evergreen, dry deciduous, scrub, deciduous, moist deciduous, riparian, woodland savanna, wet evergreen, grasslands, and also vegetation like teak plantation, etc.

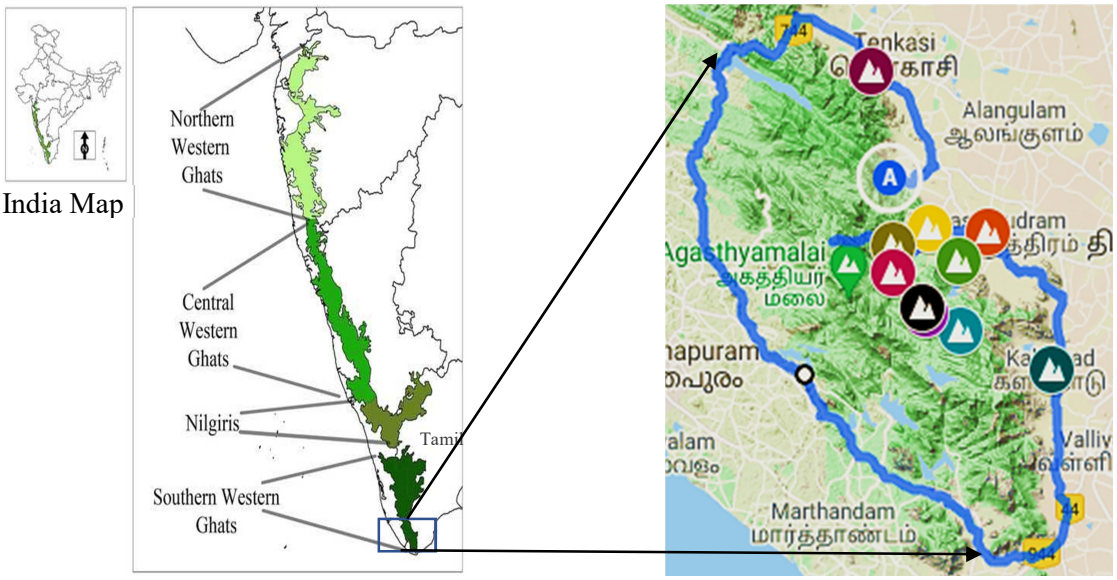
Study Period:

The study was conducted from 1.12.2018 to 31.12.2020, the field survey and sample were noted weekly once in all ten selected sites.

Collection Methods:

Samples were collected from selected ten sites of Southern Western Ghats during the study period by Intensive survey method by handpicking. In each site, 5 sampling points were selected at a 20m distance along a 100m transect (Ashwini and Sridhar, 2008). Samples were taken from leaf litter, dead woods, debris and under rocks lifting up by "L" shaped iron tool. The millipedes were collected by sterilized forceps and gloved hands. Collected millipedes were stored in a 400ml plastic airtight jar along with moistened moss of soil. The soil moisture and stress were maintained during travel. When collecting, jar lids were

punctured with many tiny holes pins for ventilation. After reached to the laboratory, it was introduced in a vial containing 75% ethanol for preservation after rinsing that collected millipede with distilled water to remove soil substances (Means and Francis *et al*., 2015). In subsequent observations, the repeated collections of the same specimens were avoided and photographs are taken for further identification. Eventually, the millipedes were morphologically identified and confirmed based on observation of valuable keys, available kinds of literature and taxonomist suggestions.



Western Ghats-Showing Southern Western Ghats part. Tirunelveli Map- Showing ten selected study sites.

Ten selected study sites- Name of the site & (Lat. Long. Alt.)

Fig. 1. Map showing the Western Ghats, Ten selected study sites with coordinates and altitude.

Data Analysis:

The data was collected and analyzed by using windows based statistical package mainly MS Excel. To calculate the diversity of the millipedes following indices were used namely Mean, SD, SE, Shannon Index (H), Simpson index (D), Evenness Index (E), Richness Index (R). The α diversity index was calculated by e- software packages of BPMSG [Version 14.02.13] tool, Al young biodiversity calculator, Species evenness index Calculator, Standard error calculator, and Statistics calculator. The maps were executed using Google earth and Adobe Photoshop CC software. The weather factors; humidity was measured by a hydrometer, the air temperature was measured by a glass thermometer and rainfall data were retrieved from (accuweather) online tool.

RESULT AND DISCUSSION

A total of 1615 individuals of millipedes belonging to 7 genera and 10 species within 3 families were recorded during the study period (Table-1). The family Pachybolidae (4 species, 40%) and Arthrosphaeridae (4 species, 40%) were the high dominant index contributing and followed by Paradoxosomatidae (2 species, 20%) relatively low. The predominance of Arthrosphaeridae over another millipede group in the Western Ghats (Ashwini and Sridhar, 2008; Sridgar and Ambarish, 2013; Kadamannaya and Sridhar, 2009) and in the Eastern Ghats (Periasamy Alagesan *et al.,* 2013; Chezhian & Prabakaran, 2016) has earlier been reported. A large number of individuals was observed in paradoxosomatidae (n=823 individuals) followed by pachybolidae (n=412) and arthrosphaeridae (n=383) being the least. (Table-2). Totally seven genera were recorded in this, Arthrosphaera is the dominant genus which was the only genus with four species documented in this study. Similarly, the abundance and biomass of Arthrosphaera were significantly high in the Western Ghats and endemic to Southern India (Kadamannaya and Sridhar, 2009), they are usually dominated with single species in a specific location of the Western Ghats and west coast of India (Ashwini and Sridhar, 2008) and remaining six genera each genus one species recorded in each. Among the ten species, *Anoplodesmus saussurii* was the most common polyphagous recorded in all studied sites, it is able to survive in all the habitats. Whereas *Eucentrobolus maindroni* (n=4) and *Arthrosphaera hendersoni* (n=6) had the lowest total abundance and rarely recorded species.

Among the ten selected study sites, courtallam and papanasam were the greater number of individuals observed followed by manimutharu, kalakad and ambasamudrm were observed more or less similar account. Moreover manjolai, kannikatti and kuthiraivetti were cited with fewer individuals recorded compared to other sites. (Table-3).

Diversity indices:

The diversity indices of the study area were calculated month-wise. A total of 1615 individuals were recorded during the study period. Monthly variation in abundance, species richness and evenness varied in each month. Diversity indices such as Simpson Index (D) was calculated and the value ranged from 0.3387 to 0.1462. The maximum was recorded during the month of Oct-2019 and the lowest being in Jan-2020. Similarly, the Shannon- Wiener Index recorded the maximum density in Jan-2020 (H=2.819) and the least in Jul-2019 (H=2.106). These two diversity indices showed much difference in millipede distribution and diversity (Alagesan *et al.,* 2013).

Evenness ranged from 0.9565 to 0.177, the maximum was observed in Aug-2020 and minimum in Jul-2019.

Table 1. The list of millipede species recorded during the study period.

S. No	Order	Family	Genus	Species
1.	Polydesmida (Leach, 1815)	Paradoxosomatidae (Daday, 1889)	*Gyrodrepanum* (Carl, 1932)	*Gyrodrepanum lamprum*
2.			*Anoplodesmus* (Carl, 1932)	*Anoplodesmus saussurii*
3.	Spirobolida (Bollman,189)	Pachybolidae (Cook, 1897)	*Xenobolus* (Carl, 1919)	*Xenobolus carnifex*
4.			*Eucentrobolus* (Pocock, 1903)	*Eucentrobolus maindroni*
5.			*Aulacobolus* (Pocock, 1903)	*Aulacobolus gravelyi*
6.			*Trigoniulus* (Pocock, 1894)	*Trigoniulus corallinus*
7.	Sphaerotheriida (Brandt, 1833)	Arthrosphaeridae (Jeekel, 1974)	*Arthrosphaera (*Pocock, 1895)	*Arthrosphaera brandtii*
8.				*Arthrosphaera dalyi*
9.				*Arthrosphaera hendersoni*
10.				*Arthrosphaera magna*

Table 2. Family-wise dominant index of millipedes showing genera, species and individuals recorded.

S. No	Name of the species:	Selected study sites.										
		Courtallam	Papanasam	Manimutharu	kalakkad	Ambasamudrm	Manjolai	Kannikatti	Mundanthurai	Kuthiraivetti	Karayar	Total number of individuals of each species
1	*Gyrodrepanum lamprum*	63	13	21	19	24	-	-	32	-	24	196
2	*Anoplodesmus saussurii*	98	120	101	98	89	9	2	70	6	34	627
3	*Xenobolus carnifex*	106	-	-	-	-	-	-	-	-	-	106
4	*Eucentrobolus maindroni*	-	-	-	-	-	-	3	-	1	-	4
5	*Aulacobolus gravelyi*	49	12	6	9	11	-	-	20	-	41	148
6	*Trigoniulus corallinus*	99	52	-	-	-	-	-	-	-	-	151
7	*Arthrosphaera brandtii*	63	48	-	-	-	-	-	18	-	-	129
8	*Arthrosphaera dalyi*	-	79	-	-	-	-	-	-	-	35	114
9	*Arthrosphaera hendersoni*	2	1	-	1	1	-	-	-	-	1	6
10	*Arthrosphaera magna*	48	-	-	-	22	-	-	12	-	52	134
Total		528	325	128	127	147	9	5	152	7	187	1615

Table 3. No. of individuals of each species in the selected sites.

S.No	Family	No.of Genera (%)	No. of Species (%)	No. of individuals (%)
1	Paradoxosomatidae	2 (28.58%)	2 (20%)	823 (50.97%)
2	Pachybolidae	4 (57.14%)	4 (40%)	409 (25.32%)
3	Arthrosphaeridae	1(14.28%)	4 (40%)	383 (23.71%)
Total	3	7 (100%)	10 (100%)	1615 (100%)

Note: (-) Indicates an absence of the individual.

Diversity abundance:

The abundance of millipedes fluctuated widely over the months, to determine the abundance of species month-wise the curve was plotted and it resulted as an increase in species abundance from the beginning of October, November and December of 2019 and 2020 because of the post-monsoon (October) (Ashwini and Sridhar, 2008) and decline from late January-February to the end of summer (Fig. 2 & Table-4).The number of individuals were observed maximum during Dec-2019 (n=240), Nov-2019 (n=176), Oct-2019 (n=177), similarly in Nov-2020 (n=163), Oct-2020 (n=154) and the low abundance was observed during April and July of 2019 & 2020. During the month of May and June of 2019 & 2020, there were no species recorded. It clearly denotes those millipedes are increased in abundance during rainy seasons especially during the post-North-east monsoon (Oct-Nov-Dec) and are rarely found in the summer season (Ashwini and Shridhar, 2006). In the present study, a greater number of millipedes were observed during the periods of post-monsoon.

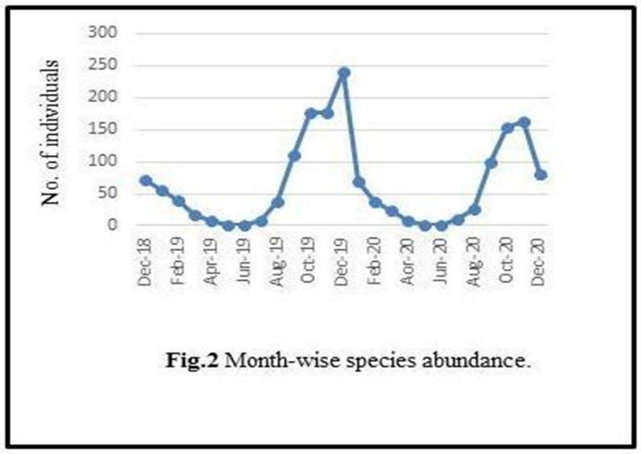


Fig.2 Month-wise species abundance.

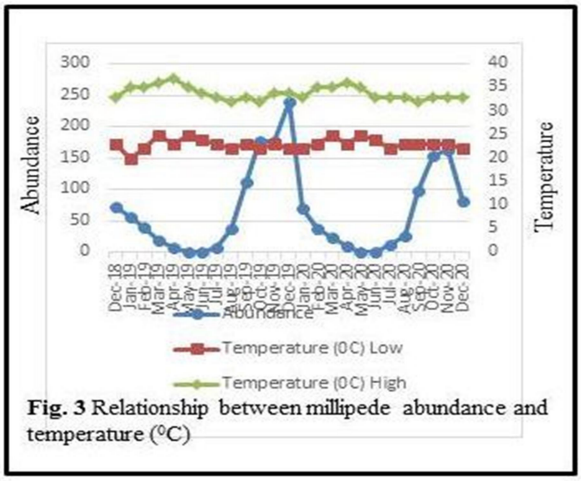


Fig. 3 Relationship between millipede abundance and temperature (^{0}C)

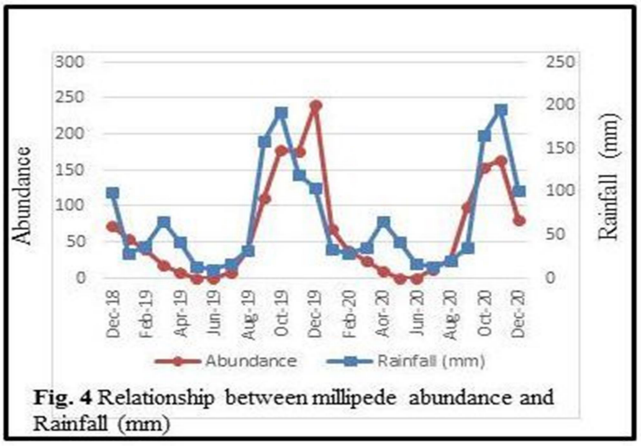


Fig. 4 Relationship between millipede abundance and Rainfall (mm)

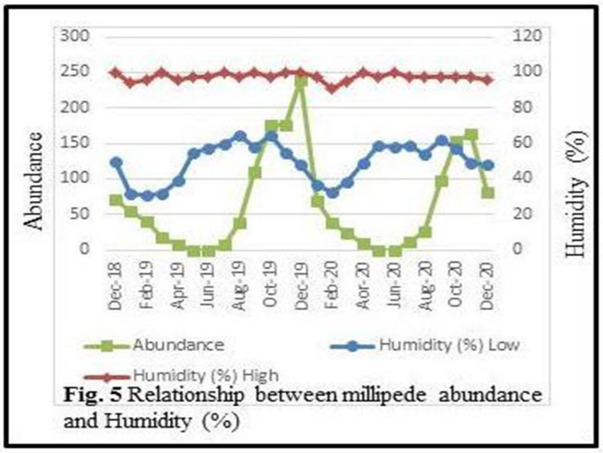


Fig. 5 Relationship between millipede abundance and Humidity (%)

Table 4. Diversity indices of millipedes recorded in the study area from December 2018-

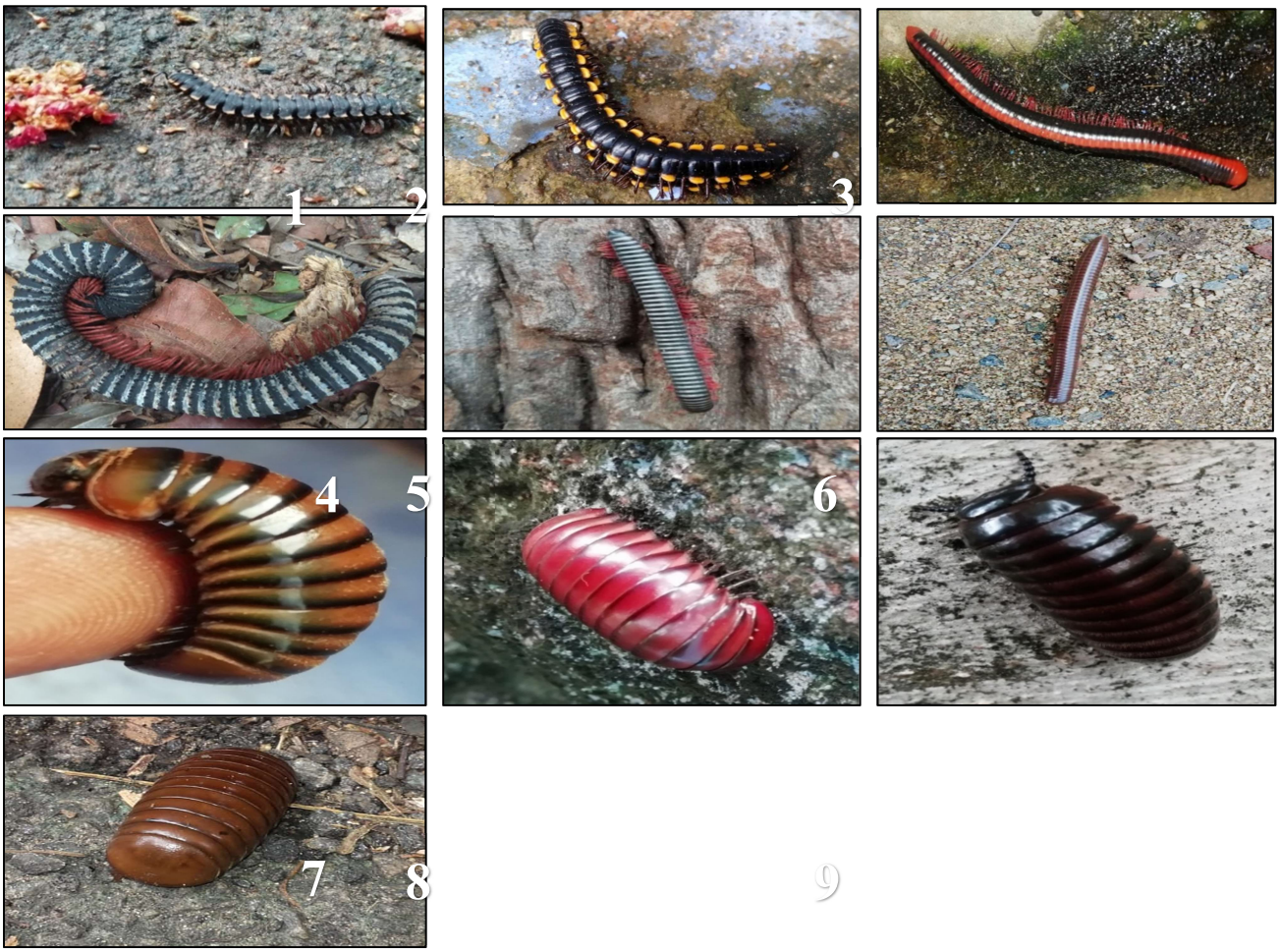
Months	Abundance	Shannon Weiner Index (H)	Simpson Index (D)	Evenness (E)	Species Richness (R)
Dec- 18	72	2.466	0.1956	0.6856	1.403
Jan- 19	55	2.776	0.1529	0.8523	1.747
Feb-19	40	2.679	0.159	0.9139	1.898
Mar-19	18	2.177	0.1961	0.9235	1.384
Apr-19	7	2.067	0.2857	0.195	1.542
May-19	-	-	-	-	-
June-19	-	-	-	-	-
July-19	8	2.106	0.1786	0.177	1.443
Aug-19	38	2.636	0.1494	0.895	1.649
Sep-19	111	2.498	0.2416	0.6383	1.699
Oct-19	177	2.258	0.3387	0.5207	1.739
Nov-19	176	2.395	0.2751	0.5471	1.547
Dec-19	240	2.633	0.2213	0.886	1.642
Jan- 20	69	2.819	0.1462	0.8083	1.653
Feb-20	38	2.627	0.1679	0.9125	1.924
Mar-20	23	2.431	0.1976	0.423	1.914
Apr-20	9	2.111	0.2222	0.392	1.365
May-20	-	-	-	-	-
June-20	-	-	-	-	-
July-20	11	2.187	0.1636	0.1972	1.668
Aug-20	26	2.483	0.1567	0.9565	1.553
Sep-20	99	2.689	0.1688	0.6979	1.523
Oct-20	154	2.815	0.161	0.6549	1.391
Nov-20	163	2.351	0.2712	0.5464	1.571
Dec-20	81	2.676	0.184	0.7444	1.82

December 2020.

Species abundance in relation with metrological parameters:

The distribution of millipede's abundance was correlated with mean temperature, rainfall and humidity. Baker (1974) stated millipede populations are directly and indirectly influenced by the temperature, so we correlated temperature and abundance, their abundance and richness increased with

increasing the rainfall and relative humidity, the abundance drastically decreased at high temperatures in summer (33^0C). The maximum temperature was recorded in the month of April-2019 (37^0C) followed by April-2020 (36^0C), March (36^0C -2019, 35^0C -2020) being the hottest weather shows a decline in the abundance of species (Fig. 3). Striganova (1977) observed physiological rest in many species when the temperature drops below the lower limit of their feeding and locomotor activity. Such early preparations allow surviving cold periods. Similarly, Kadamannaya1 and Sridhar (2009) observed an increase in air and soil temperatures induce the resting phase in *A. dalyi*.



1. *Gyrodrepanum lamprum* (Chamberlin, 1920)
2. *Anoplodesmus saussurii* (Humbert, 1865)
3. *Xenobolus carnifex* (Fabricius, 1775)
4. *Eucentrobolus maindroni* (Bouvier, 1903)
5. *Aulacobolus gravelyi* (Silvestri, 1916)
6. *Trigoniulus corallinus* (Gervais, 1847)
7. *Arthrosphaera brandtii* (Humbert, 1865)
8. *Arthrosphaera dalyi* (Pocock, 1895)
9. *Arthrosphaera hendersoni* (Pocock, 1895)
10. *Arthrosphaera magna* (Attems, 1936)

Photographic Plate- 1 The ten millipedes recorded in the Southern Western Ghats of Tirunelveli

Millipedes prefer the rainy season with conducive humidity to dry habitat. The Southern Western Ghats receives good rain during the North-east monsoon, the abundance increases from the beginning of post-monsoon the abundance was higher in Dec-2019 (240), October, November and December show maximum abundance (Fig. 4), a similar trend was previously recorded by (Ashwini and Sridhar 2008) during the post-monsoon season in the Western Ghats and reproductive phase may be confined to an early period of post-monsoon season (October-January) (Kadamannaya and Sridhar, 2009). Moreover, the humidity cause fluctuation in millipede populations (Baker, 1988). Our observed humidity ranged from 31% to 100%. The highest abundance was recorded in the month of Dec-2019 where the humidity was

100%. Rainfall was recorded maximum in the month of Oct-2019 (192mm), followed by Nov-2020 (195mm), Sep-2019 (158mm) and Dec-2019 (104mm), the highest abundance observed during the month of Dec-2019 (240 individuals) (Fig. 5). Millipedes are seasonal arthropods, they are commonly found in the rainy season and rarely found in the summer season because fluctuation in temperature affects a millipede (Ashwini and Shridhar, 2006). It is observed that the post-rain months resulted in high abundance because of an increase in habitat with an increase in humidity along with a decrease in temperature. This selected abiotic factor has strongly correlated with species abundance. Similarly, Ashwini and Sridhar (2006) found that millipede abundance and biomass were positively correlated with rainfall, soil moisture, soil calcium content and soil temperature in forests.

CONCLUSION

The present study resulted in a list of ten species of millipede's record, this study area Southern Western Ghats of Tirunelveli is rich in millipede species, representing many families when compared to records from other parts of India. With this present baseline inventory, the furthermore documentation is needed to study more about the diversity, distribution, and abundance with sufficient data, and also more studies and records are needed from the other parts of India. Currently, climate change is the most discussed topic, still, the effects of climate change on invertebrates are inadequate, in the present study, meteorological parameters play a vital role in the millipedes. Further study is to be conducted on the effect of seasonality, seasonal fluctuations on millipede diversity. Moreover, the conservation strategies are to be planned along with documentation. More awareness and encouragements are essential among the researchers about the millipedes.

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