
*Tropical and
Subtropical
Agroecosystems*

SHORT NOTE [NOTA CORTA]

DIURNAL PERIODICITY OF THREE ENDEMIC SPECIES OF PILL
MILLIPEDES (*ARTHROSPHAERA*) IN WESTERN GHATS, INDIA

[PERIODICIDAD DIURNA DE TRES ESPECIES ENDEMICAS DE
MILIPEDOS (*ARTHROSPHAERA*) EN LOS GHATS OCCIDENTALES,
INDIA]

B.S. Kadamannaya¹ and K.R. Sridhar^{2*}

¹Department of Zoology, Field Marshal K.M. Cariappa College,
Madikeri 571 201, Karnataka, India

²Microbiology and Biotechnology, Department of Biosciences,
Mangalore University, Mangalagangothri, Mangalore 574 199, Karnataka, India.

E-mail - sirikr@yahoo.com

*Corresponding author

SUMMARY

Diurnal periodicity and behavior of three species of endemic pill millipedes belonging to the genus *Arthrosphaera* (Sphaerotheriidae) (*Arthrosphaera dalyi*, *A. davisoni* and *A. fumosa*) were assessed in two mixed plantations (Kadaba and Basrikallu) and a semi-evergreen forest (Madikeri) of the Western Ghats during monsoon season. Increase in air (27.44°C) and soil (26.13°C) temperatures induced resting phase in *A. dalyi* in Kadaba plantation. Resting phase was not much influenced by temperature in *A. davisoni* (Basrikallu plantation: air, 20.5°C; soil, 19.81°C) and *A. fumosa* (Madikeri forest: air 19.69°C; soil, 19.13°C) due to relatively low temperature regimes in their habitat. In diurnal pattern of behavior, most of the crawling, feeding and burrowing activities of *Arthrosphaera* are confined to dusk or night. The overall diurnal behavior pattern of *A. dalyi*, *A. davisoni* and *A. fumosa* has been predicted due to species, geographical location (Western Ghat and foothill) and habitat (plantation and forest) differences.

Key words: Pill millipedes; diurnal periodicity; behavior; Western Ghats; forest; plantations.

RESUMEN

Se evaluó la periodicidad diurna y conducta de tres especies endémicas de milípedos pertenecientes al género *Arthrosphaera* (Sphaerotheriidae) (*Arthrosphaera dalyi*, *A. davisoni* y *A. fumosa*) en dos plantaciones mixtas (Kadaba y Basrikallu) y en un bosque semi-perene (Madikeri) durante la estación de monzon. El incremento de las temperaturas del aire (27.44 °C) y suelo (26.13 °C) indujeron un fase de descanso en *A. dalyi* en Kadaba. La fase de descanso no fue influenciada por la temperatura en *A. davisoni* (Basrikallu: aire, 20.5 °C, suelo 19.81 °C) y en *A. fumosa* (Madikeri: aire, 19.69 °C, suelo 19.13 °C) debido a las relativamente bajas temperaturas en su habitat. En el patron de conducta diurna, la mayoría de las actividades de *Arthrosphaera* estan confinadas al crepusculo o noche. Los patrones de conducta diurna de estas tres especies son predichas por diferencias entre localidades geográficas y habitat.

Palabras clave: Milípedos; periodicidad diurna; conducta; Ghats occidentales; bosques; plantaciones.

INTRODUCTION

The giant pill millipedes belonging to the genus *Arthrosphaera* Pocock 1895 (Sphaerotheriidae) are endemic to Southern India and Sri Lanka. Surveys in peninsular India revealed the occurrence of about 46 species of *Arthrosphaera* (Pocock, 1882; 1899; Attems, 1936; Chowdaiah, 1969; Achar, 1980; 1986; Janardanan and Ramachandran, 1983; Ashwini and

Sridhar, 2008). In India, they inhabit mainly the regions with high rainfall in Western Ghat and Eastern Ghat forests (Maharashtra, Karnataka, Kerala, Tamil Nadu and Andhra Pradesh). A recent survey of 21 locations comprising high altitude (Western Ghats), moderate altitude (foothill of Western Ghats) and low altitude (west coast) sampling sites, ranging from 120-910 m during post-monsoon season, revealed the occurrence of several species of *Arthrosphaera*

(Ashwini and Sridhar, 2008). Adult individuals were usually thrive in upper soil strata along with litter layers and the juveniles exist at 5-10 cm soil depth. Abundance and biomass of *Arthrosphaera* were significantly high in the Western Ghats.

The activity of millipedes is confined to upper strata because of high quality food source, mate acquisition and to avoid saturated soil conditions (Telford and Dangerfield, 1993). Invasion of a variety of *Arthrosphaera* species from the forest to mixed plantations have been evident at the Western Ghats, foothill of Western Ghats and west coast locations (Ashwini and Sridhar, 2006). Ashwini and Sridhar (2006) compared the seasonal periodicity of *Arthrosphaera magna* Attems in mixed plantation as well as semi-evergreen forest at the foothill of Western Ghats and found peak of its abundance and biomass during monsoon season. As there are no studies on the diurnal or circadian rhythms in abundance and behavior of *Arthrosphaera*, the present study focuses on the diurnal pattern of occurrence and behavior of *Arthrosphaera dalyi* Pocock, *A. davisoni* Pocock and *A. fumosa* Pocock (Figure 1) found in mixed plantation of the foothill of Western Ghats (Kadaba), mixed plantation of the Western Ghats (Basrikallu) and semi-evergreen forest of the Western Ghats (Madikeri) respectively.

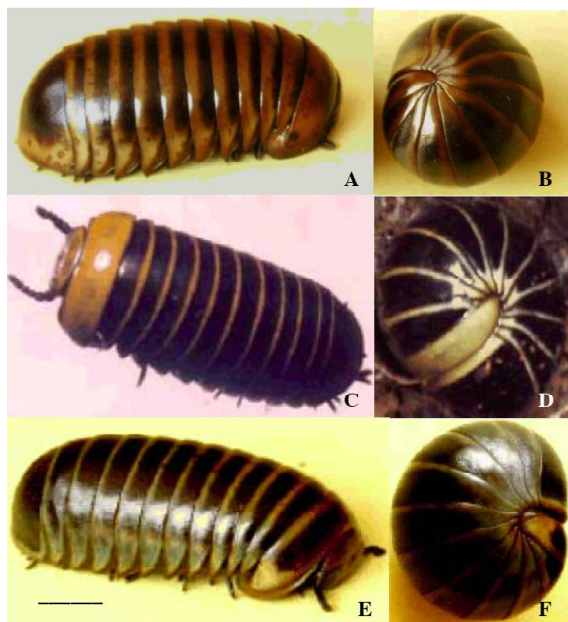


Figure 1: *Arthrosphaera dalyi*: whole animal (A), conglobated animal (B); *Arthrosphaera davisoni*: whole animal (C), conglobated animal (D); *Arthrosphaera fumosa*: whole animal (E), conglobated animal (F).

Scale bar for all pictures: 1 cm.

MATERIAL AND METHODS

Study location

Western Ghats of India (8°20'-20°40' N, 73°-77° E) cover an area of about 160,000 km² in a stretch of 1,600 km at the southwestern peninsula. Being a hotspot of biodiversity, Western Ghats endowed with a variety of flora, fauna and microorganisms. Wide range of vegetation (evergreen forests, semi-evergreen forests, moist and dry deciduous forests, shoals, scrub jungles and grasslands) spreadover in a wide range of land scapes up to about 2,500 m altitude. Several plant and animal species are endemic to the Western Ghats (Myers *et al.*, 2000).

Kadaba plantation (12°44'37" N, 75°29'54.4" E) located at the foothill of Western Ghats (124 m), receives rainfall about 250-400 cm/annum and temperature ranges between 21-22°C (minimum) and 34-36°C (maximum). Common plantations include: *Areca*, *Cocoa*, *Coffea*, *Musa*, *Piper*, *Syzygium* and *Theobroma* grown along with forest tree species (*Acacia*, *Ailanthus*, *Albizia*, *Alstonia*, *Aporosa*, *Artocarpus*, *Butea*, *Calamus*, *Calophyllum*, *Carallia*, *Cinnamomum*, *Dalbergia*, *Ficus*, *Flacuortia*, *Holigarna*, *Hopea*, *Lantana*, *Lagerstroemia*, *Mangifera*, *Mimusops*, *Ochlandra*, *Pterocarpus*, *Syzygium*, *Tectona*, *Terminalia* and *Zizypus*).

Madikeri semi-evergreen forest (12°25'13.19" N, 75°44' 23.77" E) situated at high altitude (1147 m), consists of cool and humid climate with rainfall about 400-600 cm/annum. The temperature ranges between 10-12°C (minimum) and 30-32°C (maximum). Common genera of forest tree species includes: *Acacia*, *Ailanthus*, *Albizia*, *Alstonia*, *Artocarpus*, *Butea*, *Calamus*, *Calophyllum*, *Carallia*, *Careya*, *Cinnamomum*, *Flacuortia*, *Holigarna*, *Hopea*, *Lagerstroemia*, *Macaranga*, *Mimusops*, *Ochlandra*, *Pterocarpus*, *Syzygium* and *Terminalia*.

The Basrikallu plantation (13°29'36.8" N, 75°40'30.72" E) is at high altitude location (1387 m) with similar climatic conditions of Madikeri forest. The plantations crops (*Areca*, *Cocoa*, *Coffea*, *Musa* and *Piper*) are grown along with forest tree species seen in Madikeri semi-evergreen forest.

Observations and data analysis

The study was carried during monsoon season (*A. dalyi*, September 9-10, 2005; *A. davisoni*, September 19-20, 2005; *A. fumosa*, September 29-30, 2005). Four quadrants each of 5 m² were randomly selected in an area of 500 m² in each study area. Diurnal pattern of periodicity, abundance and behavior of pill millipedes in each quadrant was assessed regularly at 3 hr

intervals up to 24 hr. On every interval, five common behaviors (crawling, feeding, resting, burrowing and copulating) if any in each individual present in the litter strata of a quadrant have been recorded without disturbing the animal. After assessing the behavior, sex of each individual was ascertained. At each sampling time, air temperature was determined at 10 cm above the litter strata using a mercury thermometer (on sunny interval in shade) and soil temperature at 10 cm depth.

Paired t-test was employed to determine the difference between temperatures (air and soil) abundance (total, male and female) and behavior (crawling, feeding, resting and burrowing) between sites and millipede species using Statistica software (StatSoft Inc., 1995).

RESULTS

Diurnal periodicity of millipedes abundance (male and female) and behavior (crawling, feeding, resting and burrowing) along with temperature (air and soil) in Kadaba plantation (*A. dalyi*), Basrikallu plantation (*A. davisoni*) and Madikeri forest (*A. fumosa*) have been plotted in Figures 2, 3 and 4 respectively.

The air temperature was highest (31.5°C) at 8-11 am at the Kadaba plantation and least (24°C) during 5 am, while soil temperature at 5 pm (28°C) and 2-5 am (25°C) respectively (Fig. 2). Abundance of *A. dalyi* peaked twice in a day (highest at 11 am and second highest at 8 pm). The abundance of male and female individuals also followed more or less similar pattern. During resting phase, animals usually rolled up (conglobated) (see Fig. 1). Resting individuals were highest during 11 am with highest air temperature and elevated soil temperature. The highest number of resting animals was seen at 11 am followed by a small peak at 11 pm. Following the resting phase, feeding phase peaked at 8 pm. After feeding phase, individuals involved in burrowing attained peak at 11 pm and 2 am. Crawling individuals steadily decreased from 8 am to 5 am with alternate fluctuations.

In Basrikallu plantation, the air temperature was highest at 2 pm (23°C) and least during 2-5 am (18.5°C), while soil temperature at 2 pm (21°C) and 2-5 am (18°C) (Fig. 3). Abundance of *A. davisoni* peaked twice a day (highest peak at 8 pm followed by a second peak at 8 am). The periodicity of abundance of male and females also followed similar pattern. Crawling and feeding behaviors showed two peaks as seen in total abundance. The number of resting individuals was lower than crawling and feeding individuals and showed intermittent fluctuations. Least number of individuals involved in burrowing activity.

The air temperature was highest at 2 pm (23°C) and least during 5 am (17°C), while soil temperature at 2 pm (21°C) and 5 am (17°C) at the Madikeri forest (Fig. 4). Abundance of *A. fumosa* peaked thrice a day (highest peak at 2 am, followed by two peaks at 8 am and 5 pm). The abundance of male and female individuals also followed similar pattern. Crawling behavior of individuals peaked twice a day with highest during 5 pm followed by 8 am. Resting, the second highest behavior attained a peak at 2 am. Feeding phase of individuals was seen during 8-11 am and 11 pm to 5 am. Burrowing activity was highest during 11 pm continued up to 5 am.

The mean air and soil temperatures were highest at Kadaba plantation (27.4 and 26.1°C) and least at Madikeri forest (19.7 and 19.13°C) (Table 1). The mean individuals seen in one day was highest at plantations (10.6-19.9) than forest (5.9), so also the male and female individuals. Crawling, feeding and resting behavior of individuals were higher at Basrikallu plantation than Kadaba plantation and Madikeri forest, while the burrowing behavior was least. The air and soil temperatures, total individuals and female individuals significantly differed between Kadaba plantation vs. Basrikallu plantation; Kadaba plantation vs. Madikeri forest; Basrikallu plantation vs. Madikeri forest (Table 1). Crawling and feeding behaviors also significantly differed between Kadaba plantation and Basrikallu plantation; Basrikallu plantation and Madikeri forest.

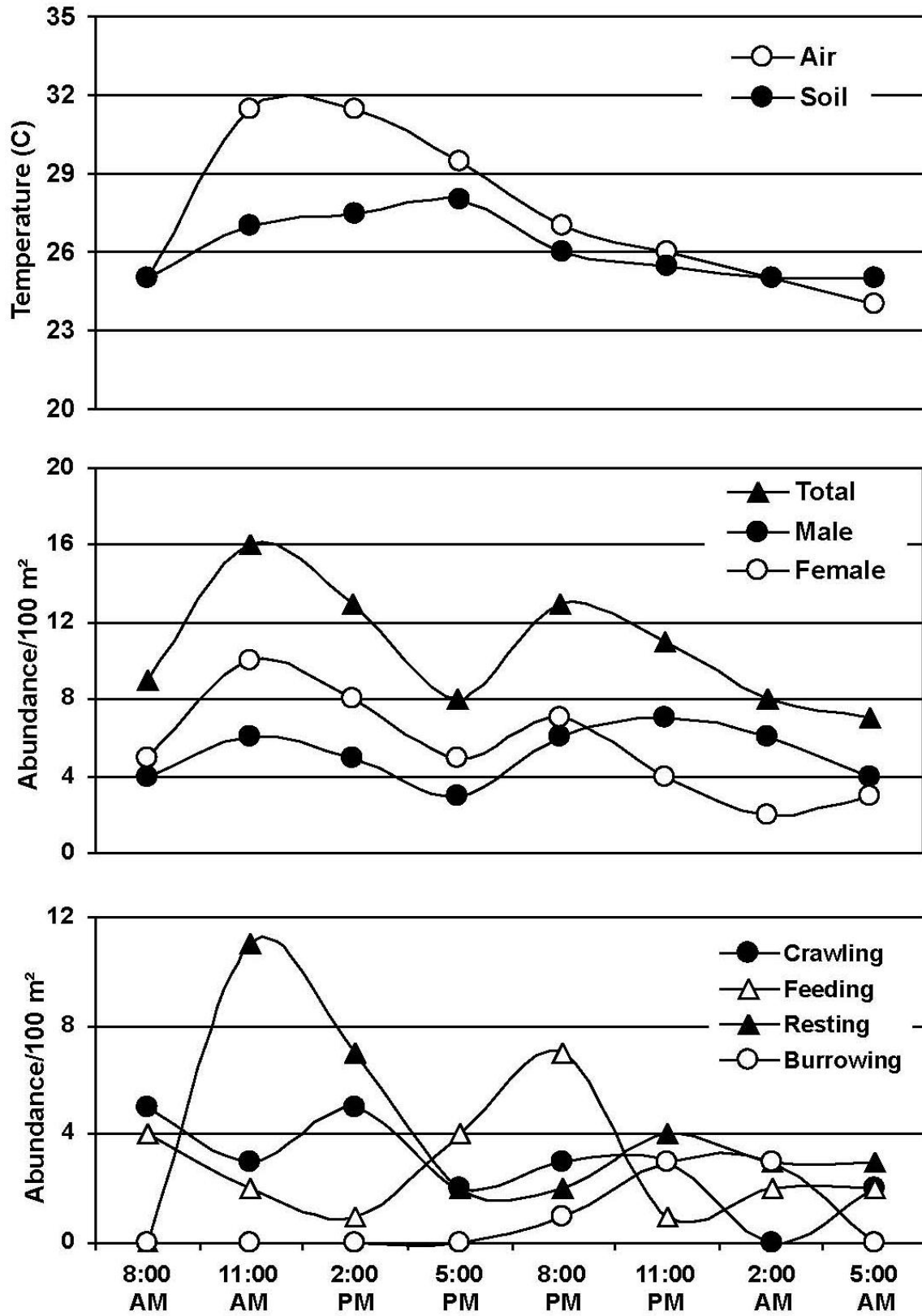


Figure 2: Diurnal periodicity in temperature, pill millipedes (*Arthrosphaera dalyi*) and their behavior at Kadaba plantation

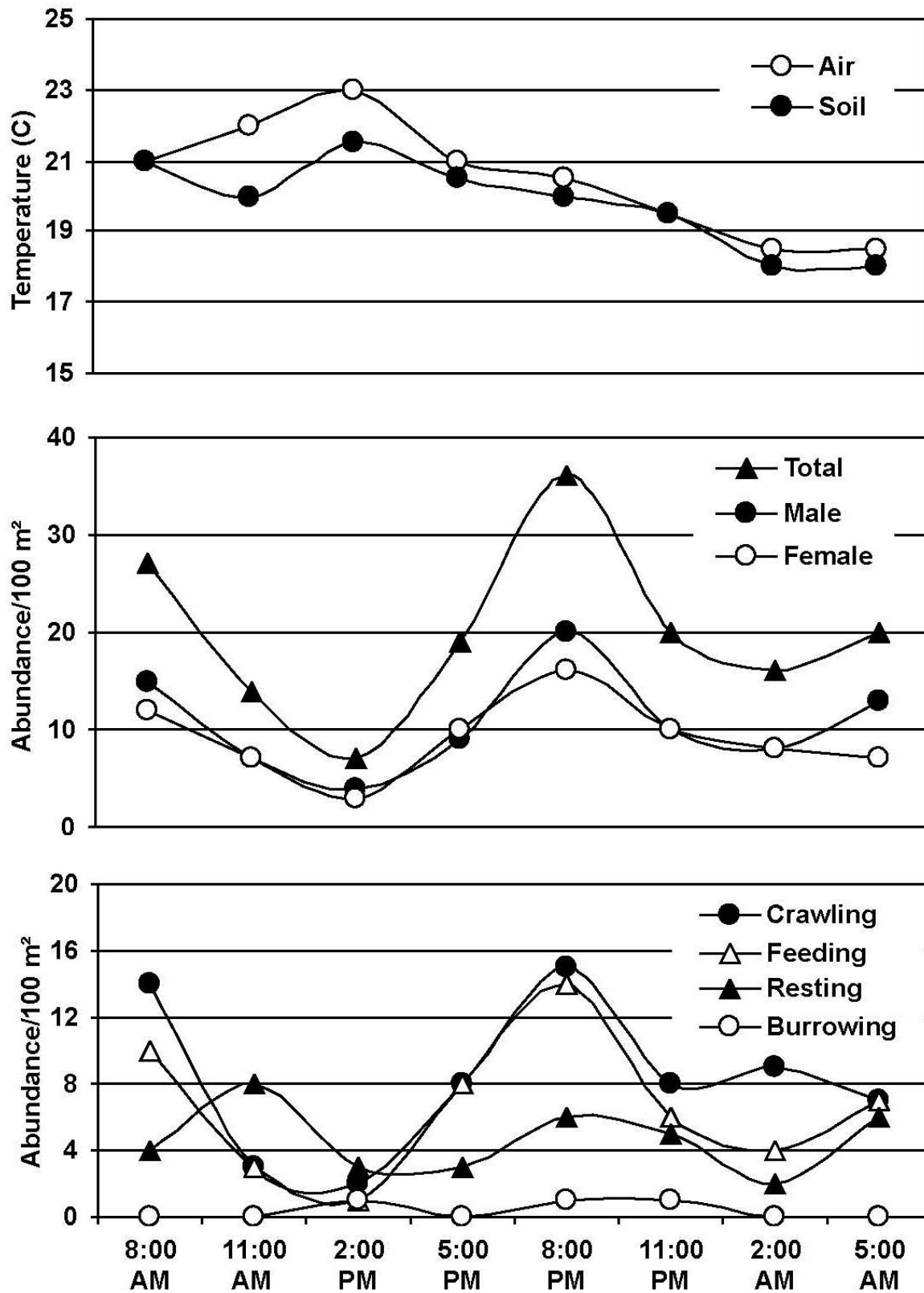


Figure 3: Diurnal periodicity in temperature, pill millipedes (*Arthrosphaera davisoni*) and their behavior at Basrikallu plantation

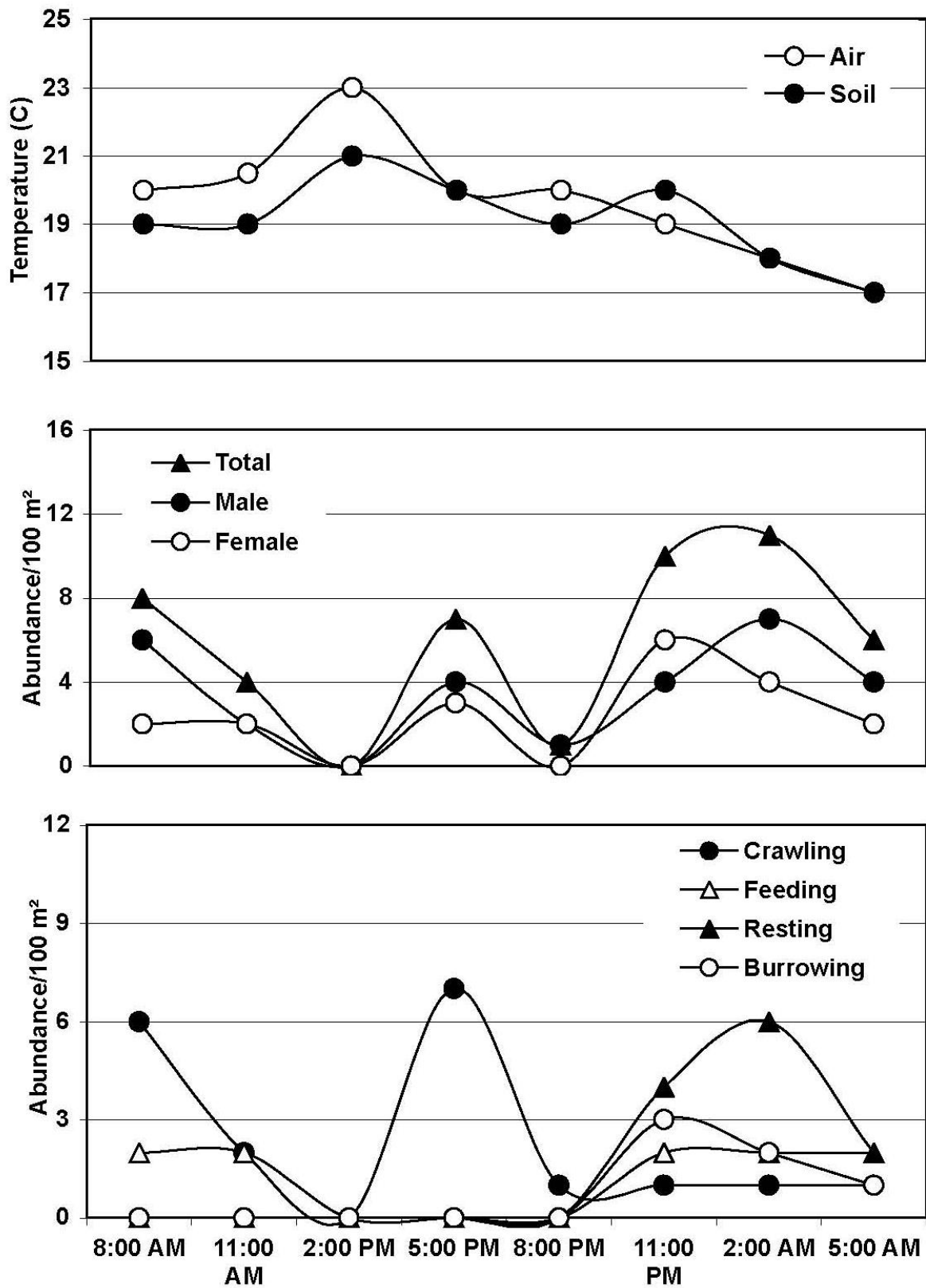


Figure 4: Diurnal periodicity in temperature, pill millipedes (*Arthrosphaera fumosa*) and their behavior at Madikeri forest

Table 1. Geographical coordinates, altitude, temperature, abundance and behavior of pill millipedes (*Arthrosphaera dalyi*, *A. davisoni* and *A. fumosa*) in 24 hr in three regions.

	Kadaba plantation (<i>A. dalyi</i>)	Basrikallu plantation (<i>A. davisoni</i>)	Madikeri forest (<i>A. fumosa</i>)
Geographical coordinates	12°44'37" N, 75°29'54.4" E	13°29'36.8" N, 75°40'30.72" E	12°25'13.19" N, 75°44' 23.77" E
Altitude (m.a.s.l.)	124	1387	1147
Air Temperature (°C)	27.44±3.00 ^a (24-31.5)	20.5±1.60 ^{ac} (18.5-23)	19.69±1.79 ^{ac} (17-23)
Soil Temperature (°C)	26.13±1.21 ^a (25-28)	19.81±1.28 ^{ac} (18-21.5)	19.13±1.25 ^{ac} (17-21)
Abundance/100 m ²			
Total	10.63±3.12 ^a (7-16)	19.88±8.68 ^{ac} (7-36)	5.88±3.98 ^{ac} (0-11)
Male	5.13±1.36 ^a (3-7)	10.75±5.06 ^{ac} (4-20)	3.50±2.39 ^{bc} (0-7)
Female	5.50±2.67 ^a (2-10)	9.13±3.87 ^{ac} (3-16)	2.38±2.00 ^{ac} (0-6)
Overall behavior			
Crawling	2.88±1.64 ^a (0-5)	8.25±4.59 ^{ac} (2-15)	2.38±2.62 ^{bc} (0-6)
Feeding	2.88±2.03 ^a (1-7)	6.63±4.14 ^{ac} (1-14)	1.25±1.04 ^{bc} (0-2)
Resting	4.00±3.46 ^a (0-11)	4.63±2.00 ^{bc} (2-8)	1.50±2.32 ^{bc} (0-6)
Burrowing	0.88±1.36 ^a (0-3)	0.38±0.52 ^{bc} (0-1)	0.75±1.17 ^{bd} (0-3)

Temperature: n=32, mean±SD; millipedes: n=8 observations, mean±SD; range in parenthesis. Values with same letters across the column significantly differed: p<0.05, paired t-test

DISCUSSION

Millipedes are diverse with long lifespan and seasonally active individuals exhibit a wide range of lifestyles. The giant pill millipedes belonging to the genus *Arthrosphaera* are endemic to Southern India and found particularly in the Western Ghat forests. Western Ghats are endowed with a variety of characteristic biomes suitable for the activity of *Arthrosphaera* (e.g. semi-evergreen forests, deciduous forests, sholas). *Arthrosphaera* are microendemic and usually dominate with single species in specific location of Western Ghats and west coast of India (Ashwini and Sridhar, 2008). A few studies have been carried out on their distribution, seasonal activities and litter preferences (Ashwini and Sridhar, 2005, 2006, 2008). Besides active at the forests, species of *Arthrosphaera* are also invaders of the plantations of Southern India (Ashwini and Sridhar, 2006). In a semi-evergreen forest, adults of *A. magna* were active up to five months (July-November), while young ones

restricted to four months (August-November). In a nearby mixed plantation, adults were active up to seven months (early or late June-January), while juveniles emerge during late July or early August, active for up to four months and hibernates in November prior to adults.

The current diurnal study has been performed during monsoon period (September). The diurnal pattern of *A. dalyi*, *A. davisoni* and *A. fumosa* vary possibly due to species, geographical (Western Ghat and foothill) and habitat (plantation and forest) differences. The overall air and soil temperature regimes were high at the Kadaba plantation (air, 27.44; soil, 26.13°C) than Basrikallu plantation (air, 20.5; soil, 19.81°C) and Madikeri forest (air, 19.69; soil, 19.13°C). The air and soil temperatures of Kadaba plantation, Basrikallu plantation and Madikeri forest were significantly different, so also the total individuals of *Arthrosphaera*. Increased air and soil temperatures (27.44 and 26.13°C) induced resting phase in *A. dalyi*

in Kadaba plantation, while resting phase of *A. davisoni* at Basrikallu plantation (20.5 and 19.81°C) and *A. fumosa* at Madikeri forest (19.69 and 19.13°C) was not much influenced by temperature due to relatively lower air and soil temperature regimes. The mean number of individuals recorded at three hours interval is fairly high at Basrikallu plantation than other locations, so also the observed behavior of millipedes except for burrowing.

The juliform millipedes in Savanna of Southern Africa exhibit two major behaviors: movement within the habitat (prominent in males) and foraging activity (Dangerfield *et al.* 1992). In the present study, feeding in *A. dalyi*, crawling and feeding in *A. davisoni* and crawling and burrowing in *A. fumosa* were prominent. In *A. dalyi*, elevation of air and soil temperatures during morning and noon induced resting phase, decrease of temperature at dusk and night increased the feeding phase followed by burrowing. The narrow range of temperature might have not influenced *A. davisoni* and thus the resting phase is not much prominent. However, both crawling and feeding activities were highest during the night. Interestingly, the resting phase in *A. fumosa* was induced at low air and soil temperatures (18-20°C) (see Fig. 4). Crawling phase is more during dusk and dawn. The feeding phase was at night and morning, while burrowing behavior confined only to night. Burrowing behavior seen mainly in *A. dalyi* and *A. fumosa* indicates the possibilities of resting of animals at a shallow soil depth besides surface litter. Overall, most activities (crawling, feeding and or burrowing) of three species of *Arthrosphaera* are confined to dusk or night.

Diurnal pattern of activity of animals is normally associated with food acquisition and reproduction. Crawling behavior is a foraging strategy in millipedes to locate high quality food sources and also for mate acquisition (Dangerfield *et al.* 1992). Interestingly, no copulating behavior was seen in all three species of *Arthrosphaera* studied indicating the study period (September) is likely a foraging phase. The reproductive phase may be confined to early period of monsoon season (June-August) or post-monsoon season (October-January) in the locations investigated. However, *Arthrosphaera magna* were active at semi-evergreen forest up to five months (July-November), while 7-8 months (June-January) in mixed plantation at the foothill of Western Ghats of Southern India (Ashwini and Sridhar, 2006). Juveniles of *A. magna* emerged during late July or early August indicates the reproductive phase will be during June and July. In the current study, abundance and activity of *Arthrosphaera* spp. was relatively high at the Kadaba and Basrikallu plantations than Madikeri forest probably due to the physicochemical features, farming practices and availability of food resources in

plantations. It is likely, the behavior of specific pill millipede is dependent on the geographical location and habitat differences. Future studies need to concentrate on the finer details of diurnal pattern of occurrence and behavior of males, females and juveniles of *Arthrosphaera* species for domestication and to improve the soil fertility in their geographical locations particularly in mixed plantations.

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