Distribution of Giant Pill-Millipedes (*Zephronia* cf. *viridescens*) and Flat-backed millipedes (*Orthomorpha variegata*) in Relation to Ecological Factors at Sakaerat Environmental Research Station, Thailand

Sirirut Sukteeka, and Nathawut Thanee

***Abstract*—**Distribution of giant pill-millipedes (*Zephronia* cf. *viridescens*) and flat-backed millipedes (*Orthomorpha variegata*) were examined in dry evergreen forest, ecotone, dry dipterocarp forest, and plantation forest in Sakaerat Environmental Research Station (SERS), Nakhon Ratchasima, Thailand between June 2010 and May 2011. Abundance of *Z.* cf. *viridescens* was highest in plantation forest during the rainy season. Density of *O. variegate* was the highest in dry evergreen forest, having two regular peaks in the winter and the rainy season. Abundance of *Z.* cf. *viridescens* was positively correlated with soil temperature, air temperature and potassium (p = 0.01), while *O. variegata* was positively correlated with soil moisture (p = 0.01). Distribution pattern, abundance and ecology of them in relation to soil qualities and climatic factors were compared with millipedes of other regions.

Keywords*—Zephronia* cf. *viridescens*, *Orthomorpha variegate*, Ecological factors, Forest types

I. Introduction

MILLIPEDES are the major saprophagous macro arthropods in temperate and tropical ecosystems [1- 3]. Their abundance and diversity facilitate soil mineralization through mechanical fragmentation of plant litter and release of essential elements [4- 6]. Despite only 10% of total decomposition of plant litter within an ecosystem takes place through millipedes, their feeding enhances microbial activities, resulting in breakdown of litter up to 90% [7].

Giant pill-Millipedes (*Zephronia* cf. *viridescens*) and flat-backed millipedes (*Orthomorpha variegata*) are the common species in Sakaerat Environmental Research Station, Thailand.

Giant pill-millipedes of Thailand are very poorly known. They occur in discontinuous geographical areas [8-10] and are separated into 4 families: the Sphaerotheriidae in South Africa, the Procyliosomatidae in Australia and New Zealand, the Arthrosphaeridae in southern India and Madagascar, and the Zephroniidae in southern China, Southeast Asia and the Sunda Islands [10]. The species, *Z.* cf. *viridescens* belongs to the Family Zephroniidae [11]. Members of the order Polydesmida are also known as **"**flat-backed**"**. The genus *Orthomorpha* (Bollman, 1893) is one of the largest millipedes amongst the Family Paradoxosomatidae, dominating the Oriental fauna and ranging from Myanmar in the west, through the entire Indochian Peninsula, to Lombok, Indonesia in the east. The Sakaerat Environmental Research Station (SERS) inNakhon Ratchasima Thailand, is one of the four UNESCO designated biosphere reserves of Thailand [12]. SERS is covered by two major forest types, dry evergreen forest and dry dipterocarp forest. Millipedes are known as indicators of environmental alteration, as they are sensitive to a narrow change in edaphic factors [13]. Thus, the present study aimed to investigate the distribution, abundance and ecology of common millipedes in relation to soil edaphic factors and climatic features of four forest types (dry evergreen forest; DEF, ecotone; ECO, dry dipterocarp forest; DDF and plantation forest; PTF) in SERS.

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II. Materials and Methods

A. Study Site

SERS is situated in mountainous terrain at an altitude of 280-762 m above sea level (Fig. 1). The area surveyed (14^o 30′ N, 101^o 55′ E) with mean annual rainfall and air temperature during the studied period were 1219 mm and 23.2°C, respectively [14]. Most of the rainfall occurs during rainy season (May-October). Each forest type consists of dominant plant species, which differ from forest to forest.

B. Population Density

Three replicate samples of soil and leaf litter were collected from the study sites once a month in June 2010-May 2011 to determine millipede diversity in these areas. Three sampling sites from each SERS forest were investigated to study the distribution of millipedes in relationship to environmental factors. The sampling method involved the selection of a good stand sampling area and establishment of the permanent plot of 20 m x 20 m (400 m^2). Millipede was sampled by forcing steel frames (30 × 30 × 30 cm) into the soil, and then the excavated soil along with litter was transferred to trays.

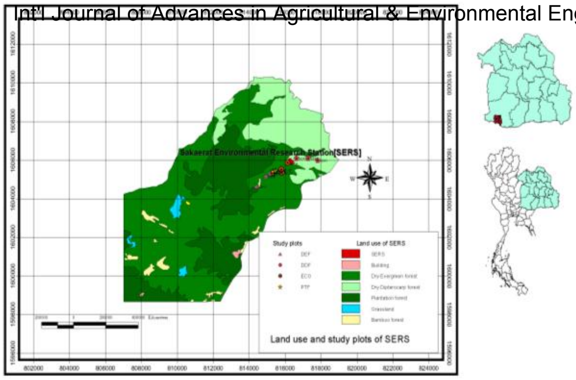

Fig. 1 Land use and study plots of Sakaerat Environment Research Station

Source: Modified from map of Sakaerat Environment Research Station, 2010

C. Data Analysis

Differences in millipede number and species abundance among forest types were analyzed using ANOVA. The Pearson correlation was employed to find relationships among soil parameters, environmental factors and millipede densities.

III. Results and Discussion

Adult of *Z.* cf. *viridescens* consists of 13 rings on the back of the animal. The collum is small and oval. The 2nd tergite is very broad and the 13th ring is the broadest. The species has no ozopores. The collected specimens of the *Z.* cf. *viridescens* are illustrated in Fig. 2.

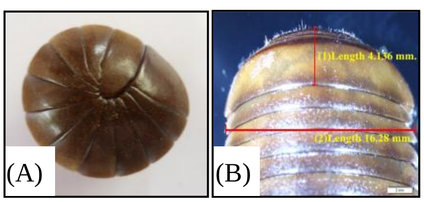

Fig. 2 Adults of *Zephronia* cf. *viridescens*. A) The rolled body (B) The anterior body

The *Z.* cf. *viridescens* was the common millipede in SERS. A total of 263 individuals were collected from the studied areas. As shown in Table I, the highest number was in the PTF (116 individuals) and the lowest was in the DEF (31 individuals).

Adult of *O. variegate* consists of 20 rings without eyes or ocelli and paranota. The first pair of legs is at the 7th ring of adult males, which are modified as gonopods. The posterior pair of 7th ring is walking legs (Fig. 3).

Orthomorpha variegata was found in DEF, DDF, ECO and PTF. A total of 125 individuals were collected from the studied areas. However, the highest number was found in DEF (48 individuals) and the lowest was in ECO (11 individuals) (Table I).

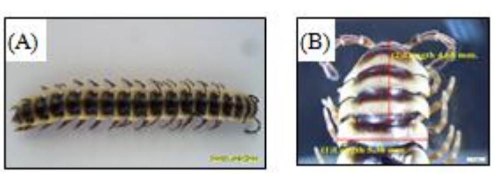

Fig. 3 Adults of *Orthomorpha variegata*. A) The dorsal part; B) the anterior part

TABLE I
OCCURRENCE OF NUMBERS OF MILLIPEDES COLLECTED IN SERS

Millipede Family/Species	Forest types(individuals/m^2) DEF	DDF	ECO	PTF	TOTAL
Zephroniidae *Zephronia* cf. *viridescens* (Attems, 1936)	31	55	61	116	263
Paradoxosomatidae *Orthomorpha variegata*	48	44	11	22	125
Total	79	99	77	138	388

The density of *Z.* cf. *viridescens* was 21.92 individuals/m^2 (Table II). However, the highest abundance was found in June May and April (rainy season), and rapidly decreased from September to February (Fig. 4), while the density of *O. variegata* was 10.42 individuals/m^2(Table II) with the highest abundance in November, and decreased in December to March (Fig. 4). In temperate regions, most species are less active in the winter. Species of *Polydesmus* are active in the spring and in the summer (occasionally in the autumn too), whereas those of *Cylindroiulus* usually have two regular peaks of activity in the spring and the autumn [5].

TABLE II
THE DENSITY OF ADULT MILLIPEDES IN DEF, DDF, ECO AND PTF.

Millipede Family/Species	Forest types (individuals/m^2) DEF	DDF	ECO	PTF	TOTAL
Zephroniidae *Zephronia* cf. *viridescens*	2.58	4.58	5.08	9.67	21.92
Paradoxosomatidae *Orthomorpha variegata*	4.00	3.67	0.92	1.83	10.42
Total	6.58	8.25	6.00	11.50	32.34

This result is similar to Bhakat [15], who estimated the density and biomass of *Streptogonus phipsoni* (Polydesmida) in grassland over a year by sampling with quadrats where there were considerable differences between months. In general, the mean population density for each month was correlated positively with mean monthly rainfall. Banerjee [16] recorded the peak activity of *Cylindroiulus punctatus* during the breeding season when adults were searching actively for mates.

The results indicated that the mean temperature was the highest (27.56±1.05°C) in DDF, and the lowest (24.25±0.56°C) in DEF. Mean of relative humidity was the highest (87.09±2.25%) in DEF, followed closely by PTF and ECO (84.51 ±1.64 % and 72.68 ±2.10 %, respectively) and the lowest (70.53±1.39%) was in DDF. Regarding light intensity, DDF had the highest value of 1999.39 ±244.82 lux, while DEF had the lowest of 649.28 ±57.24 lux. The one-way ANOVA of climatic factors from all forest types indicated significant differences at $p < 0.05$ and the comparison among mean values of climatic factors verified by Duncan's multiple range tests are shown in Table III.

TABLE III
SOIL EDAPHIC FACTORS AND CLIMATIC FEATURES OF FOUR FOREST TYPES FOR *Z.* cf. *viridescens* AND *O. variegata*

Parameters	Forest types			
	DEF	DDF	ECO	PTF
Light (lux)	649.28±57.24	1999.39±244.82	902.88±111.57	657.53±89.98
Soil temperature (ºC)	22.83±0.42	24.15±0.38	23.91±0.35	23.23±0.36
Litter moisture (%)	31.40±2.75	25.05±2.77	32.18±2.86	29.08±3.00
Soil moisture (%)	17.18±1.51	13.16±1.35	12.50±1.11	13.40±1.46
Rainfall (mm.)	94.64±15.18	94.64±15.18	94.64±15.18	94.64±15.18
Air temperature (ºC)	24.25±0.56	27.56±1.05	27.10 ±0.84	25.12 ±0.82
Humidity (%)	87.09±2.25	70.53±1.39	72.68±2.10	84.51 ±1.64
Phosphorus (ppm)	10.95±1.11	9.93±2.42	10.97±1.54	4.57±0.63
Potassium (ppm)	176.50±6.26	171.25±18.34	193.00±18.14	225.50±18.54
Total nitrogen (%)	0.29±0.01	0.19±0.01	0.28±0.00	0.23±0.02
Organic carbon (%)	3.33±0.16	1.80±0.05	2.73±0.13	2.29±0.23
Organic matter (%)	5.72±0.28	3.10±0.09	4.69±0.22	3.94±0.39
C:N Ratio	11.41±0.44	10.08±0.73	9.69±0.33	9.97±0.30
pH	4.44±0.09	5.27±0.06	5.26±0.07	5.03±0.05

The results showed that the soil of DEF was found to be rich in organic matter compared to the others (Table III). This was due to the higher amount of litter produced in DEF. In the natural vegetation community, there was always an accumulation of plant materials at the soil surface, which undergo decomposition. The results obtained in this study confirmed the above statement. Because plant residues are the 80% principal material undergoing decomposition in soils and, hence, are the primary source of soil organic matter. Therefore, it can be stated that, in general the soils of the DEF are richer in nutrients than the others. This result is similar as the result revealed by Wongseenin [17] and Suriyapong [18].

The seasonal occurrence and activity of endemic pill millipedes (*Arthrosphaera magna*) were examined in organically managed mixed plantation and semi-evergreen forest reserve in southwest India between November 1996 and September 1998 [19]. Abundance and biomass of millipedes were found to be highest in both habitats during monsoon season. However, soil moisture, conductivity, organic carbon, phosphate, potassium, calcium and magnesium were higher in plantation than in forest. The distribution of diplopod species is mainly influenced by temperature [20]. Nevertheless, moisture conditions also influenced the distribution pattern of many diplopods. For example, *P. germanicumcan* was found in high abundance in thick litter layer, which contained a high humidity around the year [21].

Generally, the temperature of all forest types varies in place and time with significant variation in plant cover. As shown in Table III, the mean temperature of all forest types was significantly different. The lowest recorded mean temperature was 24.25±0.56°C in DEF, while the highest of 27.56±1.05°C was recorded in DDF (Table III). This might be caused by plant cover. Because DEF has high density of crown canopy and moisture content, it can reduce light and radiation from the sun. The modification of temperature by plant cover is both significant and complex. Shaded ground is cooler during the day than open area. Vegetation interrupts the laminar flow of air, impeding heat exchange by convection.

The results showed that the mean relative humidity of all forest types was significantly different. In the present study, DEF had higher relative humidity than PTF, ECO and DDF, because it had higher tree density and more crown cover than other forest types. It can be argued that the relative humidity is relevant to water vapor content in the air. Water vapor gets into the air by evaporation from both the moist surfaces and the plants. This supported the results obtained by Dajoz [22], who reported that relative humidity is generally higher in forest than open area, especially in summer when transpiration from trees is at the highest. Furthermore, temperatures also influence relative humidity. Relative humidity is generally higher at night and early morning when the air temperature is lower; it is lower during the day when temperature increases. Thus, DEF had higher relative humidity than PTF, ECO, and DDF because it had lower temperature than them (Table III). Soil moisture of all forest types ranged from 12.50±1.11% to 17.18±1.51%. However, the highest moisture was recorded in DEF (17.18±1.51%) and the lowest was in ECO (12.50±1.11%) (Table III). Soil of forest types showed acidic pH ranging from 4.44±0.09 in DEF to 5.27±0.06 in DDF, with differences between the forest types. This may be caused by the presence of organic matter. In DEF, surface soil was always covered by vegetation and leaf litter all the year-round and thus, pH of soil would be affected by the organic matter supplied from the vegetation. This leaded to the soil acidification by decomposition of organic residues of microorganisms in soil [23]. The soil temperatures were significantly different among forest types. The soil temperatures were the highest in DDF (24.15±0.38°C) followed by ECO (23.91±0.35°C) and PTF (23.23±0.36°C), and the lowest in DEF (22.83±0.42°C).

Organic matter of all forest types are shown in Table 3 and Fig. 8. The highest value was found in DEF (5.72±0.28%) followed by those in ECO (4.69±0.22%) and PTF (3.94±0.28%), while the lowest was in DDF (3.103±0.09%). The results showed that the soil of DEF was richer in organic matter compared to the others due to the higher amount of litter produced in DEF. This result corresponds with the results revealed by David [24], who noted that there was a relationship between the size of millipede population and quality of the humus. The better the quality, the greater the population and consequently, the shallower was the litter layer. The most detailed work relating distribution of millipedes to their environment has been conducted by Kime and co-workers in Belgium. It was concluded in a study of soil-dwelling species that distributions were a function of edaphic and climatic factors [25]. The important factors related to the millipede distribution were: soil texture, soil water content, temperature, mineral content (especially, calcium and magnesium), and humidity and humus type. Ordination procedures have been used to illustrate the relative importance of these factors to a range of species [26], 25].

Nitrogen contents of all forest types were slightly different ranging from 0.19±0.01% to 0.29±0.01%. The highest value of that was recorded in DEF and the lowest in DDF. Nitrogen contents of ECO and PTF were 0.28±0.01% and 0.23±0.02%, respectively. The mean of phosphorus contents of all forest types were slightly different ranging from 4.57±0.63 to 10.97±1.54 ppm. The highest mean concentration of phosphorus was in ECO (10.97±1.54), followed by those in

DEF (10.95±1.11 ppm) and DDF (9.93±2.42 ppm), and the lowest in PTF (4.57±0.63 ppm). Potassium contents of all forest types ranged from 171.25±18.34 ppm to 225.50±18.54 ppm. The highest value was documented in PTF, followed by those in ECO, DEF and DDF, which comprised of 225.50±18.54, 193.00±18.14, 176.50±6.26 and 171.25±18.34 ppm, respectively. Organic carbon contents of all forest types are shown in Table 3. The highest carbon value was found in DEF (3.33±0.16%), followed by ECO (2.73±0.13%) and PTF (2.29±0.23%), whereas the lowest was obtained in DDF (1.80±0.05%).

TABLE IV
SOIL EDAPHIC FACTORS AND CLIMATIC FEATURES OF FOUR FOREST TYPES FOR *Z.* cf. *viridescens* AND *O. variegata*

Parameter	*Z.* cf. *viridescens*	*O. variegats*
Light (lux)	-0.01	-.079
Soil temperature (ºC)	0.223**	0.138
Litter moisture (%)	0.176*	0.131
Soil moisture (%)	0.04	0.263**
Rainfall (mm.)	0.06	0.021
Air temperature (ºC)	0.433**	-0.043
Humidity (%)	0.169*	0.046
Phosphorus (ppm)	0.07	0.181*
Potassium (ppm)	0.280**	0.059
Total nitrogen (%)	-0.15	-0.118
Organic carbon (%)	-.173*	-0.045
Organic matter (%)	-.172*	-0.045
C:N Ratio	-0.10	0.141
pH	0.16	-0.103

PEARSON CORRELATION COEFFICIENT: *, ** SIGNIFICANT AT P < 0.05 AND P < 0.01, RESPECTIVELY

With respect to light intensity, the mean of all forest types had significant differences. Light intensity of DDF was the highest (1,999.39±244.82 lux), while that of DEF was the lowest (649.28±57.24 lux). This might be caused by crown density, stands density and canopy gap. DEF consists of densed crown, densed stands and low canopy gap. This factors usually influence the reduction of light intensity on the forest floor. The open area such as DDF is an area dominated by *Shorea obtusa* Wall and *Shorea siamensis* Miq with some small shrubs and grass species of *Arundinaria pusilla* Chevel. Thus, this area will receive full sunlight. This result agrees with Smith [27] that the light intensity varied according to average light conditions in the stand and the canopy. A crown dominant would receive full sunlight, while co-dominant, sub-dominant, suppressed and understory plants generally receive progressively less light.

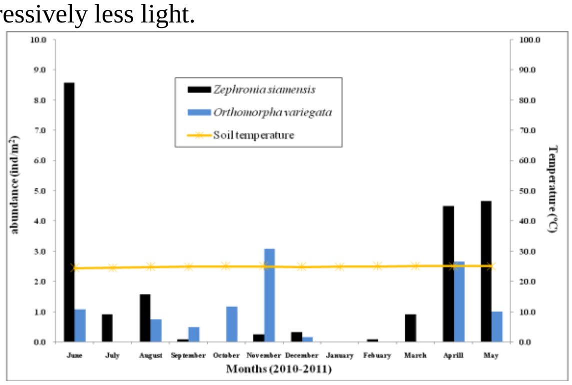

Fig. 4 Abundance of millipedes related to soil temperature inSERS

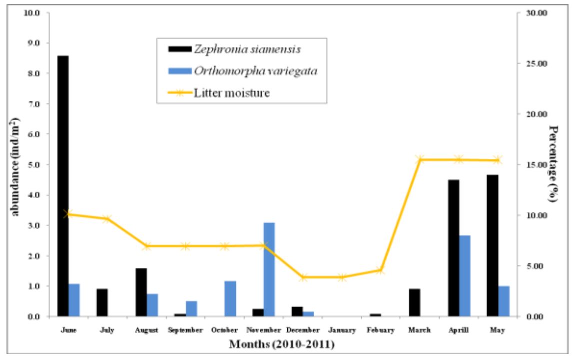

Fig. 5 Abundance of millipedes related to litter moisture in SERS

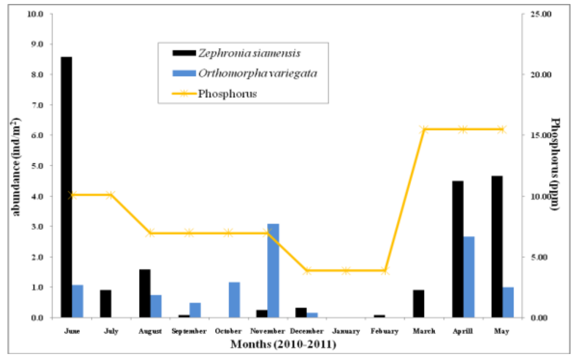

Fig. 6 Abundance of millipedes related to phosphorus in SERS

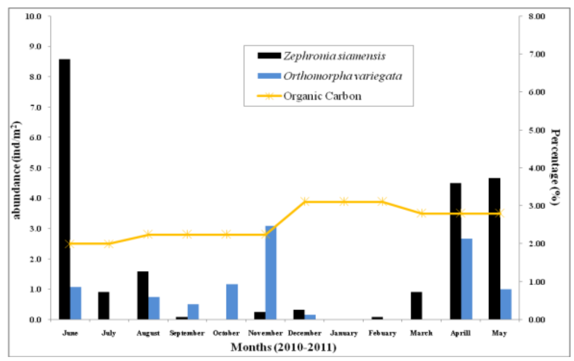

Fig. 7 Abundance of millipedes related to organic carbon in SERS

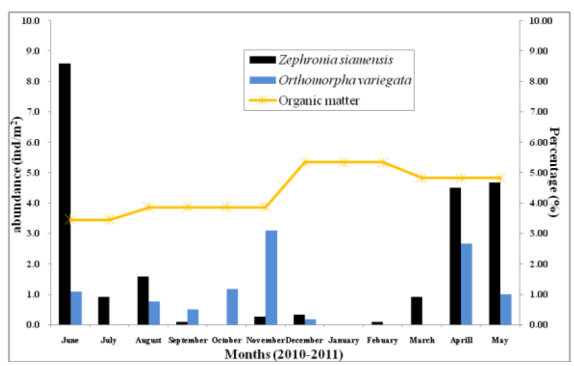

Fig. 8 Abundance of millipedes related to organic matter in SERS

This result is similar to Bhakat [15], who estimated the density and biomass of *Streptogonus phipsoni* (Polydesmida) in grassland over a year by sampling with quadrats. However, considerable differences were observed between months. In general, the mean density for each month was correlated positively with mean monthly rainfall. The studies of David in France have dealt mainly with populations of diplopods and their effects on forests soil. In one such study, David [24] considered just one species. The maximum density was in May corresponded with the recruitments from the new generation; the minimum in February/March represented the end of the old generation. Seasonal activity was also governed by various factors. Conclude your work nicely with at least one sentence here????

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