RESEARCH REPORT

The NEF Bio-ecological Nature Conservation Project in Mountainous Region of North Vietnam

SPECIES DIVERSITY OF SOIL INVERTEBRATES IN MOUNTAINOUS REGION OF NORTHERN VIETNAM

Prepared by

SOIL INVERTEBRATE GROUP

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1. GENERAL INFORMATION

1.1 Authors of the report

Nguyen Duc Anh, Nguyen Thi Thu Anh, Vu Thi Thanh Tam, Phung Thi Hong Luong, Le Xuan Son. 2021. *Species diversity of soil invertebrates in mountainous region of northern Vietnam*. Technical report. Nagao Environmental Foundation of Japan. Hanoi.

1.2 Group name and names of all members

Group name:	Soil Invertebrates
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2. RESEARCH

2.1 Abstract

- ***In Cham Chu NR:***

  A total of 19 myriapods, 29 spiders, 62 nematodes and 66 collembolan species were recorded in the Cham Chu Nature Reserve. We also did investigate in caves, and found several interesting species: two myriapods (*Glyphiulus* sp. and *Sinocallipus* sp.), five spider species (*Heteropoda* sp.1, *Platocoelotes* sp.1, *Telema* sp., *Oedignatha* sp.1 and *Theridion* sp.1). Most of all recorded species have been found in natural habitats.

- ***In Bac Me NR:***

  A total of 16 myriapods (14 genera, 13 families), 65 spiders (41 genera, 18 families), 57 nematodes (23 genera, 13 families, 2 orders) and 63 collembolan (36 genera, 13 families) species were recorded in the Bac Me Nature Reserve, Ha Giang Province. We also did investigate in caves, and found several interesting species. Three myriapods (*Eutrichodesmus* sp.1, *Eutrichodesmus* sp.2 and *Thereuopoda longicornis* Fabricius, 1783) were found in both entrance and dark zones of caves. Four spider species *Agraecina* sp. (family Liocranidae), *Khorata* sp. (Pholcidae), *Phocus phami* (Pholcidae), và *Thrandina* sp. (Salticidae) were only distributed in entrance zone of cave, where still received sunlight; two species *Heteropoda* sp. (Sparassidae) và *Telema* sp. (Telemidae) were only distributed in dark zone; 6 species *Cyclosa* sp. (Araneidae), *Hickmania* sp. (Sicariidae), *Phocus bifidus* (Pholcidae), *Heteropoda venatoria* (Sparassidae), *Alaria* sp. (Theridiosomatidae) và *Zosis* sp. (Uloboridae) were found in both entrance and dark zones. Most of all recorded species

have been found in natural habitats and plantations. The natural forests in Bac Me NR is very poor, and more likely to be disturbed by local people. There are a few places with rich forests which mostly located in top of mountain, and relatively far from local villages.

- ***In Phia Oac-Phia Den NP***
  A total of 9 millipede species (6 genera, 4 families, 4 orders), 17 large centipede species (8 genera, 3 families) and 4 other centipede species (2 genera, 2 families, 2 orders), 53 spider species (29 genera, 10 families) 48 nematods (23 genera, 12 families, 2 orders) and 46 collembolans (31 genera, 13 families) were recorded in Pia Oac – Pia Den National Park, Cao Bang Province.

- ***In Nam Xuan Lac HSCA***
  A total of 7 myriapods in 7 genera, 7 families; 25 species of 17 genera, 9 families of spiders; 31 species belonging to 15 genera, 11 families; 20 collembolan species in 16 genera, 9 families were found in Nam Xuan Lac Nature Reserve, Bac Can Province.
  Of which, the order nematode Dorylaimida includes 20 species belonging to 16 genera, 9 families and the order Mononchida has 37 species belonging to 8 genera, 4 families. The species of *M. baeticus* Jimenez-Guirado, Alhama & Guitierrez, 1997 is a new record for nematode fauna in Vietnam.

Education and training:

- Regarding training purpose, three research assistants have increasingly improved their research capacity and skills including collecting and examining skills, literature seeking and manuscript preparing and submitting for publication…
- One of the research assistants successfully completed her Master thesis in the Graduate University of Science and Technology, Vietnam Academy of Science and Technology.
- One of the research assistants successfully enrolled in the PhD course in Faculty of Biology, University of Science, Hanoi National University.

Environmental and conservation concern: For soil invertegrates, three maijor threats were investigated as pesticide overusing in Cham Chu, plastic rubbish pollution in caves, and changes of landuse.

Publications:

ISI journals:

1. Nguyen A.D., Nguyen M.H., Nguyen T.T.A., Phung T.H.L. 2019. Review of dragon millipedes (Diplopoda, Polydesmida, Paradoxosomatidae) in the fauna of Vietnam, with descriptions of three new species. Zoological Studies, 58:14. https://doi.org/10.6620/ZS.2019.58-14

2. Nguyen A.D., Sierwald P., Marek P.E., 2019. The pill millipedes of Vietnam: a key to genera and descriptions of five new species (Diplopoda: Glomerida: Glomeridae). Raffles Bulletin of Zoology, 67: 260–297. https://doi.org/10.26107/RBZ-2019-0020
3. Nguyen A.D., Nguyen G.S., Eguchi K., 2021. A new *Rhopalomeris* species (Diplopoda: Glomerida: Glomeridae), and notes on the phylogenetic relationships between glomeridans in Vietnam. Zootaxa 4927(2): 257-264. https://doi.org/10.11646/zootaxa.4927.2.5
4. Vu T.T. Tam, Katarzyna Rybarczyk-Mydłowska, Andrij Susulovsky, Magdalena Kubicz, Łukasz Flis, Le Thi Mai Linh & Grażyna Winiszewska, 2021. Descriptions of two new and one known species of Parkellus Jairajpuri, Tahseen and Choi, 2001 (Nematoda: Mononchidae) and their phylogenetic position among Mononchida. Journal of Nematology, 53: e2021-76. https://doi.org/10.21307/jofnem-2021-076
5. Vu TH, Nguyen DH, Le XS, Eguchi K, Nguyen AD, Tran TTB, 2020. A review and notes on the phylogenetic relationship of the centipede genus *Otostigmus* Porat, 1876 (Chilopoda: Scolopendromorpha: Scolopendridae) from Vietnam. Zootaxa, 4808(3): 401-438. https://doi.org/10.11646/zootaxa.4808.3.1
6. Vu TTT, 2020. Description of a new species, *Actus hagiangensis* (Monochida, Mylonchulidae) from Ha Giang Province, Vietnam. Zootaxa 4861(1): 131-138. https://doi.org/10.11646/zootaxa.4861.1.9.

Scopus journal:

7. Son L.X., Anh N.T.T., Binh T.T.T., Nguyen T.A.T. & Nguyen A.D. (2021). Diversity and distribution of the large centipedes (Chilopoda: Scolopendromorpha) in the Phia Oac - Phia Den National Park, Vietnam. Journal of Threatened Taxa 13(8): 19102–19107. https://doi.org/10.11609/jott.7451.13.8.19102-19107

National journal/conference:

8. Vu Thi Thanh Tam, 2020. New records of the genus Miconchus (Mononchida, Anatonchidae) for Vietnam. Vietnam Academia Journal of Biology, 42(3): 7-14.
9. Phung Thi Hong Luong, Nguyen Thi Thu Anh, Nguyen Duc Anh, 2020. The preliminary study on species compostion and distribution of spiders (Arachnida: Araneae) in the Du Gia – Cao Nguyen Da Dong Van National Park, Ha Giang province. The proceeding of the national congress on entomology.

2.2 Background of the study

Tropical rain forests are recognized as ideal natural laboratories for taxonomic, natural history, and bio-geographic research (Dirzo & Raven 2003). Vietnam contains a large proportion of tropical rain forests, which are mainly located on high mountains in the northern part of the country and Truong Son Range. A wide range of elevations and the complexity of landforms have given the montane region a great diversity of natural habitats and a high level of biodiversity (Sterling et al. 2006). Of this biodiversity, the soil fauna of Vietnam has currently been studied with nearly 2,348 species, 744 genera, 212 families of myriapods, oligochaete, microarthropods, and arachnids (Vu 2018). However, this number is still far from the true biodiversity of Vietnam. It is estimated that we know only 20-30% of soil invertebrates of Vietnam; many taxa or animal groups have been poorly studied, for example Velvet worms (Onychophora), Whip spiders (Amplypygi), Whip scorpions (Uropygi), Symphylans, Pauropods, some spider families (Solifugae,…). In addition, environmental pollution and landuse changes can be adversely affecting on soil invertebrates. It threatens to the diversity and distribution of soil invertebrates.

The NEF Bio-ecological Nature Conservation Project in Mountainous Region of North Vietnam aims to explore the biodiversity and to evaluate conservation potentials of limestone karst forests of northeastern Vietnam. As a part of this project, the soil invertebrate group intends to evaluate the species diversity, distribution pattern and threatening factors in four target protected areas: Cham Chu NR (Tuyen Quang Province), Bac Me NR (Ha Giang Province), Phia Oac-Phia Den NP (Cao Bang Province) and Nam Xuan Lac HSCA (Bac Kan Province).

2.3. Literature review

- *Cham Chu*

Cham Chu nature reserve is located in Chiem Hoa and Ham Yen districts, Tuyen Quang province. The nature reserve is centred on Mount Cham Chu, which, at 1,587 m, is the highest point in Tuyen Quang province. Near Mount Cham Chu, there are several other peaks above 1,000 m, although most of the proposed nature reserve is below 800 m in elevation. In the south-west of the proposed nature reserve, about 8 km from Mount Cham Chu, there is a large area of limestone karst, which is bisected by the Lo river. The area is boundaried by the Lo river in the west, by the Gam river in the east. Cham Chu nature reserve supports lowland evergreen forest, lower montane evergreen forest and limestone forest.

- *Bac Me:*

Bac Me nature reserve is situated in Bac Me district in south-eastern Ha Giang province. The topography of the proposed nature reserve is mountainous, and there are several peaks above 1,000 m, the highest of which is 1,420 m, on the border with Tuyen Quang province. The lowest point in the proposed nature reserve is under 200 m.

Streams originating in the north and west of the nature reserve feed the Gam river, which flows south, into Tuyen Quang province, and eventually meets the Lo river. Streams originating

in the south-east of the proposed nature reserve feed the Pao Nam river, a tributary of the Gam river.

Bac Me proposed nature reserve supports a representative example of the limestone forest ecosystem typical of north-eastern Vietnam. To date, however, the biodiversity of the site has not been comprehensively surveyed.

- *Phia Oac – Phia Den*

Nui Pia Oac Nature Reserve is located in Tinh Tuc town and Quang Thanh, Thanh Cong, Phan Thanh, Mai Long, Ca Thanh, Vu Nong and Hung Dao communes, Nguyen Binh district, Cao Bang province. The national park supports only 3,174 ha of natural forest, which is mainly distributed above 1,000 m. The forest has been subjected to high levels of disturbance in the past and is secondary in places. Natural regeneration does, however, appear to be taking place. Below 700 m, the vegetation is dominated by scrub and grassland. In the west of the nature reserve, there are areas of limestone karst without forest, and, at lower elevations in the south, there are *Pinus massoniana* plantations.

Below 1,000 m, most of the natural forest in the nature reserve has been cleared for cultivation. Above, 1,000 m, however, the natural forest is distributed on steep hillsides at high elevations, which are unsuitable for cultivation. Consequently, clearance for agriculture is not a major threat to biodiversity at Nui Pia Oac.

- *Nam Xuan Lac*

Nam Xuan Lac is situated in western Bac Kan province in three communes Xuan Lac, Dong Lac and Ban Thi, Cho Don district. To the west, the site is contiguous with the Ban Bung of Na Hang nature reserve. The total protected area is about 4,000 ha. The topography of the site is characterised by steep limestone karst formations, separated by flat-bottomed valleys.

Remarks. Although four target areas have rich biodiversity and conservation importance, they have not been comprehensively understanding on their biodiversity. In most cases, fieldsurveys have been conducted on some groups, especially plants, mammals, birds and reptiles. No data are available for soil invertebrates eventhough these groups are also important for ecosystem systainability. It is, therefore, necessary to have biodiversity investigation on soil invertebrates of four target areas: Cham Chu, Bac Me, Phia Oac – Phia Den and Nam Xuan Lac.

2.4 Group's purpose and subjects

Purpose and subjects

The project aims 1) to document the biodiversity of soil invertebrates in karst regions, including discovery new taxa for science and new records for Vietnam's fauna: 2) to investigate the distributional pattern of soil invertebrates in karst region, especially in different habitats; and 3) To train young researchers for skills of taxonomy, systematics and biodiversity conservation.

Objectives

Specific objectives of this study are:

Three main subjects are investigated and undertaken as 1) documenting biodiversity, 2) investigating distributional pattern, and 3) training.

2.5 Materials and Methods

2.5.1 Working schedule and study sites

Fieldworks were conducted two times to better understand the diversity of soil invertebrates in each area (Cham Chu, Bac Me, Phia Oc – Phia Den, Nam Xuan Lac). The detailed surveys are listed in below.

Table 1. Time surveys in four localities in northern Vietnam

No	Location	Time	Notes
1	Cham Chu NR	24-31/10/2018 19-26/4/2019	Limestone forests and plantations
2	Bac Me NR	18-25/7/2019 24-31/10/2019	Limestone forests, cultivation lands and plantations
3	Phia Den – Phia Oac NP	3-10/6/2020 5-12/5/2021	Evergreen forests in high elevations
4	Nam Xuan Lac SHC	11-18/7/2020 28/10-4/11/2021	Limestone forests and mining sites.

2.5.2 Methods

Myriapods and Spiders

Myriapods and spiders were collected using several following methods:

- Litter sieving: This method is used to collect specimens (spiders and other arthropods) in the leaves carpet, gravel, and soil inside the forest or cave floor.
- Leaf beating: This method is used to collect specimens that live or active on low foliage, shrubs or grasslands.
- Manual sampling: We use the eyes to find specimens in different habitats (ground surface, leaves carpet, trunk, branches, foliage, ...) then use forceps, straws or empty plastic vials... to collect them.
- Pitfall trapping: 5 traps were placed in each habitat for 5-7 days to collect all soil invertebrates.

Collembolans:

The collecting and study methods follows Ghilarov (1975). Samples were collected in different habitats including (1) uncultivated lands surrounding crop/corn fields; (2) residential gardens; (3) shortterm tree plantation, (4) specific tree plantation, (5) natural forests on limestone,

(6) bamboo forests and (7) shrub and bush land.

Soil cores were collected 8-10 for each habitat from top soil layer (0-10cm) in square 5cmx5cm. Soil samples were placed inside plastic bags with a label of full information (collecting date, habitat, locality, collector). Collembolan specimens were extracted from soil samples using the Berlese- Tullgren method in the laboratory, and identified using taxonomic documents, e.g. Gisin, 1960; Stach, 1965; Yosii, 1982a, 1982b, 1983, Deharveng et Bedos, 1965, 1966, 2000.

All speciemens are preserved in formalin 4% and deposited in Department of Soil Ecology, Institute of Ecology and Biological Resources.

Data were calculated following Gorny & Grum (1993), including the following bioecological indexes: the number of species, the number of individuals, the Shanon-Weaver diversity (H'),

- The Shanon Weaver index (H')

$$H' = -\sum_{i=1}^{s} \frac{n_i}{N} x \log 2\left(\frac{n_i}{N}\right)$$

s – number of species

n_i – total individuals of species i.

N – total individuals of all species

Nematods:

Soil samples were collected from different habitats in the study areas. Each soil sample contained 100g soils. Nematodes were extracted from soil samples by modified Baermann funnel technique using a combination of sieves with a pore size 500-250-100-63 μm. Nematodes were killed by heat, fixed in formaldehyde 4%, transferred to anhydrous glycerol according to Seinhorst (1959), and mounted on glass slides for microscopic observation. The numbers of nematodes in solution were counted in 5 categories of feeding types. Permanent slides were stored at the Department of Nematology, IEBR. Photographs were taken with a Nikon digital camera on a Nikon microscope *Eclipse Ni* and edited by Adobe Photoshop CS6.

2.6 Results

2.6.1. Species diversity in Cham Chu

a. Myriapods

A total of 19 species belonging to 16 genera, 12 families, 11 orders, 2 classes were recorded in the Cham Chu NR. Of 19 species, two (Paradoxosomatidae sp.1 and Paradoxosomatidae sp.2) were only recognized as new members of the family Paradoxosomatidae. These species are considered to be new taxa, but need more information to confirm exactly.

Most of myriapod species were found in the natural forests; four common species were found in crop habitats as: *Helicorthomorpha holstii*, *Oxidus gigas*, *Trigoniulus corallinus* and

Otostigmus scaber. Only two species were found in caves as: *Glyphiulus* sp. and *Sinocallipus* sp. Of two species, *Glyphiulus* sp. was very common in five investigated caves while *Sinocallipus* sp. was found in two caves.

Three recently described species, *Rhopalomeris sauda* Nguyen, Sierwald & Marek, 2019, *Tonkinomeris napoensis* Nguyen, Sierwald & Marek, 2019 and *Hylomus namek* Nguyen et al., 2019, were also recorded in Cham Chu NR. These species were described from Duc Xuan commune, Duc Quang district, Ha Giang province which is next to Cham Chu NR.

b. Spiders

There are 29 species of 25 genera, 12 families of spiders were collected from the four habitats (Natural forest on limestone mountains (NFLM), Natural forest along streams (NFS), Planted forests and scrublands in planted forests and residential areas (PFaS), and Caves habitat (CH) in Cham Chu NR. Among them, 19 species were collected in NFLM, 6 species collected in NFS, 8 species in PFaS, and 5 species in CH.

Among 12 spider families collected from Cham Chu NR, the two families Salticidae and Araneidae were found with highest number of species (11 and 6 species, respectively). The two families are also known as the biggest families of the species composition in not only Vietnam but also in the world. The other families found in Cham Chu are only with one to two species.

The four families Corrinidae (1 species), Lycosidae (1 species), Salticidae (11 species) và Sparassidae (1 species) are free hunting spiders. They are usually active (or stand and wait) on ground surface, leaves carpet, trunk, branches, foliage to search preys. When find a prey, they will ambush then pounce to cath the prey. The other families found in Cham Chu NR are web spiders. They make a web to live and wait for a prey.

Of 29 spider species collected from Cham Chu NR, three species *Heteropoda* sp. 1, *Platocoelotes* sp. 1 and *Telema* sp. 1 were only found in the dark area of caves; the two species *Oedignatha* sp. 1 và *Theridion* sp. 1 were found in both cave (entrance area) and NFLM (outside of cave); the other 24 species were only found outside of caves.

In the three habitats outside of caves (NFLM, NFS and PFaS), *Araneus* sp.1 is the species that found in both NFLM and NFS, but not found in PFaS; *Argiope aemula* was found in both NFLM and PFaS, but not in NFS; the two species *Oxyopes javanus* and *Phintella vittata* were found in NFS and PFaS, but not in NFLM; *Rhene* sp.1 was only found in NFS; the four species *Barvia annamita, Menemerus bivittatus, Mymarachne* sp.1 and *Phintella versicolor* were only found in PFaS; the other 14 species were only found in NFLM (Fig. 1).

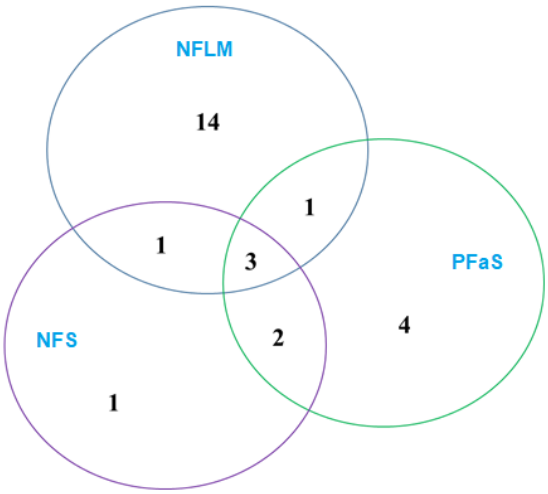


Figure 1. The number of species distributed in the three habitats outside of caves

In cave habitat, we collected spiders from five caves and recorded 5 species. Among them, three web spider species *Platocoelotes* sp.1, *Oedignatha* sp.1 and *Theridion* sp.1 were only distributed in entrance area where still received sunlight. The two species *Oedignatha* sp.1 and *Theridion* sp.1 were also found outside of cave. The other two species *Heteropoda* sp.1 (free hunting spider) và *Telema* sp.1 (web spider) were only distributed in dark area of caves.

c. Free-living terrestrial Nematodes

The result has shown that a total of 62 species belonging to 26 genera, 11 families, 2 orders Dorylaimida and Mononchida were recorded in the Cham Chu NR. In there, order Dorylaimida includes 29 species belong 20 genera, 8 families and the other order Mononchida has 33 species belonging to 7 genera, 4 families.

In the order Dorylaimida, the family Qudsianematidae was highest with 7 species accounting for 11.3% of general; followed by Belondiridae family with 5 species accounted 8.1%; Aporcelaimidae family has 4 species and accounting 6.5%; 3 families (Leptonchidae, Mydonomidae and Nordiidae), each has 3 species (accounting for 4.8%); the family Dorylaimidae has only recorded 2 species (Fig. 2).

In order Mononchida, the family Mylonchulidae was highest with 10 species, accounting 17.7% and 2 other families Anatonchidae and Iotonchidae have 7 species for each (accounting 11.3% total species).

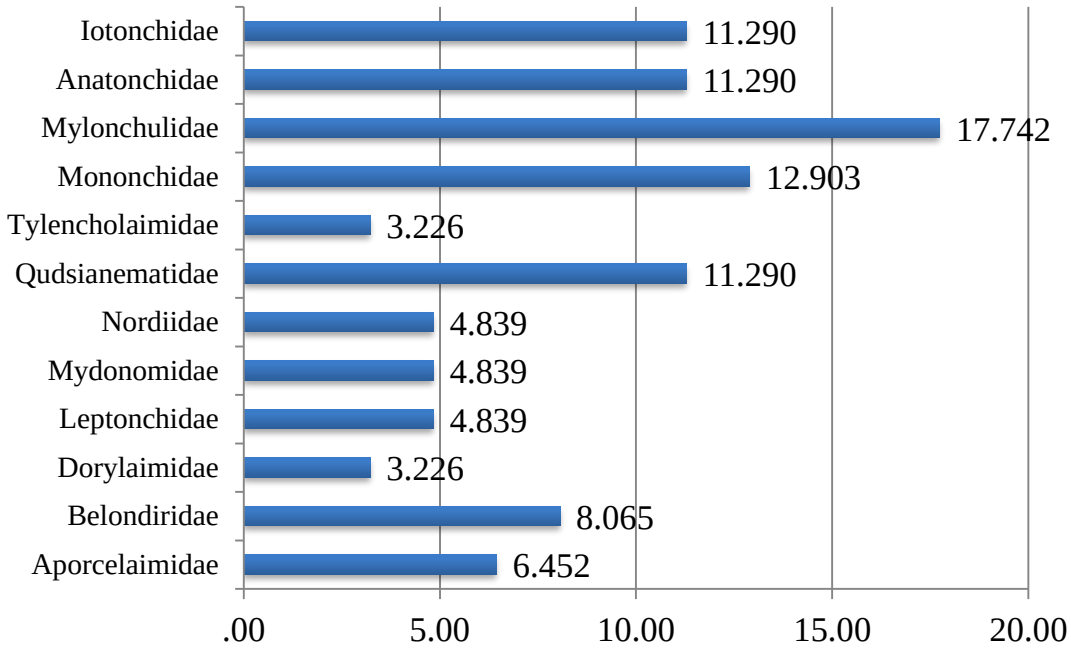


Figure 2. The percentage of recorded species in nematod families

For each research site at the Cham Chu natural reservation area: in Phu Luu commune was found 38 species belong 18 genera and 12 families in both orders Dorylaimida and Mononchida. Those numbers of species and genera level are always lower than in Yen Thuan commune. In fact, at Yen Thuan commune was recorded 46 species, higher more than 21% at Phu Luu commune. The same tendency with genera level, at Yen Thuan commune was found 42 genera, 16.6% higher than if compared to at Phu Luu research site (Fig. 3).

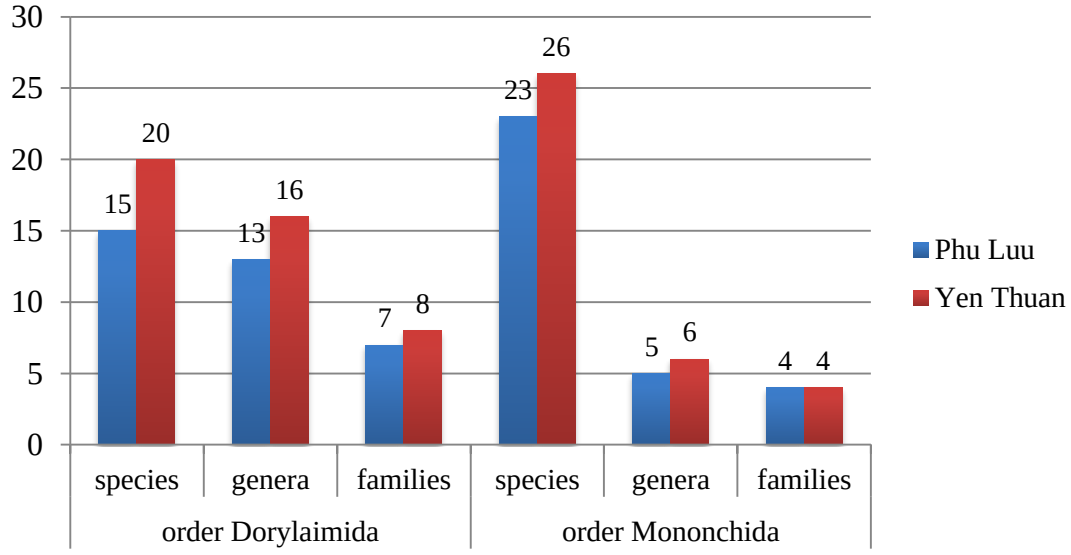


Figure 3. Distribution of species at Cham Chu natural reservation area.

Nematodes as an indicator of enrichment soils at Cham Chu natural reservation area

Based on the life history syndromes, families of nematodes can be ordered on a colonizer-persister (cp) scale. The scale ranges from 1 (early colonizers of new resources) to 5 (persisters in undisturbed habitats). The maturity index (MI) for a soil is the weighted mean cp value of the individuals in a representative soil sample. In practice, MI values for soil subjected to varying levels of disturbance range from less than 2.0 in nutrient enriched disturbed systems, between 3.0 to 4.0 is in undisturbed, pristine environments (Bongers and Ferris, 1999).

Following the recipe as bellow:

$$MI = \sum_{i=1}^{n} v(i) \times f(i)$$

Note: MI: Maturity index
v(i): the level of taxon (i)
f(i): the number of taxon (i)

The c-p value of research sites at Cham Chu natural reservation was showed in Table 1.

Table 2. Feeding groups of nematods and c-p value in the Cham Chu NR

Nematodes	Feeding group	C-P value	Cham Chu natural reservation/100g soil	
			Phu Luu	Yen Thuan
ORDER DORYLAIMIDA				
Suborder Dorylaimina				
Family Aporcelaimidae	Omnivorous	5	157	32
Family Belondiridae	Hyphal feeding	4	92	214
Family Dorylaimidae	Omnivorous	4	344	554
Family Leptonchidae	Omnivorous	4	112	65
Family Mydonomidae	Hyphal feeding	4	48	23
Family Nordiidae	Omnivorous	4	227	221
Family Qudsianematidae	Omnivorous	4	334	434
Family Tylencholaimidae	Hyphal feeding	4	186	89
ORDER MONONCHIDA				
Family Mononchidae	Predaceous	5	47	132
Family Mylonchulidae	Predaceous	5	124	221
Family Miconchidae	Predaceous	5	32	78
Family Iotonchidae	Predaceous	5	97	68
ORDER RHABDITIDA				
Family Rhabitidae	Bacterial	1	355	514

	feeding			
Family Cephalobidae	Bacterial feeding	2	314	224
Family Diploscapteridae	Bacterial feeding	1	89	118
Family Bunonematidae	Bacterial feeding	1	145	88
Family Panagnolaimidae	Bacterial feeding	1	44	97
ORDER AEROLAIMIDA				
Family Alaimidae	Bacterial feeding	4	65	198
ORDER TYLENCHIDA				
Family Anguinidae	Plant feeding	2	55	49
Family Tylenchidae	Plant feeding	2	232	78
Family Aphelenchidae	Plant feeding	2	77	54
Family Pratylenchidae	Plant feeding	3	35	21
Family Hoplolaimidae	Plant feeding	3	24	35
Family Heteroderidae	Plant feeding	3	246	112
Total			**3484**	**3719**
MI			**3.11**	**3.22**

Note:

C: colonizers P: pesisters

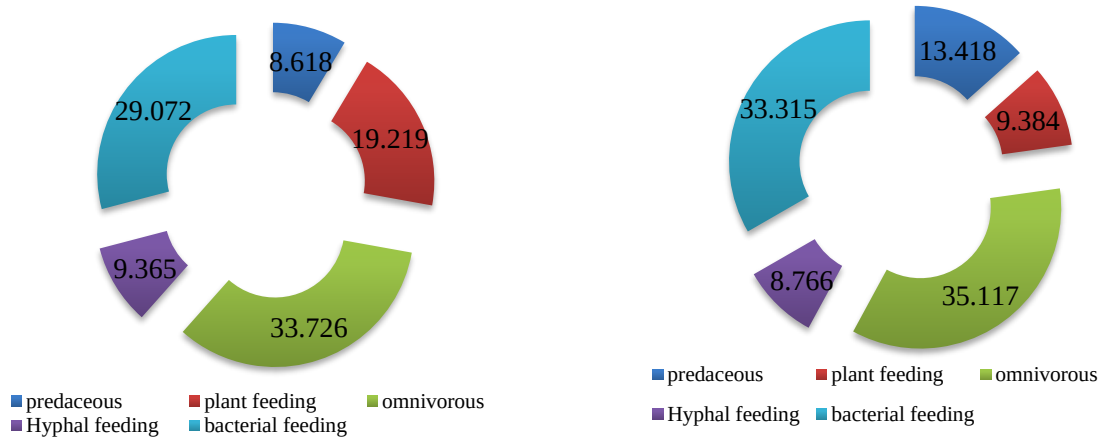
c-p: values are given for family level taxa that occur at the survey point.

The results showed that in both research sites as Phu Luu and Yen Thuan communes at Cham Chu natural reservation area were MI as 3.11 and 3.22. Compared to with Bongers and Ferris ´s index of MI, at our research sites was arranged between 3-4 and indicates undisturbed soils.

Feeding groups of nematodes at Cham Chu natural reservation area

The feeding types of nematode groups were divided in 5 categories and the ratios of feeding types of nematode community at the Cham Chu natural reservation area were shown in the figure 3 and 4.

At the Phu Luu commune: the nematodes of omnivorous group were highest and accounting 33.7%; the group of bacterial feeding was 29.1%; the third place is nematode group of plant feeding and accounting 19.2%; 2 groups of hyphal feeding and predation were lowest with 9.4% and 8.6%. Plant feeding of nematode group at Phu Luu commune is high and can be explained caused by cultivated orange trees (Fig. 4).



A **B**

Figure 4. The ratio of feeding types of nematode community at Phu Luu (A), and Yen Thuan communes (B)

The same tendency with the ratio of feeding types at Yen Thuan commune. The group of omnivorous nematodes was highest and accounting 35.1% and the second place is bacterial feeding group with 33.3%. However, the nematode community at Yen Thuan commune was different if compared to with nematode community at Phu Luu commune. The ratio of plant feeding group was lower than in Yen Thuan and accounting only 9.4%. This result was fitted well with habitats at Yen Thuan commune as natural forests.

d. Collembola

- *Species diversity*

A total of 66 collembolan species belonging to 37 genera, 15 families were recorded in 7 habitats of Cham Chu NR. Of 66 species, 52 were identified into species level (accounting for 78.8% total species), and 14 species (accounting for 21.2% total species) were only identified into generic level.

All recorded species can be divided into two groups based on their presence/absence in habitats. The widely distributed group consists of species that were recorded in 6-7 habitats in both dry and rainy seasons. There are five species: *Sphaeridia zaheri, Friesea sublimis, Entomobrya lanuginosa, Isotomodes pseudoproductus, Proisotoma submuscicola.* These species are considered to be typical collembolans for the agroforestry ecosystem in Cham Chu Nature Reserve. These species are typically characterized by tiny body size, unpigmented or less pigmeneted, appendages being reduced or absent to adapt to live inside soil layers.

The narrowly distributed group contains species that were recorded in only a habitat in one season. They are 23 species recorded in different habitats.

+ Natural forests (18 species): *Odontella pseudolamellifera, Pseudachorutella parvulus, Lepidocyrtus (Acr.) heterolepis, Lepidocyrtus (Asc.) medius, Lepidocyrtus (Asc.) aseanus, Lepidocyrtus (Asc.) dahlii, Willowsia* sp.$_1$, *Salina celebensis, Callyntrura tamparuliana,*

Callyntrura sp.$_1$, *Tomocerus* sp.$_1$, *Megalothorax minimus, Sminthurides* sp.$_1$, *Sminthurinus victorius, Sminthurinus* sp.$_1$, *Deuterosminthurus* sp.$_1$, *Sphyrotheca nepalica, Calvatomina tuberculata*.

+ Shrubs (1 species): *Protaphorura yodai*.

+ Short-term tree plantation (2 species): *Lobellina* sp.$_1$, *Entomobrya muscorum*.

+ Gardens (2 species): *Acherontiella sabina, Folsomides americanus*.

- *Seasonal distribution:*

There were 60 species recorded in the rainy season, and 48 species found in the dry season. Of 66 species, 42 were recorded in both rainy and dry seasons, and 24 species were recorded in only either dry season or rainy season. They are:

+ 18 species were recorded in only rainy season: *Sphyrotheca nepalica*, *Sphyrotheca boneti, Deuterosminthurus* sp.$_1$, *Sminthurides* sp.$_1$, *Megalothorax minimus, Tomocerus* sp.$_1$, *Salina celebensis, Callyntrura tamparuliana, Callyntrura* sp.$_1$, *Willowsia* sp.$_1$, *Entomobrya muscorum, Isotomiella minor, Folsomides americanus, Lobellina* sp.$_1$, *Pseudachorutella* sp.$_1$, *Pseudachorutella parvulus, Protaphorura yodai, Acherontiella sabina*.

+ 6 species were recorded in only rainy season: *Sminthurinus victorius, Lepidocyrtus (Asc.) cinctus, Lepidocyrtus (Asc.) aseanus, Lepidocyrtus (Asc.) medius, Lepidocyrtus (Acr.) heterolepis, Homidia subcingula*.

- *Taxon diversity and distribution*

The number of collembolan taxa (families, genera, and species) is different between habitats. The differences depend on habitat environment, and be shown in below figure.

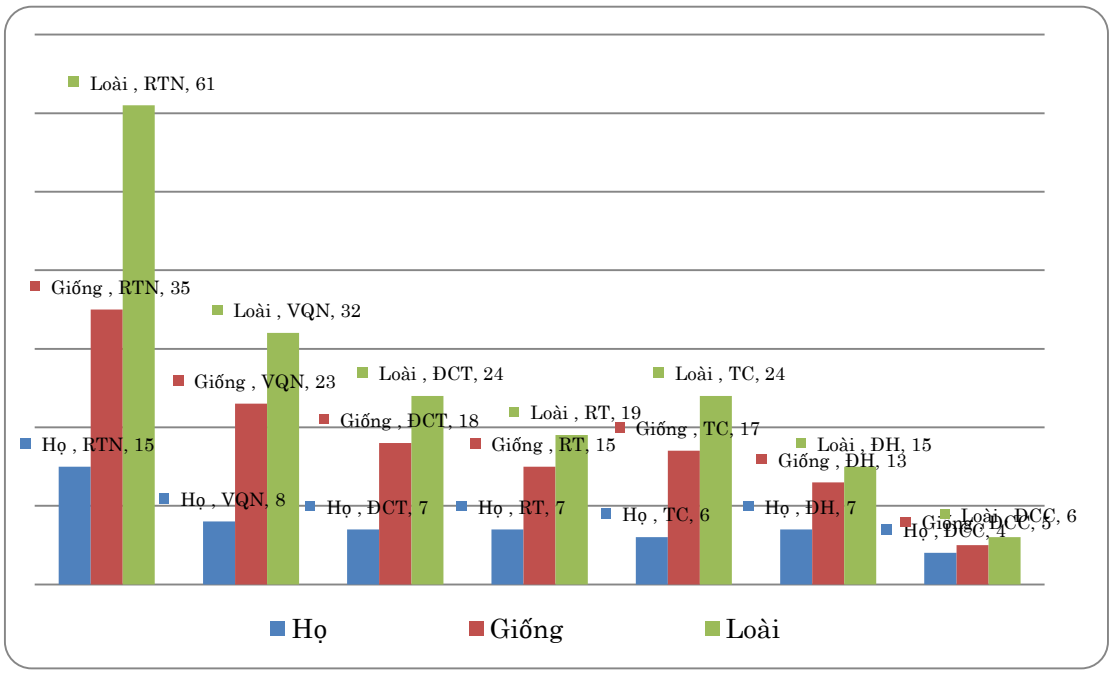


Figure 5. The number of taxa in different habitats in Cham Chu NR

- In family level: Natural forests have a maximum number of family (15). The number of family reduces in other habitats, for example: 8 families in residential gardens (absence of Sminthuridae, Bourletielidae, Katiannidae, Neelidae, Tomoceridae, Paronellidae, Odontellidae), 7 families in shortterm tree plantations and bamboo forests (absence of Odontellidae, Cyphoderidae, Paronellidae, Tomoceridae, Neelidae, Katiannidae, Bourletiellidae, Dicyrtomidae), 7 families in uncultivated lands (absence of Odontellidae, Paronellidae, Tomoceridae, Neelidae, Katiannidae, Bourletiellidae, Sminthuridae, Dicyrtomidae), 6 families in grass and shrub lands (absence of Odontellidae, Onychiuridae, Cyphoderidae, Paronellidae, Tomoceridae, Neelidae, Katiannidae, Bourletielidae và Dicyrtomidae), 4 specific tree plantations (absence of Odontellidae, Onychiuridae, Cyphoderidae, Paronellidae, Tomoceridae, Neelidae, Katiannidae, Bourletielidae, Sminthuridae, Dicyrtomidae, Entomobryidae) (Fig. 5).

- In the generic level: the number of genera were highest in natural forests (35), then reduced to lowest in specific tree plantations (26).

- In the species level: the number of species were highest in natural forests (61), then reduced to lowest in specific tree plantations (6).

- *Species similarity between habitats*

The formula Sorensen (1948) was used to calculate the similarity of collembolan species between different habitats. The results were shown in the Czekanowski square diagram. The value of Sorensen index (S') strongly varies among habitats, and formed three groups:

- Habitat group has high similarity on species composition (S'>50%), including residential gardens – natural forests – grass & shrub lands – shortterm tree plantations.
- Habitat group has S' index less than 30% including natural forest – specific tree plantation – residential gardens.
- Habitat group has S' index of 30-50%, including uncultivated lands – bamboo forests.

	RTN	VQN	TC	DCT	RT	DH	DCC
RTN							
VQN	64.52						
TC	56.47	53.57					
DCT	51.76	53.57	54.17				
RT	47.5	39.22	69.77	46.51			
DH	36.84	46.81	51.28	41.03	41.18		
DCC	17.91	15.79	33.33	33.33	32	38.09	

>50% 41-50% 31-40% <30%

Figure 6. Similarity on species composition between habitats in Cham Chu NR

2.6.2. Species diversity in Bac Me

a. Myriapods

A total of 16 species belonging to 14 genera, 13 families, 9 orders, 2 classes were recorded in the Bac Me NR, Ha Giang. Most of myriapod species were found in the natural forests; three common species were found in crop habitats as: *Helicorthomorpha holstii*, *Trigoniulus corallinus* and *Otostigmus scaber*.

Only three species were found in caves as: *Eutrichodesmus* sp.1, *Eutrichodesmus* sp.2 and *Thereuopoda longicornis* Fabricius, 1783. Two *Eutrichodesmus* species was relatively abundant in caves when collected.

The species, *Polydesmus vietnamicus* Nguyen, 2009 was recorded in Bac Me for the first time. It is considered to be a new record in this region because this species had been described and recoded only from its type locality (Tam Dao NP).

Several taxa have been recognized as sp. species. Due to their morphological differences, they can be new species, but we need more time to confirm and compare more detailed with their congeners.

b. Spiders

There are 65 species of 41 genera, 18 families of spiders were collected from the three habitats (Natural forest on limestone mountains – NFLM; Planted forests and scrublands in planted forests and residential areas – PFaS; and Caves habitat - CH) in Bac Me NR (Table 2). There are 37 species belong to 27 genera, 12 families found in NFLM; 33 species belong to 22 genera, 7 families found in PFaS; and 12 species belong to 10 genera, 9 families found in CH.

Among 65 species found in Bac me NR, 19 species were only found in NFLM; 17 species were only found in PFaS; 10 species were only found in cave habitat; 17 species were found in both habitats NFLM and PFaS; 2 species were found in both NFLM and CH; there are no species found in both PFaS and CH (Fig. 7).

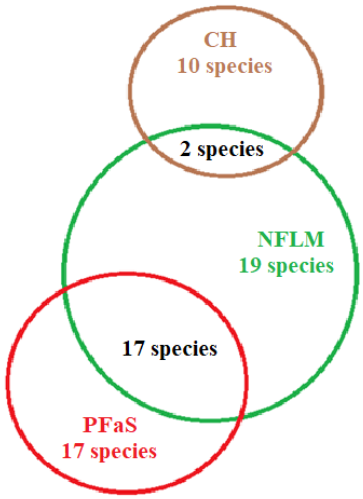


Figure 7. The distribution of spiders in Bac Me NR.

Among 18 families found in Bac Me NR, the two families Salticidae (with 21 species) and

Araneidae (17 species) are the most diverse families, then is Linyphiidae with 5 species; Pholcidae with 3 species; the other families are only with one or two species. The families Liocranidae, Sicarriidae, Telemidae and Theridiosomatidae were found only in cave habitat. The 2 genera of family Araneidae *Cyclosa* and *Araneus*, and two genera of family Salticidae và *Myrmarachne* are with the high number of species in Bac Me NR (6, 5, 4, 3 species, respectively); other genera are with one to two species.

In cave habitat, the four species *Agraecina* sp. (family Liocranidae), *Khorata* sp. (Pholcidae), *Phocus phami* (Pholcidae), và *Thrandina* sp. (Salticidae) were only distributed in entrance zone of cave, where still received sunlight; two species *Heteropoda* sp. (Sparassidae) và *Telema* sp. (Telemidae) were only distributed in dark zone; 6 species *Cyclosa* sp. (Araneidae), *Hickmania* sp. (Sicariidae), *Phocus bifidus* (Pholcidae), *Heteropoda venatoria* (Sparassidae), *Alaria* sp. (Theridiosomatidae) và *Zosis* sp. (Uloboridae) were found in both entrance and dark zones.

The similarity of species composition of spiders between NFLM and PFaS is very high with 45.71%; between NFLM and CH is 8.16%; there is no similarity of species composition between PFaS and CH (Table 2 and Fig. 8).

Table 3. The species similarity in the three habitats in Bac Me NR

	NFLM	PFaS	CH
NFLM			
PFaS	45.71		
CH	8.16	0	

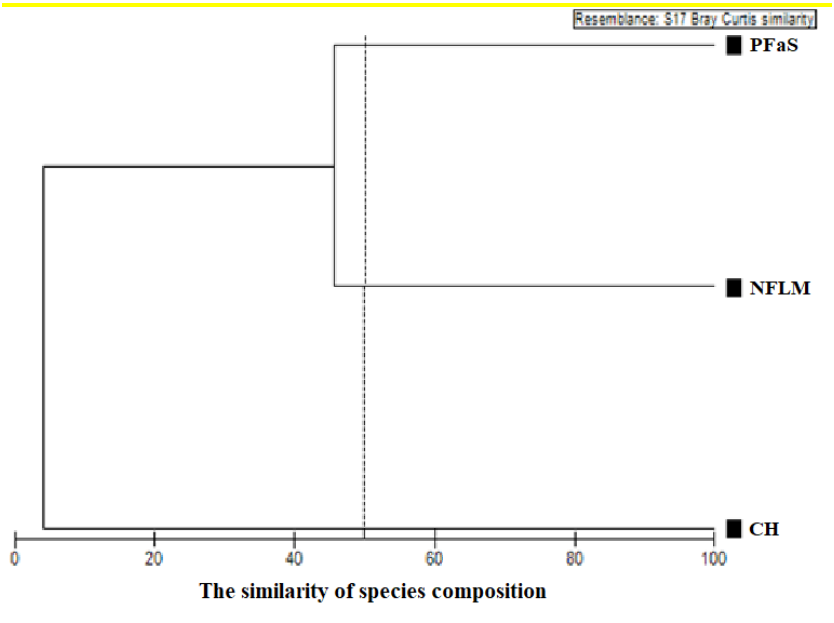


Figure 8. The species similarity in the three habitats in Bac Me NR

c. Free-living terrestrial Nematodes

- *The species diversity of free-living terrestrial nematodes*

The result has shown that at the Bac Me natural reservation area was recorded 57 species

belong 24 genera, 13 families, 2 orders Dorylaimida and Mononchida and indicated in the table 4. In there, the order Dorylaimida includes 20 species belong 16 genera, 9 families and the other order Mononchida has 37 species belong 8 genera, 4 families.

At the site of Lung Cang village (Minh Ngoc district) has found 53 species of Dorylaimida and Mononchida with 93% of all species were recorded at Bac Me natural reservation area. On the other site at Khen and Phia Ven villages (Lac Nong) have recorded only 44 species with 77.2%, less than 21% if compared to with Lung Cang (Minh Ngoc district). This result can be explained by the higher humidity than at Lung Cang. Small note wants to be show is nematode community was recorded in the summer much bigger than in winter for the year of 2019.

In order Mononchida, at Bac Me-Du Gia was found 37 species including 2 new records for nematode fauna in Vietnam such as *Clarkus sheri* (Mononchidae) and *Miconchus baeticus* (Anatonchidae) and 3 other species seem to be new species for science, that belong genera of *Parkellus*, *Clarkus* and *Coomansus*.

In the order Dorylaimida, the family Qudsianematidae was highest with 5 species accounting for 8.8% of total; the second place are family Belondiridae and Aporcelaimidae with with 3 species for each and accounted 5.3%; 3 families as Mydonomidae, Leptonchidae and Dorylaimidae were recorded 3 species and accounting 3.5%; Dorylaimidae and Nordiidae were found only 1 species for each and accounting 1.8% (Fig. 8).

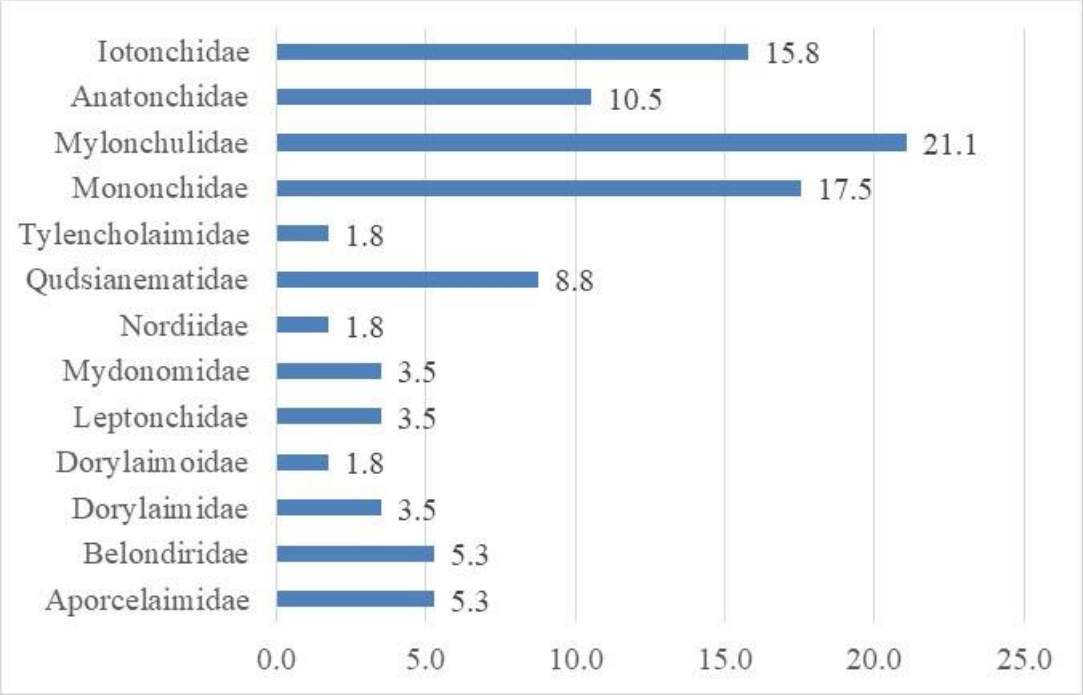


Figure 9. The percentage of recorded species in families

In order Mononchida, the family Mylonchulidae was highest with 12 species, accounting 21.1% of total; Mononchidae has 10 species with 17.5% and other family Iotonchidae has 9 species and accounting 15.7% total of species (Fig. 9).

- *Feeding groups of nematodes*

Among the soil inhabiting organisms, the nematodes dominate over all others, both in number and species. These nematodes mainly fall into five categories: i) Omnivorous; ii) hyphal feeding; iii) predaceous; iv) bacterial feeding and v) plant feeding. The feeding groups of nematodes community at Bac Me-Du Gia natural reservation area were showed in the table 4.

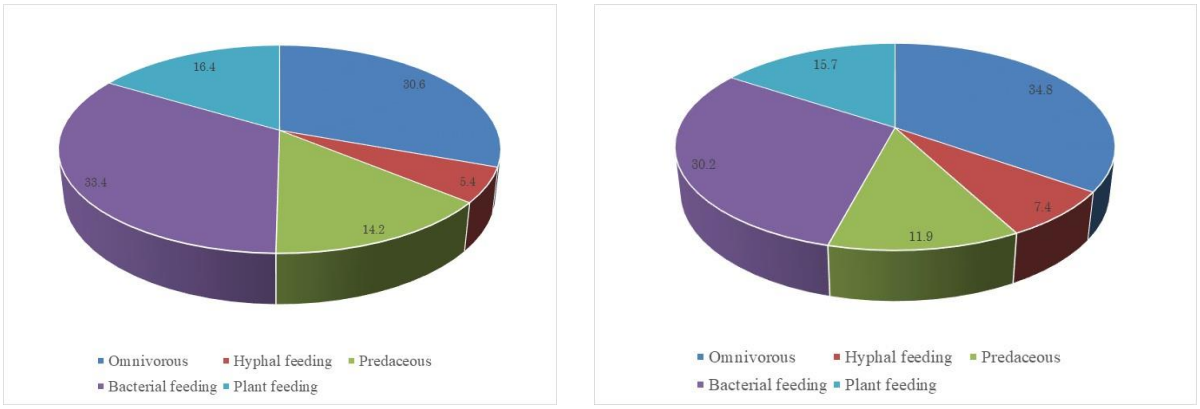
Table 4. Feeding groups of nematode community at Bac Me NR

Nematodes	Feeding group	C-P value	Bac Me-Du Gia natural reservation/100g soil	
			Minh Ngoc	Lac Nong
ORDER DORYLAIMIDA				
Family Aporcelaimidae	Omnivorous	5	117	55
Family Belondiridae	Hyphal feeding	4	112	78
Family Dorylaimidae	Omnivorous	4	543	423
Family Dorylaimoidae	Omnivorous	4	33	17
Family Leptonchidae	Omnivorous	4	76	56
Family Mydonomidae	Hyphal feeding	4	23	22
Family Nordiidae	Omnivorous	4	37	45
Family Qudsianematidae	Omnivorous	4	227	149
Family Tylencholaimidae	Hyphal feeding	4	47	76
ORDER MONONCHIDA				
Family Mononchidae	Predaceous	5	94	45
Family Mylonchulidae	Predaceous	5	221	117
Family Miconchidae	Predaceous	5	89	66
Family Iotonchidae	Predaceous	5	77	53
ORDER RHABDITIDA				
Family Rhabitidae	Bacterial feeding	1	277	131
Family Cephalobidae	Bacterial feeding	2	356	187
Family Diploscapteridae	Bacterial feeding	1	216	118
Family Bunonematidae	Bacterial feeding	1	117	88
Family Panagnolaimidae	Bacterial feeding	1	56	112
ORDER AEROLAIMIDA				
Family Alaimidae	Bacterial feeding	4	145	78
ORDER TYLENCHIDA				
Family Anguinidae	Plant feeding	2	4	3
Family Tylenchidae	Plant feeding	2	375	227
Family Aphelenchidae	Plant feeding	2	21	11
Family Pratylenchidae	Plant feeding	3	45	43
Family Hoplolaimidae	Plant feeding	3	55	67

Family Heteroderidae	Plant feeding	3	54	21
Total			**3417**	**2288**

The nematode community at the Bac Me-Du Gia were estimated. At the research site that belong Minh Ngoc commune was calculated 3417 nematodes/100ml samples and at Lac Nong is 2288 nematodes/100ml. The number of nematodes at the Minh Ngoc was higher 33% than in Lac Nong and the result was fitted well with the soil humidity

At the Minh Ngoc commune: the nematodes of bacterial feeding group was highest and accounting 33.4%; the following group is omnivorous group with 30.6%; Two groups of plant feeding and predaceous are not different in a ratio with 16.4% and 14.2%. The nematode group of hyphal feeding is lowest with only 5.4% (Fig. 10A).



A **B**

Figure 10. The ratio of feeding types of nematode community at Minh Ngoc commune (A) and Lac Nong commune (B)

The same tendency with the ratio of feeding types at Lac Nong commune (Fig. 10B). However, the group of omnivorous nematodes was highest and accounting 34.8% and the second place is bacterial feeding group with 30.2%, plant feeding group is 15.7% and predaceous group is 11.9%. The lowest is hyphal feeding with 7.4%

There is no different significance in ratio of feeding groups of nematodes in between Minh Ngoc and Lac Nong.

d. Collembola

- *Species diversity*

A total of 63 species belonging to 26 genera, 13 families has been recorded in four different habitats in two communes (Minh Ngoc and Lac Nong), Bac Me district, Ha Giang province. Of which, 51 ones have been named (accounting for 80.95%), and 12 ones have been identified as sp. species (accounting for 19.05%).

Based on absence/presence of species in habitats, 63 species can be divided into different

groups as the following:

+ *Widely distributed group* includes all species recored in 3-4 habitats. This group consists of 20 species (accouting for 31.75%) including: *Acherontiella sabina, Protaphorura tamdaona, Brachystomella parvula, Friesea sublimis, Folsomides exiguus, Cryptopygus thermophilus, Entomobrya lanuginosa, E. muscorum, Sinella coeca, S. pseudomonoculata, Pseudosinella immaculata, Lepidocyrtus (Asc.) dahlii, Dicranocentrus indicus, Cyphoderus javanus, Megalothorax minimus, Sminthurides aquaticus, Sphaeridia pumilis, Calvatomina antena, C. tuberculata, Proisotoma submuscicola*. These species can be considered as the representatives of collembolan community for the study region. They are diagnosed by soil-living, small body size, unpigmented or less pigmented.

+ Narrowly distributed group includes only species recorded in 1-2 habitats and in only one season. This group comprises 28 species (accounting for 44.44%), such as: *C. paraligudorsa, C. succinea, P. yodai, Protaphorura* sp.$_1$*, P. hortensis, Pseudachorutes subcrasus, Neanura* sp.$_1$ *, Lobellina* sp.$_1$*, Paralobella* sp.$_2$, *F. americanus, F. parvulus,, Folsomina onychiurina, H. glassa, H. social, L. (Lepidocyrtus) cyaneus, L. (L.) lanuginosa, L. (L.) simsim, L. (Acrocyrtus) heterolepis, Lepidocyrtus (Ascocyrtus) aseanus, L. (Asc.) cinctus, Lepidocyrtus (Ascocyrtus)* sp.$_1$*, W. mesothoraxa, S. celebensis, Salina* sp.$_1$*, S. bothrium, Sphaeridia zaheri, Sminthurinus* sp.$_1$, *S. maccrochaeta.*

+ *Seasonal distribution group*: There are 49 species found in rainy season and 53 ones recorded in dry season. Of which, 39 species have been found in both two seasons, and 25 ones have been recorded either in rainy season or in dry season. They include:

- 10 species found only in rainy season: *C. paralagulidorsa, P. hortensis, Neanura* sp.$_1$*, F. americanus, F. parvulus, F. onychiurina, I. pseudoproductus, L. (L.) simsim, Salina* sp.$_1$, *S. bothrium.*
- 14 species found only in dry season: *C. succinea, P. yodai, Protaphorura* sp.1, *Onychiurus* sp.$_1$, *P. subcrassus, Lobella* sp.$_1$, *Paralobella* sp.$_2$, *H. glassa, L. (L.) cyaneus, L. (Acr.) heterolepis, L. (Asc.) cinctus, Lepidocyrtus (Ascocyrtus)* sp.$_1$, *W. mesothoraxa, S. celebensis*.

- *Taxon diversity and distribution in habitat.*

The number of taxa recorded in different habitats is shown in Figure 11. In the family level: Each habitat has 11 families. Some families were present or absent in different habitats. For example, Paronellidae is absent in natural forests and plantations, but present in other habitats. Ecologically, this family is often found in the forests with rich litter layer. However, natural forest is very poor in the study area. This is reason to explain the absence of the family Paronellidae in two habitats.

In generic level: there is no differences in number of genera between habitats. Plantation has 27 genera, but other three habitats have 29 ones.

In species level: about 40-43 species have been found in each habitat. Natural forest and grassland has 40 species for each, cultivated land has 42 species, and plantation has 43 species.

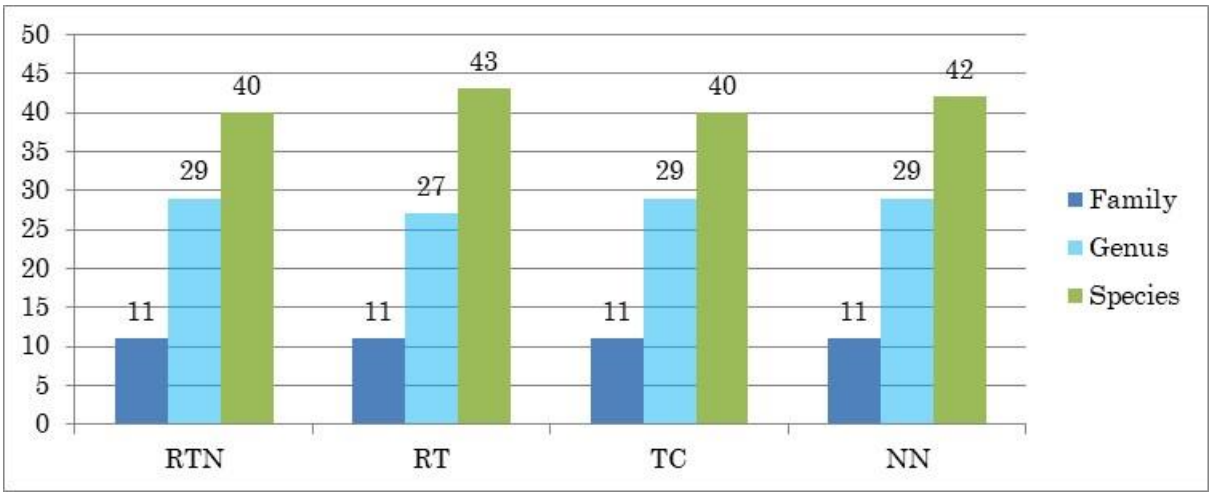


Figure 11. The number of taxa and distribution in habitats

- *Taxon diversity and distribution in season*

The number of species increases from rainy season (49) to dry season (53). The number of different taxa (families, genera and species) in two seasons are presented in the Fig 11.

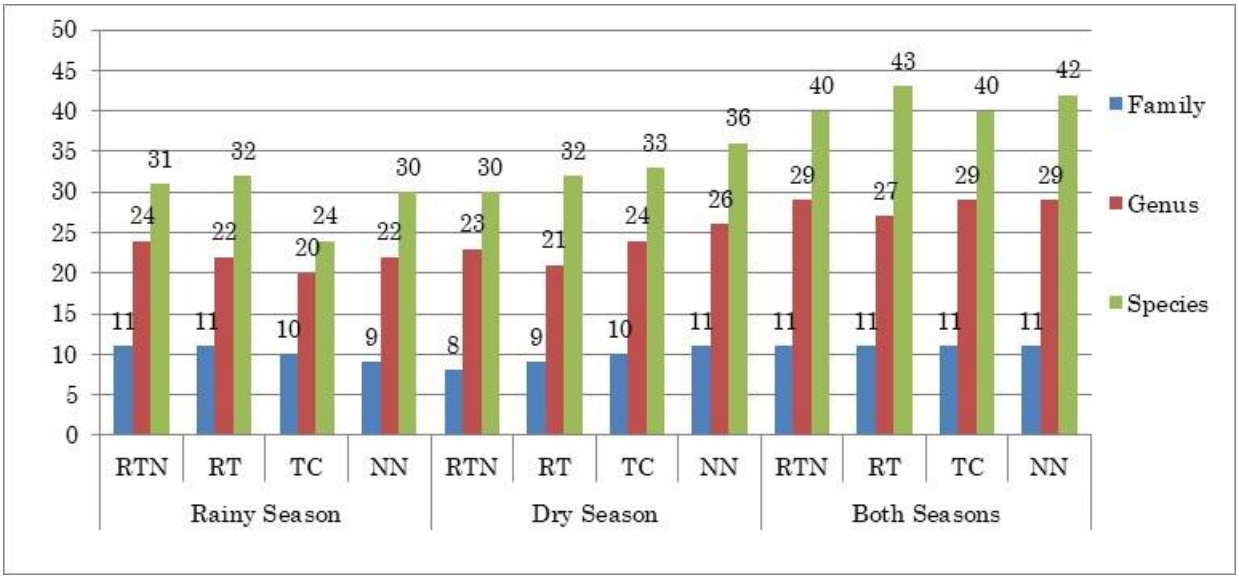


Figure 12. The number of taxa and distribution in season

It shows the similar number of families recored in two seasons, but there are significant differences in number of genera and species between two seasons.

- *Quantitative characteristics of collembolans in Bac Me NR*

Several biological indexes are employed to analyze the differences between habitats in Bac Me NR. These indexes are presented in the Table 5.

Table 5. Quantitative characteristics of collembolans in different habitats

No.	Indexes	Habitats			
		RTN	RT	TC	NN
1	Number of species	40	43	40	42
2	Number of individuals	407	487	447	479
3	H' index	3.44	3.34	3.07	3.26

Number of species and individuals

The number of collembolan species is about from 40-43 and the number of individuals is about 407-487 in different habitats. These numbers are lowest in natural forest (40 species and 407 ind.), increases in grassland and cultivated land (40 species - 447 ind. and 42 species - 479 ind., respectively) and highest in plantation (43 species - 487 ind.).

The H' index

Both natural forest and plantation have higher values of H' index (3.44 and 3.34, respectively).

2.6.3. Species diversity in Phia Oac – Phia Den

a. Myriapods

Millipedes:

A total of 16 myriapod species have been recorded in Pia Oac – Pia Den National Parl. As this is the results for the first survey, we believe that the number is far from reflecting the true biodiversity of myriapods in this protected area.

Of 16 species, we found 9 millipede species in 6 genera, 4 families, 4 orders; 7 centipede species in 4 genera, 4 families, 3 orders. We also described a new species to science, *Rhopalomeris nagao* Nguyen et al., 2021.

The distribution of species in elevations is also presented in the table 8. Most recorded species were more likely to be found in the elevations of 1200-1600 in natural forests. Several species were also found in the lower elevation of 850m. The forest in the lower elevation was likely regenerated forests and in very good condition while the forest in higher elevations were well protected and in well condition.

Large centipedes

A total of 17 species of 8 genera, 3 families (Scolopendridae, Cryptopidae and Scolopocryptopidae) were recorded in the national park. Three species, *Tonkinodentus lestes*, *Asanada brevicornis* and *Rhysida longipes,* were recorded for the first time in northern Vietnam. These species were previously found in central and southern Vietnam, and two species *A. brevicornis* and *R. longipes* has been widely distributed in Southeast Asia (Tran *et al.* 2013). In addition, the distribution of two species, *Otostigmus aculeatus* and *Otostigmus multidens*, was also expanded northward (Vu *et al.* 2020).

Two habitats, WF (= wood forest) and WBF (= wood-bamboo mixed forest), were the most

diverse one in terms of number of species (11 for each habitat) and number of genera (six in WF and seven in WBF). The diversity reduced from BF (= bamboo forest) habitat (8 species, 6 genera, 3 families) to PF (= pine forest) (six species, four genera and two families). The lowest number of species, genera and families were recorded in GS (= grass-shrubs) habitat (two species in one genus, one family).

Of 17 centipede species, three (*Asanada brevicornis, Cryptops spinipes* and *Tokinodentus lestes*) were commonly found in four habitats; four (*Scolopendra subspinipes, Scolopendra cingulatoides, Scolopocryptops spinicaudus* and *Scolopocryptops* sp.) were found in only three habitats; four (*Otostigmus aculeatus*, *Cryptops doriae*, *Cryptops* sp. and *Scolopocryptops rubiginosus*) were found in only two habitats; two species (*Alluropus demangei* and *Rhysida longipes*) were recorded only in WBF while other two (*Otostigmus voprosus* and *Otostigmus multidens*) were found only in PF habitat.

Regarding topological distribution, the highest species diversity was recorded in the elevation range of 1,000 – 1,600 m a.s.l. (15 species, 7 genera, 3 families) while other elevation ranges had lower diversity (11 species, 6 genera, 2 families in >1,600 m and 9 species, 3 genera, 2 families in <1,000m). However, this result may not reflect the true diversity of centipedes in different elevation. This may depend on our collecting efforts, and it requires more intensive surveys in the elevation range of less than 1.000m.

Three species (*Asanada brevicornis, Scolopendra cingulatoides* and *Cryptops spinipes*) were found in all three elevation ranges; nine species were recorded at two elevation ranges and five species were found at only one elevation ranges.

Other centipedes

Four species in two genera, two families has been recorded in the Phia Oac – Phia Den NP. They are mainly distributed in the elevation range of 1200-1600 and in the natural forests.

b. Spiders

There are 53 species of 29 genera, 10 families of spiders were collected in Phia Oac – Phia Den NP, Cao Bang province.

Among 53 species of found in Phia Oac-Phia Den NP, 25 species were distributed at the elevation of 700 – 900m, 17 species were distributed at the elevation of 1000 – 1600m, 11 species were found at the elevation of 700-1600m.

Among 10 families of spiders collected from Phia Oac – Phia Den NP, the three families Salticidae, Araneidae and Thomisidae were found with highest number of species (19, 13 and 9 species, respectively). The three families are also known as the three big families (Salticidae and Araneidae are the two biggest families) of the species composition in not only Vietnam but also in the world. The other families found in Phia Oac – Phia Den NP are only with one to two species.

The three families Lycosidae (2 species), Salticidae (19 species) and Thomisidae (9 species) are free hunting spiders. They are usually active (or stand and wait) on ground surface, leaves carpet, trunk, branches, foliage to search prey. When find prey, they will ambush then pounce to

catch the prey. The other families found in Phia Oac – Phia Den NP are web spiders. They make a web to live and wait for prey.

c. Free-living terrestrial Nematodes

At the Phia Oac National Park, the result has shown that 42 species belonging to 20 genera, 12 families, 2 orders Dorylaimida and Mononchida. There, the order Dorylaimida includes 14 species belonging to 10 genera and 7 families and the other order Mononchida has 28 species belonging to 10 genera and 5 families.

New records of genus level for Vietnamese fauna such as *Cobbonchus* Andrassy, 1958 and *Jensenonchus* Jairajpuri & Khan, 1982. The species *J. sphagni* (Brezki, 1960) is a new record for nematode fauna in Vietnam. The species of the genus *Cobbonchus* Andrassy, 1958 seemed to be a new species for science. However, more detail of identification is needed to be sure about this matter. In addition, the species *Parkellus* sp3 has some different characteristics compared with *Parkellus hagiangensis* sp. n. (was found in Du Gia Nature Reserve, Bac Me District, Ha Giang Province) and *P. tuyenquangensis* sp. n. (was found in Cham Chu Nature Reserve). These different characteristics also need more time to be carefully identified.

At the Phia Oac National Park, two families Mononchidae and Mylonchulidae belonging to order Mononchida were recorded as 8 species with 19% of total species. The second place is the family Iotonchidae belonging to order Mononchida with 7 species and accounting for 16.7% of total. Less than family Iotonchidae, two families as Qdsianematidae (belonging to order Dorylaimida) and Anatonchidae (belonging to order Mononchida) recorded 4 species with 9.5% of the total species. Other families have shown from 1-3 species (Fig. 12).

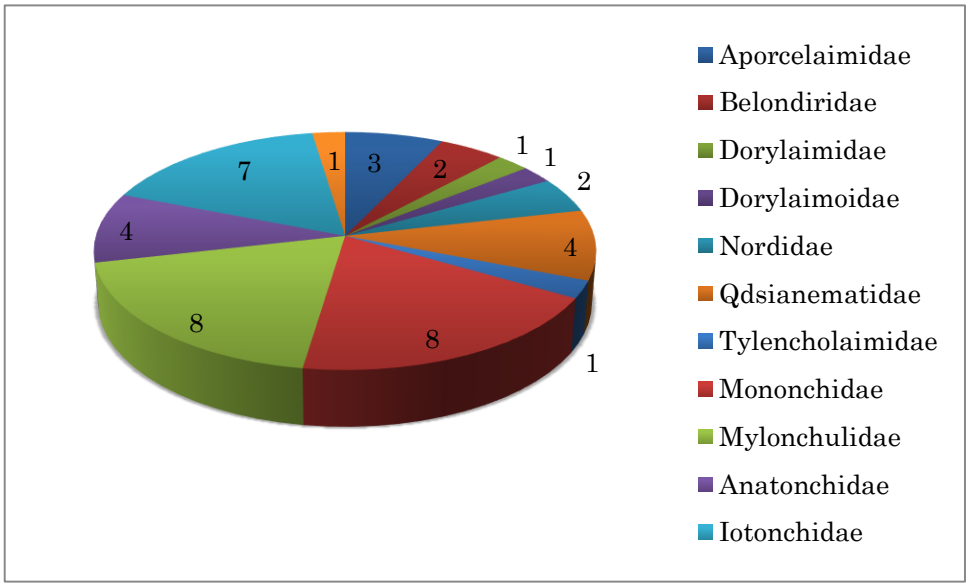


Figure 13. The ratios of species recorded at the Phia Oac National Park

d. Collembola

- *Species diversity*

A total of 46 collembolan species belonging to 31 genera, 13 families were recorded in natural forests but in different elevations in Pia Oac – Pia Den National Park. Of 46 species, 30 have been identified with scientific names (65.22% total species), 16 have been identified to generic level (34.78% total species). Of 13 families, Neanuridae, Isotomidae and Entomobryidae have highest number of species, other families have 1-3 species.

All recorded collembolan species can be grouped into different groups based on distribution in elevations and occurrence frequencies.

+ *Widely distributed group*: includes all species which are present in 4-6 elevations and in 4-5 soil samples. Only three species: *Onychiurus* sp., *Cryptopygus thermophilus* and *Sphaeridia zaheri*.

+ *Narrowly distributed group*: comprises species which are present only in 1-2 elevations and in one soil sample. Only four species, namely *Entomobrya* sp.$_3$*, Vietanura* sp., *Arrhopalites* sp., *Isotoma* sp., are in this group.

+ *Distribution in elevations*:

- 18 species were recorded in only one elevations. They are *Cyphoderus javanus* (815m)*, Entomobrya* sp.$_3$*, Vietnura* sp., *Deuterobella* sp., *Lepidocyrtus* sp.$_2$, *Lepidocyrtus* sp.$_3$, *Pseudachorutella* sp. (1200m), *Entomobrya muscorum, Friesea sublimis, Lepidocyrtus (Asc) dahlii*, *Calvatomina* sp., *Pseudachorutella asigillata* (1300m)*, Arrhopalites* sp. (1600-1700m)*, Pseudosinella alba, Isotoma* sp.*, Xenylla humicola, Calvatomina scutellina, Ceratophysella denticulata* (1846m).

- 16 species were found in 2-3 different elevations, including: *Choreutinula* sp. (815m, 1600-1700m), *Folsomides parvulus, Protaphorura* sp. (1200m, 1846m), *Brachystomella parvula* (1200m, 1300m, 1846m), *Vitronura* sp. (815m, 1200m), *Proisotoma submuscicola* (1300m, 1500m), *Megalothorax minimus, Salina celebensis, Homidia sauteri sinensis* (1300, 1846m), *Homidia subcingula* (1300m, 1600-1700m), *Homidia* sp. (815m, 1200m, 1500m), *Pseudosinella octopunctata* (1200m, 1300m, 1500m), *Lepidocyrtus (L.) cyaneus* (815m, 1200m, 1600-1700m), *Sphaeridia pumilis* (1200m, 1600-1700m), *Calvatomina antenna* (1500m, 1600-1700m), *Sinella pseudomonoculata* (1300m, 1846m).

- 12 species were found in 4-6 elevations: *Sphyrotheca macrochaeta, Deuterosminthurus* sp.*, Sphaeridia zaheri, Sminthurides aquaticus, Dicranocentrus indicus, Lepidocyrtus* sp.$_1$, *Entomobrya* sp.$_1$, *Entomobrya* sp.$_2$, *Onychiurus* sp., *Folsomina onychiurina, Cryptopygus thermophilus, Sinella coeca*.

- *Quantitative indexes of the collembolan fauna in Pia Oac – Pia Den NP*

Several biological indexes are employed to analyze the differences between elevations in Pia Oac – Pia Den NP. These indexes are presented in the Table 6.

Table 6. Quantitative indexes of the collembolan fauna in Pia Oac – Pia Den NP

Elevation / Indexes	815m	1200m	1300m	1500m	1600-1700m	1846m

Number of samples	4	5	4	5	4	5
Number of species	15	25	24	8	15	21
Chỉ số H'	2.48	2.48	2.46	1.89	2	2.68
Chỉ số J'	0.92	0.77	0.78	0.91	0.74	0.88

Number of species varies from 8 to 25 species in different elevations. The higher numbers were recorded in 1200m, 1300m, and 1846m (25, 24 and 21 species, respectively). The elevation of 1500m has lowest number (8 species).

The H' index varies from 2 to 2.68 in five elevations (815m, 1200m, 1300m, 1600-1700m, 1846m), but only 1.86 in the elevation of 1500m. The J' index also changes in different elevations, from 0.88 (in 1846m) to 0.92 (in 815m).

2.6.4. Species diversity in Nam Xuan Lac

a. Myriapods

A total of 7 species in 7 genera, 7 families of two classes (Diplopoda and Chilopoda) were recorded in the Nam Xuan Lac. Of which, only one species, *Glyphiulus* sp.1 was found inside the caves. This species has been also known from other caves in Bac Me and Cham Chu NRs. The myriapod diversity of the Nam Xuan Lac is relatively poor in comparison with other localities (Bac Me, Cham Chu and Phia Oac – Phia Den). This could be due to limitation of survey efforts and effects of mining activities.

b. Spiders

There are 25 species of 17 genera, 9 families of spiders were collected in Nam Xuan Lac, Bac Can province.

Among 9 families of spiders collected from Nam Xuan Lac, the three families Salticidae, Araneidae and Thomisidae were found with highest number of species (8, 5 and 4 species, respectively). The three families are also known as the three big families (Salticidae and Araneidae are the two biggest families) of the species composition in not only Vietnam but also in the world. The family Oxyopidae was found with three species. Each of the other families found in Nam Xuan Lac are only with only one species.

The two families Salticidae (8 species) and Thomisidae (4 species) are free hunting spiders. They are usually active (or stand and wait) on ground surface, leaves carpet, trunk, branches, foliage to search prey. When find prey, they will ambush then pounce to catch the prey. The other families found in Nam Xuan Lac are web spiders. They make a web to live and wait for prey.

c. Free living nematods

A total of 31 species belonging to 15 genera, 11 families were recorded in the Nam Xuan Lac Nature Preservation area. Of which, the order Dorylaimida includes 20 species belonging to

16 genera, 9 families and the order Mononchida has 37 species belonging to 8 genera, 4 families. The species of *M. baeticus* Jimenez-Guirado, Alhama & Guitierrez, 1997 is a new record for nematode fauna in Vietnam.

The family Mylonchulidae belonging to the order Mononchida was recorded as 7 species with 12.5% of total species. The second place is the family Iotonchidae (belonging to order Mononchida) with 5 species and accounting 8.9%. Less than family Iotonchidae are two families Mononchidae and Anatonchidae belonging to the order Mononchida with 4 species and accounting for 7.1% of total. Other families have shown from 0-3 species (see figure 14).

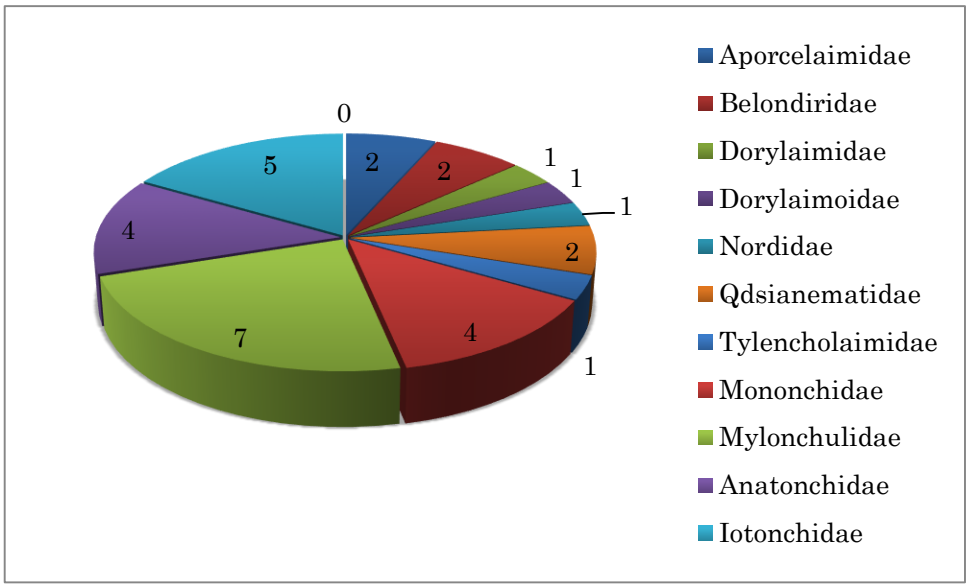


Figure 14. The ratios of species recorded at the Nam Xuan Lac Nature Preservation Area.

d. Collembolans

A total of 20 collembolan speciesin 16 genera, 9 families were found in three different types of habitats (natural forests, limestone and maize crops) in Nam Xuan Lac Nature Reserve, Bac Can Province. Of which, 15 species were identified their nomenclature, and 5 one were identified as sp. species. Three families, Isotomidae, Entomobryidae and Dicyrtomidae has highest number of species (3-5), other families have only 1-3 species each. Some species were distributed commonly in three habitats, for example *Sphaeridia zaheri.* Other species were found only in one habitat: *Xenylla humicola, Pseudosinella octopunctata, Deuterosminthurus* sp.1 in natural forests; *Cyphoderus javanus*, *Salina* sp., *Sphyrotheca* sp.1, *Calvatomina scutellina* in limestone; *Calvatomina tuberculata*, *Sinella coeca, Isotomiella minor* and *Folsomides parvulus* in maize crops.

2.7 Discussion

2.7.1 Biodiversity exploration

- *Myriapods*

Comparing on the species similarity between four areas, it was shown that Cham Chu and

Bac Me have the most similar species composition of myriapods. It also reflects the fact that two areas are located closely to each, and limestone forests are mostly dominated in both areas. On the contrary, Phia Den – Phia Oac forms a clade with Nam Xuan Lac, but their myriapods were not very similar. It is simply due to the elevation differences in two areas. Phia Oac – Phia Den is located in high elevation, and samples were collected from above 1,000m, while Nam Xuan Lac is located in lower elevation. The survey habitats are also different in Phia Oac – Phia Den (evergreen mountains) and Nam Xuan Lac (limestone mountains).

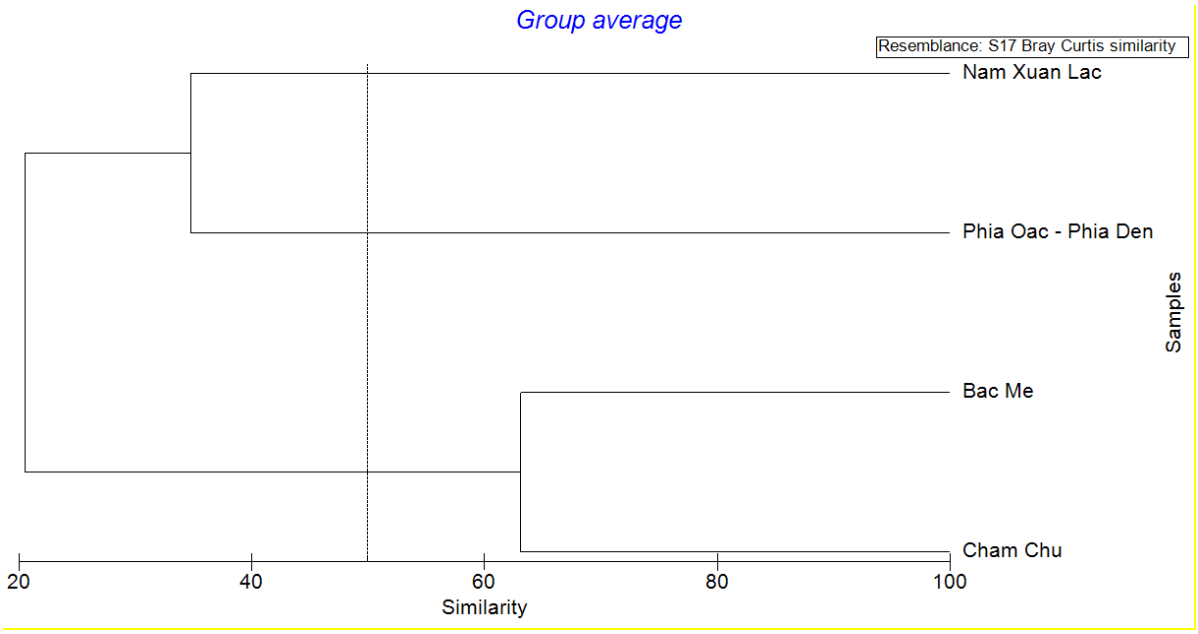


Figure 15. Species similarity of myriapods between four areas.

- *Spiders:*

In total, 131 species of spiders were recorded at the four localities in Mountainous region of North Vietnam. Among them, 65 species were found in Bac Me, 53 species in Phia Oac-Phia Den, 29 species in Cham Chu and 25 species in Nam Xuan Lac. There are 51 species were only found in Bac Me; 29 species were only found in Phia Oac-Phia Den; 11 species were only found in Cham Chu; 13 species were only found in Nam Xuan Lac.

The similarity of species composition of spiders between the four localities is very low (lower than 30%; table 7, Fig. 16).

Table 7. The similarity of species composition of spiders at the four areas in Mountainous region of North Vietnam

	Bac Me	Phia Oac Phia Den	Cham Chu	Nam Xuan Lac

Bac Me				
Phia Oac Phia Den	7.27			
Cham Chu	17.20	26.67		
Nam XUan Lac	4.55	22.86	18.87	

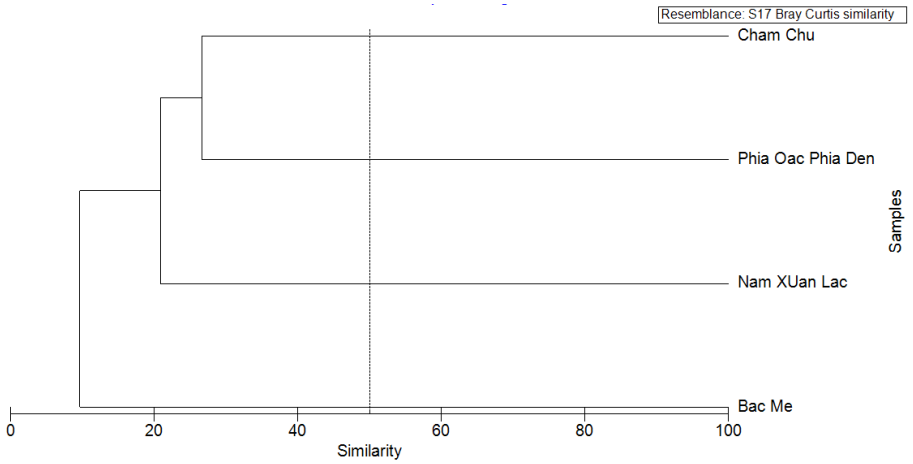


Figure 16. The similarity of species composition of spiders at the four localtities in Mountainous region of North Vietnam

- *Nematods*

In general, 89 species were recorded belonging to 35 genera, 13 families and 2 orders as Dorylaimida and Mononchida. The number of species were recorded at the Cham Chu Nature Reserve in both Dorylaimida and Mononchida order and accounted for 69.7% of found species. The lowest level at Nam Xuan Lac Nature Reserve with 33.7% (see figure 17).

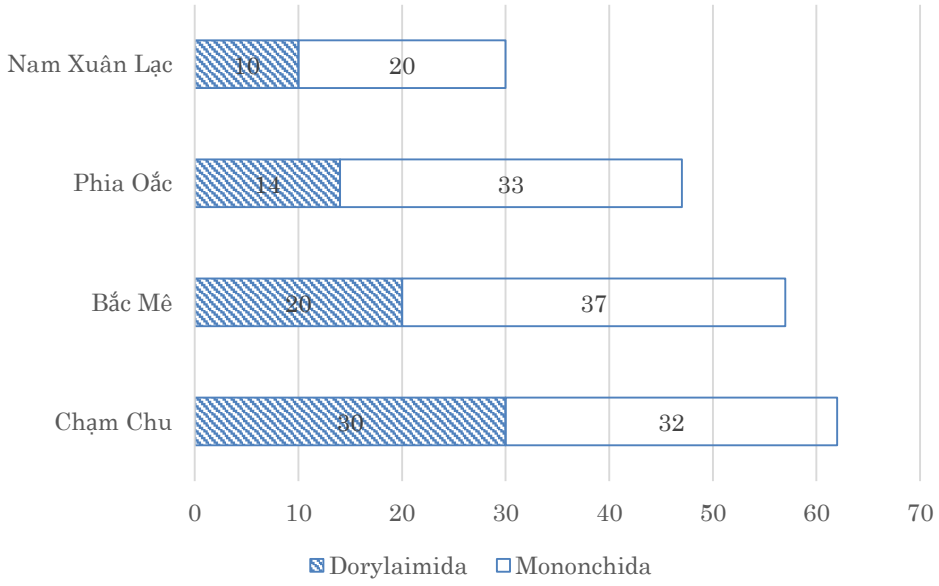


Figure 17. Contribution of nematodes species at studied places.

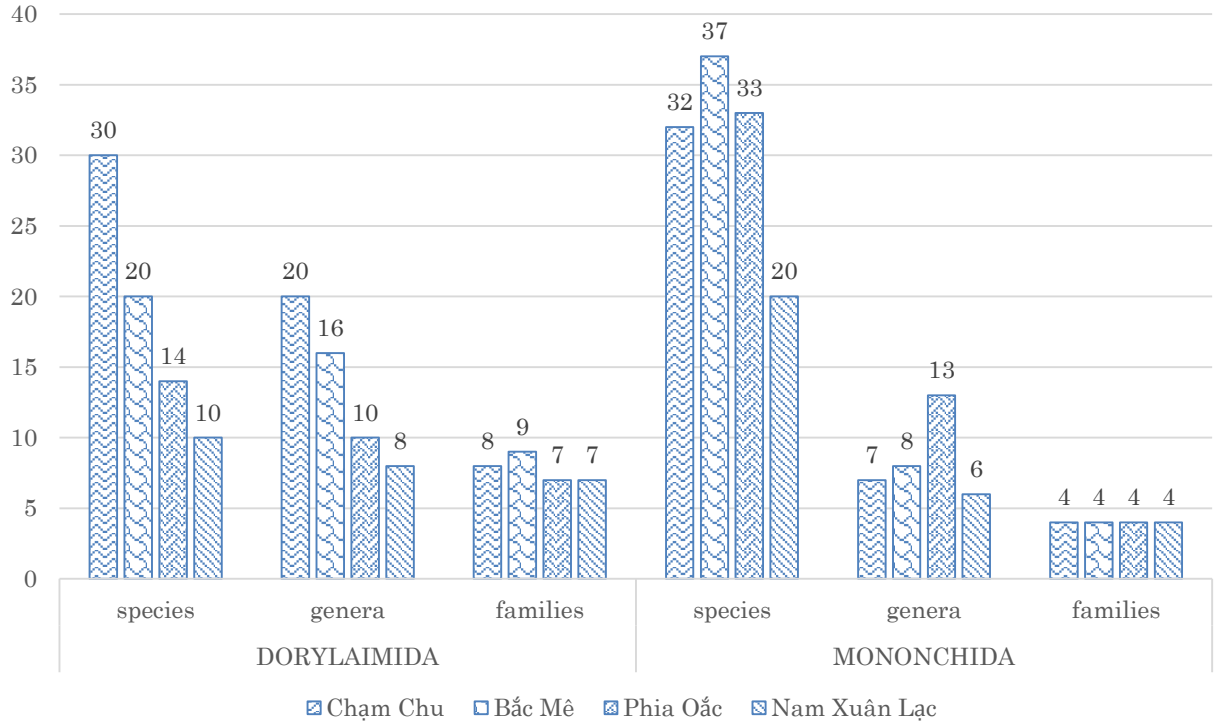


Figure 18. Distribution of nematode species in order Dorylaimida and Mononchida at studied places

In order for Dorylaimida, there were no significant differences in terms of familier numbers between different studied places. However, species and genera are quite different. The highest number was found at the Cham Chu Nature Reserve with 30 species and even triple when compared to Nam Xuan Lac Nature Reserve. The same tendency with the number of genera.

In order Mononchida, the number of species were not different between Cham Chu, Bac Me and Phia Oac, arranged 32 to 37 species, but with quite different significance at Nam Xuan Lac Nature Reserve. The numbers of genera and families are not different between different studied places except at Phia Oac National Park in terms of genera.

The biodiversity of nematode species as well as the number of free living nematodes at Nam Xuan Lac Nature Reserve are lowest and the reason may cause by human activities. In fact, one Mining company operating inside the Nature Reserve

- *Collembolans:*

A total of 97 collembolan species were recorded at the four localities in Mountainous region of North Vietnam. Among them, 63 species were found in Bac Me, 46 species in Phia Oac-Phia Den, 66 species in Cham Chu and 29 species in Nam Xuan Lac.

The similarity of species composition of collembolans between the four localities is presented in figure 19. Accordingly, Bac Me and Cham Chu has high species similarity (>70%) while Nam Xuan Lac is somewhat different from other localities (species similarity less than 50%)

	BM	CC	PO	NXL
BM				
CC	0,73			
PO	0,5	0,57		
NXL	0,38	0,35	0,42	

Figure 19. The similarity of species composition of collembolans at the four localtities in Mountainous region of North Vietnam

2.7.2 Environmental and conservation issues

The plastic rubbish was observed in manu cave entrances and even inside caves in Cham Chu, Bac Me and Nam Xuan Lac. Obviously, it was not due to tourism because these areas do not develop tourism and almost no visitor come there. Rubbish pollution was mainly from local people who visited caves and sometimes destroy cave stones.

During the fieldwork in Cham Chu, we observed the overuse of pesticides in the fruit plantations. The local people use chemicals to protect their crops, but chemical concerntration was much enough to creat the fogy environment. It was too harm to people health, environment and biodiversity as well.

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3. EMPOWERMENT OF YOUNG SCIENTISTS

3.1 Guiding principles for education and training

Three young reseachers have been involved in this project. During the project, they have been improving their research capacity through the participation in field surveys, specimen examination in laboratory, photo taking, data analysis, and manuscript preparing and submitting.

3.2 Achievement of each young scientist

During the project, one young researcher was succesfuly obtained her Master Degree with the thesis entitled "Species diversity of the centipede genus Otostigmus (Scolopendromorpha: Scolopendridae) in Vietnam".

Three papers have been published by young reseachers:

1. **Vu TH**, Nguyen DH, Le XS, Eguchi K, Nguyen AD, Tran TTB, 2020. A review and notes on the phylogenetic relationship of the centipede genus Otostigmus Porat, 1876 (Chilopoda: Scolopendromorpha: Scolopendridae) from Vietnam. Zootaxa, 4808(3): 401-438.
2. **Son LX**, Anh NTT, Binh TTT, Nguyen TAT. & Nguyen AD (2021). Diversity and distribution of the large centipedes (Chilopoda: Scolopendromorpha) in the Phia Oac - Phia Den National Park, Vietnam. Journal of Threatened Taxa 13(8): 19102–19107. https://doi.org/10.11609/jott.7451.13.8.19102-19107
3. **Phung Thi Hong Luong**, Nguyen Thi Thu Anh, Nguyen Duc Anh, 2020. The preliminary study on species compostion and distribution of spiders (Arachnida: Araneae) in the Du Gia – Cao Nguyen Da Dong Van National Park, Ha Giang province. The proceeding of the national congress on entomology.

4. APPENDIXES

Appendix 1. List of soil invertebrate species recorded in four research areas

Table A1. Species diversity of myriapods in four study areas

No	Species	Cham Chu	Bac me	Phia Oac – Phia Den	Nam Xuan Lac
	DIPLOPODA				
	ORDER POLYXENIDA				
	Family Alloloproctidae				
	Genus *Monographis* Attems, 1907				
1	*Monographis demangi* Attems, 1937		+		
	ORDER GLOMERIDA				
	Family Glomeridae				
	Genus *Rhopalomeris* Silvestri, 1917				
2	*Rhopalomeris sauda* Nguyen, Sierwald & Marek, 2019	+			+
3	*Rhopalomeris nagao* Nguyen et al., 2020			+	
	Genus *Tonkinomeris* Nguyen, Sierwald & Marek, 2019				
4	*Tonkinomeris napoensis* Nguyen, Sierwald & Marek, 2019	+	+		
	ORDER SPHAEROTHERIIDA				
	Family Zephroniidae				
	Genus *Sphaerobelum* Verhoeff, 1924				
5	*Sphaerobelum hirsutum* Verhoeff, 1939	+	+		+
	ORDER CALLIPODIDA				
	Family Sinocallipodidae				
	Genus *Sinocallipus* Zhang, 1983				
6	*Sinocallipus* sp.	+			
	ORDER SPIROSTREPTIDA				
	Family Cambalopsidae				
	Genus *Glyphiulus* Gervais, 1847				
7	*Glyphiulus* sp.1	+	+		+
8	*Glyphiulus* sp.2	+	+		
9	*Glyphiulus* sp.3			+	
	ORDER JULIDA				
	Family Julidae				
	Genus *Nepalmatoiulus* Mauriès, 1983				
10	*Nepalmatoiulus* sp.1	+	+	+	+
11	*Nepalmatoiulus* sp.2		+		
	ORDER SPIROBOLIDA				
	Family Trigoniulidae				
	Genus *Trigoniulus* Pocock, 1894				
12	*Trigoniulus corallinus* (Eydoux & Souleyet,	+	+		

	1841)					
	ORDER CHORDEUMATIDA					
	Family Metopidiotrichidae					
	Genus *Metopidiothrix* Attems, 1907					
13	*Metopidiothrix* sp.	+		+		
	ORDER POLYDESMIDA					
	Family Polydesmidae					
	Genus *Polydesmus* Latreille 1802					
14	*Polydesmus vietnamicus* Nguyen, 2009		+			
	Family Paradoxosomatidae					
	Genus *Anoplodesmus* Attems, 1914					
15	*Anoplodesmus* sp.		+	+		
	Genus *Helicorthomorpha* Attems, 1914					
16	*Helicorthomorpha holstii* (Pocock, 1895)	+	+			
	Genus *Hylomus* Cook & Loomis, 1924					
17	*Hylomus namek* Nguyen et al., 2019	+				
18	*Hylomus holstii* Golovatch & Enghoff, 1994	+		+		
19	*Hylomus* sp.1			+		
	Genus *Nedyopus* Attems, 1914					
20	*Nedyopus mahunkai* (Golovatch & Korsós, 1989)	+				
	Genus *Oxidus* Cook, 1911					
21	*Oxidus gigas* (Attems, 1953)	+				
	Genus *Tonkinosoma* Jeekel, 1953					
22	*Tonkinosoma jeekeli* Nguyen, 2010		+			
	Genus *Tylopus* Jeekel, 1968					
23	*Tylopus hilaroides* Golovatch, 1984			+		
24	*Tylopus roseiparatega* Nguyen, 2012			+		
	Family Opisotretidae					
	Genus *Eutrichodesmus* Silvestri, 1910					
25	*Eutrichodesmus* sp.1	+	+			
26	*Eutrichodesmus* sp.2	+	+			
	Family Pyrgodesmidae					
27	Pyrgodesmidae sp.		+			
	Family Cryptodesmidae					
	Genus *Trichopeltis* Pocock, 1894					
28	*Trichopeltis* sp.	+				
	CHILOPODA					
	ORDER SCOLOPENDROMORPHA					
	Family Scolopendridae					
	Genus *Otostigmus* Porat, 1876					
29	*Otostigmus scaber* Porat, 1876	+	+			
	Genus *Scolopendra* Leach, 1815					
30	*Scolopendra subpinipes* Leach, 1815			+		+
	Family Scolopocryptopidae					
	Genus *Scolopocryptops* Newport, 1845					

31	*Scolopocryptops rubiginosus* Koch, 1878			+	
32	*Scolopocryptops spinicaudus* Wood, 1862			+	
	ORDER GEOPHILOMORPHA				
	Family Mecistocephalidae				
	Genus *Mecistocephalus* Newport, 1843				
33	*Mecistocephalus* sp.1			+	+
34	*Mecistocephalus* sp.2			+	
	Family Geophilidae				
	Genus *Geophilus* Leach, 1814				
35	*Geophilus* sp.	+	+		
	ORDER LITHOBIOMORPHA				
	Family Lithobiidae				
	Genus *Lithobius* Leach, 1814				
36	*Lithobius* (*Monotarsus*) sp.1			+	+
37	*Lithobius* (*Monotarsus*) sp.2			+	
	ORDER SCUTIGEROMORPHA				
	Family Scutigeridae				
	Genus *Thereuopoda* Verhoeff, 1904				
38	*Thereuopoda longicornis* Fabricius, 1783	+	+		
	Total	**20**	**18**	**16**	**7**

Table A2. Species diversity of spiders in four study areas

	Family	Species	Bac Me	Phia Oac-Phia Den	Cham Chu	Nam Xuan Lac
1	Agelenidae	*Malthonica* sp. 1		x		
2		Malthonica sp. 2				x
3		*Platocoelotes* sp. 1			x	
4	Araneidae	*Agalenatea* sp. 3				x
5		*Agalenatea* sp. 4				x
6		*Araneus blaisei* Simon, 1909	x			
7		*Araneus gratiolus* Yin *et al.*, 1990	x			
8		*Araneus quadratus* Clerck, 1757	x			
9		*Araneus tonkinus* Simon, 1909	x			
10		*Araneus* sp.1	x	x	x	
11		*Araneus* sp.2		x		
12		*Agalenatea* sp. 1		x		
13		*Agalenatea* sp. 2		x		
14		*Argiope aemula*			x	

15		*Argiope pulchella* Thorell, 1881	x			
16		*Cyclosa bifida* (Doleschall, 1859)	x			
17		*Cyclosa centrodes* (Thorell 1887)	x			
18		*Cyclosa insulana* (Costa, 1834)	x			
19		*Cyclosa gulinensis* Xie *et al.*, 1995	x			
20		*Cyclosa* sp. 1	x	x		
21		*Cyclosa* sp. 2	x	x		
22		*Cyclosa* sp. 3		x		
23		*Cyrtarachne* sp. 1		x		
24		*Cyrtarachne* sp. 2		x		
25		*Cyrtophora moluccensis* (Doleschall, 1857)	x			
26		*Gasteracantha fornicata*		x	x	x
27		*Gasteracantha orbweaver*		x	x	x
28		*Gasteracantha hasselti* Koch, 1837	x		x	
29		*Gasteracantha cancriformis* (Linnaeus, 1758)	x			
30		*Gibbaranea* sp. 1				x
31		*Larinia* sp. 1		x		
32		*Neoscona theisi* (Walckenaer, 1841)	x			
33		*Parawixia* sp.	x			
34		*Zygiella* sp. 1		x	x	
35	Clubionidae	*Clubiona japonicola* Bösenberg & Strand, 1906	x			
36		*Clubiona sp.*1	x	x		
37		Clubiona sp.2		x		
38		*Clubiona* sp. 3				x
39	Corrinidae	*Oedignatha* sp. 1			x	
40	Gnaphosidae	*Gnaphosa kompirensis* Bösenberg & Strand, 1906	x			
41	Linyphiidae	*Bathybantes floralis* Tu, &. Li, 2006	x			
42		*Bathybantes* sp.	x			
43		*Erigone* sp. 1			x	
44		Linyphia sp. 1		x		

45		*Linyphia* sp.2	x			
46		*Neriene cavaleriei* Schenkel 1963	x			
47		*Neriene oxycera* Tu, &. Li, 2006	x			
48	Liocranidae	*Agraecina* sp.	x			
49	Lycosidae	*Pardosa birmanica* Simon, 1884	x			
50		*Pardosa* sp. 1		x	x	
51		*Pardosa* sp. 2	x			
52	Oxyopidae	*Oxyopes javanus* Thorell, 1887	x		x	
53		*Peucetia* sp. 1			x	
54		*Oxyopes* sp. 1		x		
55		*Oxyopes* sp. 2		x		x
56		*Oxyopes* sp. 3				x
57		*Oxyopes* sp. 4				x
58	Pholcidae	*Khorata* sp. 1	x		x	
59		*Phocus bifidus* Yao *et al.*, 2015 (cf.)	x			
60		*Phocus phalangioides*			x	
61		*Phocus phami* Yao *et al.*, 2015	x			
62		*Spermophora* sp. 1		x		
63		Spermophora sp. 2		x		
64	Salticidae	*Bavia annamita* Simon, 1903	x		x	
65		*Burmattus pococki* (Thorell, 1895)	x			
66		*Carrhotus coronatus* (Simon, 1885)	x			
67		*Carhotus sanio* (Thorell,1877)	x			
68		*Carhotus* sp. 1			x	
69		*Chinattus parvulus* (Banks, 1895)	x			
70		*Chinattus tibialis* Zabka, 1985	x			
71		*Epeus* sp. 1		x		
72		*Euoprys* sp. 1			x	
73		*Evacha fravocincta* (Koch, 1846)	x			
74		*Evacha* sp. 1				x

75		*Habrocestoides* sp.	x			
76		*Harmochirus brachiatus*		x		
77		*Irura longiochelicera*		x		
78		*Menemerus bivittatus*			x	
79		*Mymarachne formicaria*	x			
80		*Myrmarachne maxillosa* (C. L. Koch, 1846)	x			
81		*Myrmarachne melanocephala* MacLeay, 1839	x			
82		*Mymarachne* sp. 1		x		
83		*Mymarachne* sp. 2		x	x	
84		*Mymarachne* sp. 3		x		
85		*Mymarachne* sp. 4		x		
86		*Mymarachne* sp. 5		x		
87		*Phintella bifucilinea* (Bosenberg et Strand, 1906)	x			
88		*Phintella debilis* (Thorell, 1891)	x			
89		*Phintella versicolor*		x	x	
90		*Phintella vittata* (Koch, 1846)			x	
91		*Phintella* sp. 1	x			x
92		*Ptocasius strupifer* Simon, 1901	x			
93		*Ptocasius* sp. 1		x		x
94		*Rhene albigera*		x		
95		*Rhene rubigera* (Thorell, 1887)	x			
96		*Rhene sp.* 1		x	x	x
97		*Rhene sp.* 2		x	x	x
98		*Synagelides palpalis* Zabka, 1985	x		x	
99		*Telamonia festiva* Thorell, 1887	x			x
100		*Telamonia* sp. 1			x	
101		*Thiania bhamoensis* Thorell, 1887	x			
102		*Thiania* sp. 1		x		x
103		*Thiania sp. 2*				x
104		*Thrandina* sp.	x			

105	Sicarridae	*Hickmania* sp. 1	x			
106		*Hickmania sp. 2*				x
107	Sparassidae	*Heteropoda* sp. 1	x		x	
108		*Heteropoda venatoria* Linnaeus, 1767	x			
109	Telimidae	*Telema* sp.	x		x	
110	Tetragnathidae	*Tetragnatha maxillosa* Thorell, 1895	x			
111	Theridiidae	*Theridion blaisei* Simon, 1909	x			
112		*Theridion pictum* (Walckenaer, 1802)	x			
113		*Theridion* sp. 1		x	x	
114	Theridiosomatidae	*Alaria* sp. 1	x			
115	Thomisidae	*Ebrechtella* sp. 1		x		
116		*Ebrechtella* sp. 2		x		
117		*Ebrechtella* sp. 3		x		
118		*Ebrechtella* sp. 4				x
119		*Ebrechtella* sp. 5				x
120		*Misumena* sp. 1		x		
121		*Misumena* sp. 2		x		
122		*Misumena* sp. 3		x		x
123		*Misumena* sp. 4				x
124		*Synema* sp. 1		x		
125		*Thomisus* sp. 1		x		
126		*Thomisus* sp. 2		x		
127		*Xysticus nebulo* Simon, 1909	x			
128	Uloboridae	*Miagrammopes* sp. 1			x	x
129		*Octonoba sybotides* Bösenberg & Strand, 1906)	x			
130		*Zosis geniculatus* (Olivier, 1789)	x			
131	Zoropsidae	*Zoropsis* sp.	x			

Table A3. Species diversity of collembolans in four study areas

No.	Species	Phia Oac – Phia den						Cham Chu														Bac Me								Nam Xuan Lac		
								ĐH		VQN		ĐCT		ĐCC		RTN		RT		TC		RTN		RT		TC		NN				
		815 m	1200 m	1300 m	1500 m	1600-1700 m	>1800m	M	K	M	K	M	K	M	K	M	K	M	K	M	K	M	K	M	K	M	K	M	K	RTN	RĐV	Ngô
I	**Family Hypogastruridae**																															
1	*Hypogastrura manubrialis*										+	+	+				+															
2	*Xenylla humicola*						+	+	+					+		+				+										+		
3	*Ceratophysella denticulata*						+	+			+					+		+	+	+		+	+							+		
4	*C. paraliguladorsi*																					+										
5	*C. succinea*																										+					
6	*Ceratophysella* sp.$_1$																+	+	+	+												
7	*Xenylla humicola*																						+	+			+	+	+			
8	*Acherontiella sabina*									+												+	+	+		+	+	+	+			
9	*Choreutinula* sp.	+				+																										
II	**Family Onychiuridae**																															
10	*Protaphorura hortensis*																							+								
11	*P. tamdaona*																					+	+	+	+	+	+	+	+			
12	*P. yodai*							+																	+		+					
13	*Protaphorura* sp.		+				+			+	+					+		+	+						+		+					
14	*Onychiurus* sp.	+	+	+		+	+			+	+		+			+							+				+		+			
III	**Family Odontellidae**																															
15	*Odontella pseudolamellifera*															+	+															
IV	**Family Neanuridae**																															
16	*Brachystomella parvula*		+	+			+	+		+			+	+			+						+	+	+	+	+	+			
17	*Friesea sublimis*			+				+	+		+	+		+			+	+	+	+		+	+	+	+	+	+	+	+			
18	*Pseudachorutella asigillata*			+												+																
19	*Pseudachorutella* sp.		+													+		+														
20	*Pseudachorutes subcrassus* Tullberg																						+									
21	*Neanura* sp.$_1$																							+								
22	*Lobellina* sp.$_1$											+																	+			
23	*Vitronura giselea*																					+			+		+	+				
24	*Vitrorura* sp.	+	+																													
25	*Vietnura* sp.		+																													
26	*Deuterobella* sp.		+							+						+	+	+	+	+												
27	*Paralobella* sp.$_1$																						+				+	+				
28	*Paralobella* sp.$_2$																								+							
V	**Family Isotomidae**																															
29	*Folsomides americanus*									+																		+				
30	*Folsomides exiguus*										+	+				+	+			+		+	+	+	+	+	+	+	+	+		+
31	*Folsomides parvulus*		+				+				+					+												+				+
32	*Folsomina onychiurina*	+	+	+		+										+	+	+	+	+				+		+				+	+	
33	*Isotomiella minor*									+						+						+		+		+	+					+
34	*Proisotoma muscicola*							+								+	+	+	+													
35	*Proisotoma submuscicola*			+	+			+	+	+	+	+	+	+		+	+	+	+	+		+	+	+	+	+	+	+	+	+		+
36	*Cryptopygus thermophilus*	+	+	+		+	+	+	+	+		+	+				+				+	+	+	+	+	+	+	+	+			
37	*Isotoma* sp.						+																									
38	*Isotomodes pseudoproductus*							+	+		+	+					+	+	+	+		+				+		+				
39	*Isotomurus palustris*							+	+	+							+				+			+			+	+				
40	*I. cf. prasinus*																						+	+			+		+			
41	*I. punctiferus*							+	+				+				+				+	+		+	+			+	+			
VI	**Family Entomobryidae**																															
42	*Entomobrya lanuginosa*							+	+		+	+	+				+	+	+	+		+	+	+	+	+	+	+	+			
43	*Entomobrya muscorum*			+								+										+	+	+	+	+		+	+			
44	*Entomobrya* sp.$_1$	+		+	+	+	+																									
45	*Entomobrya* sp.$_2$	+	+	+		+				+	+		+			+	+					+		+	+		+	+	+	+	+	
46	*Entomobrya* sp.$_3$		+																													
47	*Sinella coeca*	+	+	+			+	+	+		+						+					+	+	+	+		+	+				+
48	*Sinella pseudomonoculata*			+			+			+	+	+	+			+	+	+	+			+	+	+	+	+	+	+	+			
49	*Homidia glassa*										+					+	+			+	+								+			
50	*Homidia sauteri sinensis*			+			+				+					+	+			+	+											
51	*H. socia*																+	+	+	+		+	+		+							
52	*Homidia subcingula*			+		+					+						+					+			+				+			
53	*Homidia* sp.	+	+		+																											
54	*Pseudosinella alba*						+																									
55	*P. immaculata*											+	+			+						+	+	+	+	+		+	+			
56	*Pseudosinella octopunctata*		+	+	+					+	+					+	+	+	+	+		+	+		+				+	+		
57	*Lepidocyrtus (L.) cyaneus*	+	+			+				+	+		+			+	+			+	+								+			

58	*L. (L.) lanuginosus*																									+	+						
59	*Lepidocyrtus (L.) simsim*																							+						+	+		
60	*L. (Asc.) aseanus*																+							+			+						
61	*L. (Ascocyrtus) cinctus*										+						+						+		+								
62	*L. (Asc.) concolourus*									+						+	+			+	+												
63	*Lepidocyrtus (Asc.) dahlii*			+												+	+					+	+	+	+	+	+	+					
64	*L. (Asc.) medius*																+																
65	*L. (Acrocyrtus) heterolepis*																+										+						
66	*Lepidocyrtus* sp.$_1$	+	+	+			+																							+	+		
67	*Lepidocyrtus* sp.$_2$		+																														
68	*Lepidocyrtus* sp.$_3$		+																														
69	*Lepidocyrtus (Lepidocyrtus)* sp.$_1$										+	+				+									+	+			+				
70	*Lepidocyrtus (Ascocyrtus)* sp.$_1$																						+										
71	*Willowsia mesothoraxa*																													+			
72	*Willowsia* sp.1																																
73	*Dicranocentrus indicus*	+	+	+	+	+	+			+	+		+			+	+					+	+	+	+		+	+	+				
VII	**Family Neelidae**																																
74	*Megalothorax minimus*			+			+									+						+		+	+		+	+	+				
VIII	**Họ Cyphoderidae**																																
75	*Cyphoderus javanus*	+						+			+					+	+					+	+	+	+	+	+	+	+		+		
IX	**Family Paronellidae**																																
76	*Salina celebensis*			+			+									+													+				
77	*Salina* sp.																									+					+		
78	*Callyntrura tamparuliana*															+																	
79	*Callyntrura* sp.$_1$															+																	
X	**Family Tomoceridae**																																
80	*Tomocerus* sp.$_1$															+																	
XI	**Family Sminthurididae**																																
81	*Sminthurides aquaticus*		+		+	+	+					+			+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+
82	*S. bothrium*											+			+		+	+		+	+						+						
83	*Sminthurides* sp.$_1$															+																	
84	*Sphaeridia pumilis*		+			+							+			+	+	+		+		+	+	+	+	+	+	+	+				
85	*Sphaeridia zaheri*	+	+	+		+	+	+	+	+	+	+				+	+	+		+	+			+	+			+	+	+	+	+	+
XII	**Family Katiannidae**																																
86	*Sminthurinus victorius*																+																
87	*Sminthurinus* sp.$_1$															+	+					+				+	+						
XIII	**Family Arrhopalitidae**																																
88	*Arrhopalites sp.*					+																											
XIV	**Họ Bourletiellidae**																																
89	*Deuterosminthurus* sp.	+	+	+	+											+						+		+					+	+			
XV	**Family Sminthuridae**																																
90	*Sphyrotheca boneti*											+				+																	
91	*Sphyrotheca macrochaeta*		+	+		+	+						+			+	+	+	+	+				+	+								
92	*S. nepalica*															+																	
93	*Sphyrotheca* sp.$_1$																															+	
XVI	**Family Dicyrtomidae**																																
94	*Calvatomina antenna*				+	+				+						+	+					+	+		+	+	+	+	+		+	+	
95	*Calvatomina scutellina*						+																									+	
96	*Calvatomia tuberculata*															+	+					+	+	+			+	+	+				+
97	*Calvatomina* sp.			+																													
	A total of species	**15**	**25**	**24**	**8**	**15**	**21**	**15**	**19**	**18**	**23**	**16**	**14**	**4**	**2**	**43**	**41**	**19**	**14**	**21**	**10**	31	30	32	32	24	33	30	36	10	11	9	
		46						**66**														63								20			

Table A4. Species diversity of nematods in four study areas

Locality / Species	Cham Chu	Bac Me	Phia Oac – Phia Den	Nam Xuan Lac
ORDER DORYLAIMIDA PEARSE, 1942				
Family Aporcelaimidae Heyns, 1965				
Genus *Aporcelaimellus* Thorne, 1965				
A. krygeri Ditlevsen, 1928	+			
A. obtusicaudatus (Bastian, 1865) Altherr, 1968	+	+	+	+
A. obscurus Thorne & Swanger, 1936	+	+	+	+
Genus *Sectonema* Thorne, 1930				
S. buccociliatum Alvarez-Ortega et al., 2016		+	+	
Sectonema sp1	+			
Family Qudsianematidae Jairajpuri, 1965				
Genus *Allodorylaimus* Andrassy, 1986				
Allodorylaimus sp1	+			
Genus *Mylodiscus* Thorne, 1939				
M. nanus Thorne, 1939	+	+	+	+
Genus *Crassolabium* Yeates, 1967				
C. aenigmaticum Vu et al., 2010	+	+		
Genus *Labronema* Thorne, 1939				
L. neopacificum Rahman, Jairajpuri, Ahmad & Ahmad, 1987	+	+	+	
L. glandosum Rahman, Jairajpuri, Ahmad & Ahmad, 1987	+	+	+	
Labronema sp1	+			
Genus *Discolaimus* Cobb, 1913				
D. major Thorne, 1939		+	+	+
Discolaimus sp1	+			
Family Tylencholaimidae Filipjev, 1934				
Genus *Tylencholaimus* De Man, 1876				
T. teres Thorne, 1939	+	+	+	+
Tylencholaimus sp1	+			
Family Belondiridae Thorne, 1939				
Genus *Axonchium* Cobb, 1920				
A. cf. *labiatum* Thorne, 1939	+	+	+	+

A. cf. *shamimi* Baqri & Khera, 1976	+			
A. thoubalicum Dhanachand & Jairajpuri, 1981	+	+	+	+
Genus *Belondira* Thorne, 1939				
B. murtazai Siddiqi, 1968	+			
Genus *Oxybelondira* Ahmad and Jairajpuri, 1979				
O. paraperplexa Ahmad & Jairajpuri, 1978	+			
Genus *Dorylaimellus* Cobb, 1913				
D. vietnamicus Gagarin & Nguyen, 2003		+		
Family Dorylaimidae De Man, 1876				
Genus *Dorylaimus* Dujardin, 1865				
D. stangnalis Dujardin, 1845	+	+	+	+
Genus *Mesodorylaimus* Andrassy, 1959				
M. lutosus Gagarin & Vu Thanh, 2005	+			
Genus *Prodorylaimus* Andrassy, 1959				
P. longicaudatoides Altherr, 1968		+		
Family Leptonchidae Thorne, 1935				
Genus *Proleptonchus* Lordello, 1955				
P. aestivus Lordello, 1955	+			
Genus *Tyleptus* Thorne, 1939				
T. projectus Thorne, 1939	+	+		
Family Nordiidae Jairajpuri & Siddiqi, 1964				
Genus *Longidorella* Thorne, 1939				
L. xenura Khan & Siddiqi, 1963	+			
Genus *Oriverutus* Siddiqi, 1971				
Oriverutus sp1	+	+	+	
Oriverutus sp2	+		+	
Oriverutus sp3				+
Genus *Rhyssocolpus* Andrassy, 1971				
R. iuventutis Andrássy, 1971	+			
Genus *Thornedia* Husain & Khan, 1965				
T. opisthodelphis (Jairajpuri, 1968) Siddiqi, 1982	+	+		
Family Mydonomidae Thorne, 1964				
Genus *Dorylaimoides* Thorne and Swanger, 1936				
D. arcuicaudatus Baqri & Jairajpuri, 1969	+	+		

D. micoletzkyi (de Man, 1921) Thorne & Swanger, 1936		+	+	+
D. microamphidius Ahmad & Mushtaq, 2004	+	+		
ORDER MONONCHIDA JAIRAPURI, 1969				
Family Mononchidae Filipjev, 1934				
Genus *Clarkus* Jairajpuri, 1970a				
C. papillatus (Bastian, 1865) Jairajpuri, 1970		+	+	+
C. sheri (Mulvey, 1967) Jairajpuri, 1970		+	+	
Clarkus sp.		+	+	
Genus *Coomansus* Jairajpuri & khan, 1977				
C. ouinnensis (Yeates, 1992) Andrassy, 1993	+	+		
C. parvus (de Man, 1880) Jairajpuri et Khan, 1977	+	+	+	+
C. venezolanus (Loof, 1964) Jairajipuri & Khan, 1977	+			
Coomansus sp1	+	+		
Genus *Prionchulus* Cobb, 1916				
P. bogdanowiczi Susulovsky & Winiszewska, 2006	+	+	+	
P. mordax Susulovsky & Winiszewska, 2006			+	
P. muscorum Dujardin, 1845	+	+	+	+
*P. punctatus (*Cobb, 1917)			+	
P. vescus Eroshenko, 1975	+	+	+	+
Genus *Parkellus* Jairajpuri, Tahseen & Choi, 2001b				
P. tuyenquangensis Vu et al., 2021	+			
P. hagiangensis Vu et al., 2021		+		
Parkellus sp3			+	
Family Iotonchidae Jairajpuri, 1969				
Genus *Iotonchus* Cobb, 1916				
I. basidontus Clark, 1960		+	+	+
I. chantaburensis Buangsuwon & Jensen, 1966	+	+	+	
I. clarki Mulvey & Jensen, 1967		+		

I. indicus Jairajpuri, 1969	+	+		
I. parabasidontus Mulvey & Jensen, 1967	+	+	+	+
I. paratrichodorus Siddiqi, 2001	+	+	+	+
I. risoceiae Carvalho, 1955	+	+		+
I. singaporensis Ahmad, Baniyamuddin & Jairajpuri, 2006	+	+	+	+
I. transkeiensis Buangsuwon & Jensen, 1966	+	+	+	
Genus *Iotonchulus* Andrassy, 1993b				
I. longicaudatus (Baqri, Baqri & Jairajpuri, 1978) Andrassy, 1993			+	
Genus *Jensenonchus* Jairajpuri & Khan, 1982				
J. sphagni (Brzeski, 1960) Loof & Winiszewska, 1993			+	
Family Mylonchulidae Jairajpuri, 1969				
Genus *Mylonchulus* (Cobb, 1916) Atherr, 1953				
M. aequatiroalis Orselli & Vinciguerra, 2007	+			
M. amurus Khan & Jairajpuri, 1979		+	+	
M. apapillatus Khan & Jairajpuri, 1979		+	+	
M. contractus Jairajpuri, 1970		+		+
M. dentatus Jairajpuri, 1970		+	+	
M. doliolaimus Andrassy, 1992	+			
M. hawaiiensis Cassidy, 1931	+			
M. index (Cobb, 1906) Cobb, 1917	+	+		+
M. lacustris Cobb, 1915	+	+		+
M. minor (Cobb, 1893) Andrássy, 1958	+	+	+	
M. mulveyi Jaraijpuri, 1970	+	+	+	+
M. oceanicus Andrassy, 1986	+	+	+	+
M. polonicus Stefanski, 1915	+			
M. sigmaturus (Cobb, 1917) Altherr, 1953	+	+	+	+
Genus *Actus* Baqri & Jairajpuri, 1974				
A. salvadoricus Baqri & Jarajpuri, 1974	+	+	+	+
A. *hagiangensis* Vu et al., 2020		+		
Family Anatonchidae Jairajpuri, 1969				
Genus *Miconchus* Andrassy, 1958				
M. aquaticus Khan & al., 1978	+	+	+	+

M. baeticus Jimenez-Guirado, Alhama & Guitierrez, 1997		+		+
M. citri Khan, Ahmad & Jairajpuri, 1978	+			
M. dalhousiensis Jairajpuri, 1969		+	+	+
M. digiturus Cobb, 1893	+			
M. kansaensis Mulvey & Dickerson, 1970	+			
M. studeri Steiner, 1914	+	+	+	
M. thornei Mulvey & Jensen, 1967	+	+	+	
M. triodontus Buangsowon & Jenen, 1966	+	+		+
Genus *Monileonchus* Siddiqi, 2015				
M. egregius (Andrassy, 1993) Siddiqi, 2015			+	
Genus *Parahadronchus* Mulvey, 1978				
P. shakili (Jairajpuri, 1969) Mulvey, 1978			+	
Family Cobbonchidae Jairajpuri, 1969				
Genus *Cobbonchus* Andrassy, 1958				
Cobbonchus sp3			+	
In total	**62**	**57**	**47**	**30**

Appendix 2. Images of several species recorded or recently described from four research areas.

Myriapods:

Spiders:

Synaglides palpalis

Phintella vittata

Gasteracantha fornicate

Gasteracantha hasselti

Gasteracantha orbweaver

Rhene sp.2

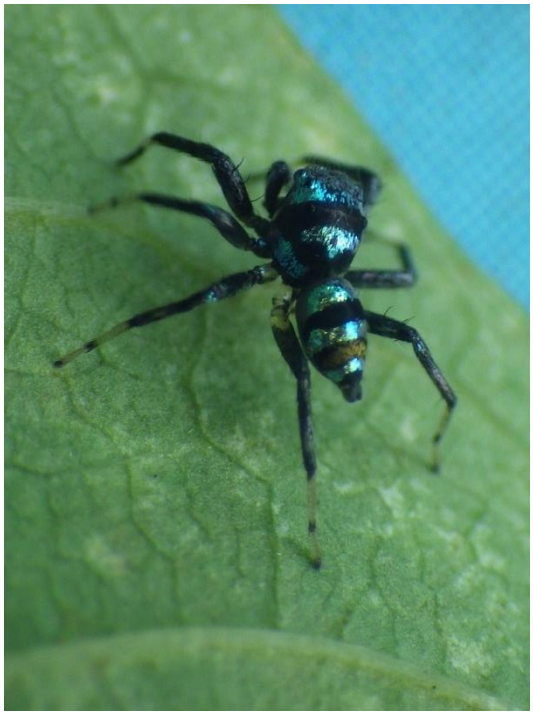
Oxyopes javanus

Phintella versicolor

Telema sp.1

Heteropoda sp.1

Mymarachne maxillosa



Phintella vittata

Phintella debilis

Phintella bifurcilinea

Carrhotus sanio

Thiania bhamoensis

Telamonia festiva

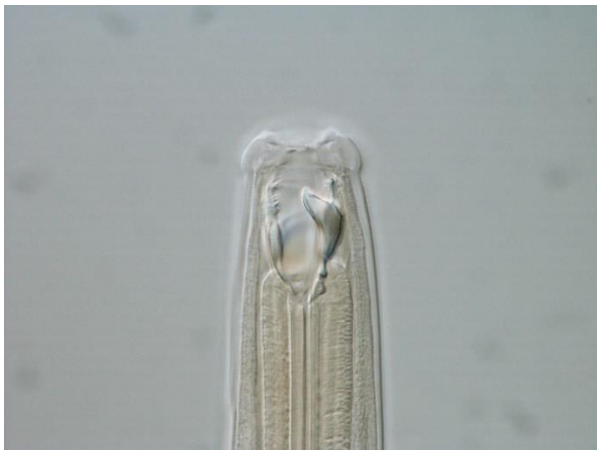
Synagelides palpalis

Phocus bifidus

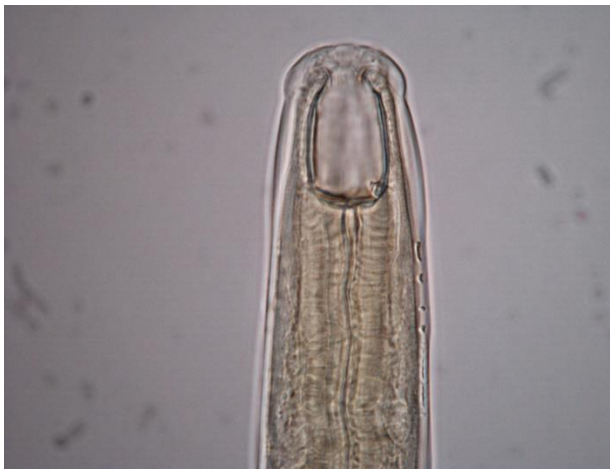
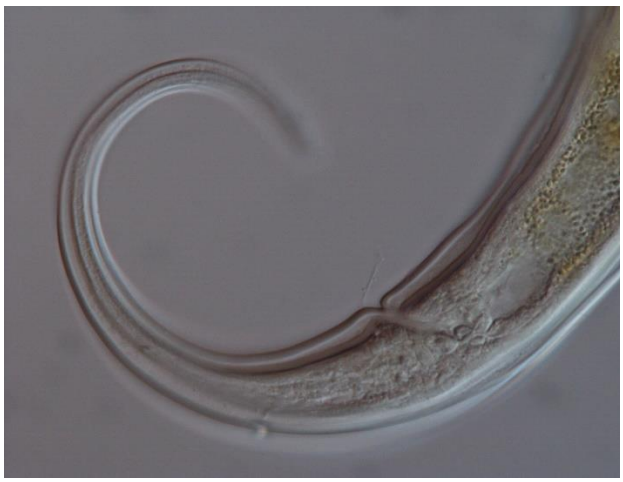
Heteropoda sp.

Nematods

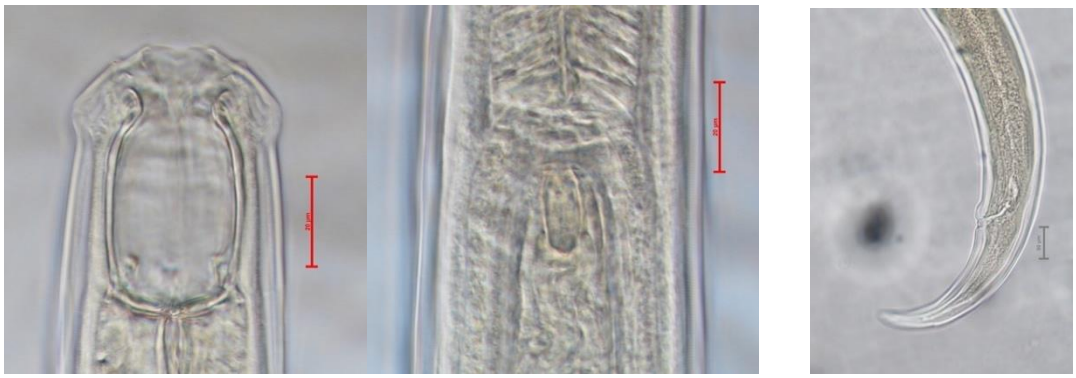

Prionchulus bongdanowiczi (head and tail region)




Mylonchulus oceanicus (head and tail region)

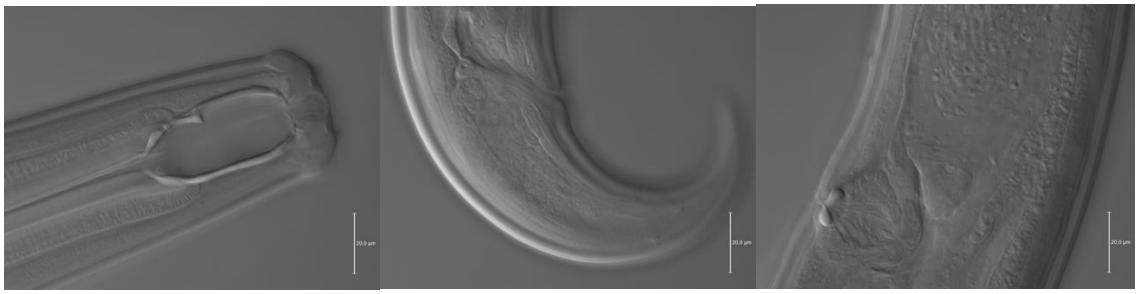



Iotonchus paratrichurus (head and tail region)



Miconchus dahouldsiensis Jairajpuri, 1969
A: Head; B: Oesophagous-intestine; C: Tail

Miconchus baeticus Jimenez-Guirado, Alhama & Gutierrez, 1997
A: Head. region; B: Tail region; C: Vulva region



Parkellus sp.
A: Head region; B: Tail region; C: Vagina region

Collembolans

Salina celebensis (Schaffer, 1898)

Willowsia mesothoraxa Nguyen, 2001

Homidia socia Denis, 1929

Isotomurus punctiferus Yosii, 1963

Sphyrotheca macrochaeta Nguyen, 1995

Dicranocentrus indicus Bonet, 1930

Lepidocyrtus (Ascocyrtus) dahlii Schaffer 1898