Study on soil biology in Vietnam - achievements and challenges

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Abstract:

The article introduces the achievements and challenges in the research on the soil biology of Vietnam. It is focussed on microfauna, mesofauna and macrofauna, including families of arachnids (Arachnida), chilopods (Chilopoda), diplopods (Diplopoda), insects (Insecta), oligochaetes (Oligochaetes), and nine orders. Until present, the soil fauna diversity of Vietnam is known to have 1,809 species and subspecies, belonging to 687 genera and subgenera, and 195 families and subfamilies. The number of soil animal species identified have decreased in the following order: (1) Araneida: 491 > (2) Oribatida: 320 > (3) Hymenoptera: Formicidae: 307 > (4) Oligochaeta: 212 > (5) Diplopoda: 136 > (6) Collembola: 132 > (7) Isoptera: 101 > (8) Chilopoda: 71 > (9) Scorpionida: 39.

Basing on the study of the oribatid mites (Oribatida) fauna, and the study results obtained during the period from 1977 until now, it also proposes further research directions on the soil biology of Vietnam as followings: (i) Study the biodiversity of soil organisms, (ii) Study ecology and function of soil organisms, (iii) Study of soil organisms contributes to the conservation and sustainable management of the environment and soil ecosystems, and (iv) Study soil organisms as indicators of environmental climate change in Vietnam.

Keywords: ***achievements, challenges, further research, soil fauna, Vietnam.***

Classification number: *3.4*

Introduction

Vietnam has been regarded as one of the 16 countries containing the highest biodiversity values in the World. The discovery of a large animal, the Sao la (*Pseudoryx nghetinhensis*) in 1993 from Vietnam, has received great attention not only from scientists but also from public media, globally (*World Conservation Monitoring Centre, 1992*). This forest-dwelling bovine, Saola, Vu Quang ox, or Asian bicorn, also, infrequently, is one of the world's rarest large mammals, found only in the Annamite Range of Vietnam and Laos.

The above-mentioned example of Saola is about a large mammal; and how about the animal communities that live in the soil of Vietnam? Soil biology is the science of the study of microbial and faunal activity and ecology in soil. Soil life, soil biota, soil fauna or edaphon is a collective term that encompasses all organisms that spend a significant portion of their life cycle within a soil profile or at the soil-litter interface. Generally, soil animals are ranged according to their size as microfauna, mesofauna, macrofauna and megafauna, with 20-200 µm, >0,2-2,0 mm, >2,0-20,0 mm and >20,0 mm, respectively *(wikipedia.org/wiki/Soil_biology*). The studies of soil animals in Vietnam were firstly carried out by Thai Tran Bai and his colleagues in the 1970-1980s of the last century [1]. As a result, it is found that Vietnam's soil fauna is extremely diverse and has a great biodiversity. In general, our understanding about the soil animals of Vietnam are not enough and still insufficient [2-6].

This paper introduces the achievements and challenges in research on the soil fauna of Vietnam. It is focussed on soil microfauna, mesofauna and macrofauna such as arachnids (Arachnida), chilopods (Chilopoda), diplopods (Diplopoda),

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insects (Insecta), and oligochaetes (Oligochaetes) [7, 8]. Basing on the case study of the oribatid mites (Oribatida) fauna, it also proposes further research directions for soil biology to address climate environment change in Vietnam [9].

Soil fauna diversity in Vietnam

Spiders (Arachnida: Araneida)

Vietnam's spider (Arachnida: Araneida) fauna was first undertaken by Simon (1886, 1903, 1904 & 1909) and Hogg (1922). After that, there has been a break for over 60 years until Zabka (1985) reported his results on taxonomy of Salticidae species, in which 51 species and 8 genera were described as new for science. Hereafter and Ono (1999, 2002, 2003, 2004a & b) described 4 new species for science of the family Liphistiidae, and 11 new species for science of the family Zodariidae. Peng and Li (2003) reported new localities of 13 species of jumping spiders, including one that was described as a new species for science. Tu and Li (2004 & 2006) did a primary report on the family Linyphiidae from Vietnam with 7 new species for science and 4 new records. Grismado and Ramizez (2004) described one new Zodariidae species. Jager and Vedel (2005) also reported one Sparassidae species from Vietnam. In the time between 2009 and 2015, 53 new species of spiders (Lin, Pham & Li, 2009; Liu, Li & Pham, 2010; Zhang, Li & Pham, 2013; Yao, Pham & Li, 2015; Pham, 2015) were recorded. A total of 205 spider species are recorded only in Vietnam so far, of which 78 species were reported by Simon (1886, 1903, 1904 & 1909), 2 species by Walckenaer (Simon, 1909), 1 species by Gunther (Simon, 1909), and 10 species by Hogg (1922); and the rest of the species were reported in recent years (after Pham Dinh Sac 2015 [10]).

At present, 491 spider species (Arachnida: Araneida) belong to 219 genera and 43 families are known from Vietnam (Table). It is probably that many of them are endemic, and further study on spider fauna, not only from Vietnam but also from other Asian Southeast countries, particularly Laos and Cambodia, is needed to be carried out.

Scorpions (Arachnida: Scorpionida)

After Vu Quang Manh (2008), Vu Quang Manh & Nguyen Dang Thin (2009) firstly presented a list of 17 species and sub-species of scorpions belonging to five families and seven genera, known in Vietnam at that time. They were as follows: I. Family BUTHIDAE C.L. Koch, 1837: (1) *Isometrus maculates* (DeGeer, 1778), (2) *Isometrus vittalus* Pocock, 1900, (3) *Lichas mucrotus* (Fabricius, 1798); II. Family CHAERILIDAE Pocock, 1893: (4) *Chaerilus celebensis* Pocock, 1894, (5) *Chaerilus truncatus* Karsch, 1879, (6) *Chaerilus variegatus* Simon, 1877, (7) *Chaerilus variegatus variegatus* Simon, 1877; III. Family ISCHNURIDAE Simon, 1879: (8) *Liocheles austrasiae* (Fabricius, 1775); IV. Family SCORPIONIDAE Latreille, 1802: (9) *Heterometrus laoticus* Couzigin, 1981, (10) *Heterometrus patersii* (Thorell, 1876), (11) *Heterometrus patersii patersii* (Thorell, 1876), (12) *Heterometrus spinifer* (Ehrenberg, 1828), (13) *Heterometrus spinifer spinifer* (Ehrenberg, 1828), and (14) *Heterometrus liurus* (Pocock, 1897); and V. Family SCORPIOPIDAE Kraepelin, 1905: (15) *Euscorpiops kaftani* (Kovarík, 1993), (16) *Scorpiops montanus* Karsch, 1879, and (17) *Scorpiops oligotrichus* Fage, 1933. Among them, *Euscorpiops kaftani*, recorded in the Cuc Phuong National Park by Kovarik, in 1993, is an endemic one. Vu Hong Quang (1996), Vu Hong Quang, Vu Quang Manh, Le Xuan Hue (1996), have made an important contribution to scorpion control and management (after Vu Hong Quang 1996 [11]; Vu Quang Manh, Nguyen Dang Thin 2009 [12]).

In recent years, the Vietnam's fauna of scorpions (Arachnida: Scorpionida) have being been investigated actively by Phan Dinh Sac and his collaborators, with descriptions of many species that are new for science (After Lourenço, Dinh-Sac Pham, 2010; Lourenco, Pham Dinh Sac, 2015; Dinh Sac Pham, Thi Hang Tran, Wilson R. Lourenço, 2017) [13]. At present, 39 scorpion species belong to 12 genera and 8 families have been recorded in Vietnam (Table).

Oribatid mites (Arachnida: Oribatida)

The investigation on the oribatid mites (Acari: Oribatida) of Vietnam started in 1967, with identifications of 33 oribatid species recovered from Vietnam. All were new for the fauna of Vietnam, and included 29 species and 4 genera that were new for science (Balogh & Mahunka, 1967). In addition to the first research done by Hungarian Balogh and Mahunka (1967), very important contributions to the knowledge of the oribatid mites of Vietnam were conducted by other foreign authors, including those of Rajski, Szudrowicz (1974), Golosova (1983, 1984), Golosova, et al. (1985), Jeleva, Vu (1987), Zonev, Vu (1987), Mahunka (1987, 1988, 1989), Behan-Pelletier (1989), Pavlichenko (1991, 1994), Stary (1993), Krivolutsky, Vu and Phan (1998) (after Vu Quang Manh, 2015b [9]; Krivolutzkij, Vu, Phan, 1998 [14]).

In 1986, the research work of Vu Quang Manh titled '*Faunal - Ecological Studies on oribatid mites (Acarina:*

Oribatei) community in Northern Vietnam' defended successfully at the Sofia University St. Kliment Ohridski (Bulgaria), for a PhD title. In this work, the author has identified 73 oribatid species from northern Vietnam, including 39 that were recorded as new for the fauna of Vietnam and 7 species described as new for science [15]. In the monograph entitled '*Fauna of Vietnam T. 21. Acari: Oribatida*', the author has included 150 Oribatid species and subspecies known to be found in Vietnam, including 44 species, which represent new records for the fauna of Vietnam [16].

In the base of the studies carried out in Vietnam during the period of 1979 until 2014, and based on the oribatid materials obtained throughout the country, it is found that the oribatid fauna of Vietnam is represented by 320 species (including four subspecies) belonging to 163 genera, 64 families (including two subfamilies) and 30 super families. It is highly diversified, with a high number of species with limited distribution; 34.68% of the total number are probably endemic species. One hundred and fifty-five species, representing 48.44% of the total oribatid fauna, were recorded for the first time as part of the fauna of Vietnam (Table). The oribatid fauna of Vietnam occupies 3.09% (320 vs. 10,342 species), 13.05% (163 vs. 1,249 genera) and 38.0% (62 vs. 163 families) of the World oribatid fauna [9, 16-20].

Recently, the Russian colleague Sergey G. Ermilov and his foreign collaborators have made an important contribution to the knowledge of the oribatid mite fauna of the Southeast and Southwest of Vietnam. Ermilov (2015) introduces a list of 535 oribatid mites (Acari: Oribatida) species of Vietnam, from 222 genera and 81 families [21]. However, some of their oribatid specimens have been obtained by unofficial lines, and Ermilov rarely collected materials by himself in the field. Some of their data on the geographical locations, names of locations and natural conditions of Vietnam have been obtained from illegal sources [22]. Particularly, the administrative maps of the socialist republic of Vietnam in their publications were presented wrongly, lacking islands and the island regions [21, 23, 24]. Therefore, the data on Vietnam's oribatid mites given by the Russian colleague Sergey G. Ermilov must be checked and revised carefully before consulting them [21]. Even so, although lacking knowledge of Vietnam's nature, this is an encouraging attempt by the Russian colleague on the study of oribatid mites of Vietnam, and it confirms the importance of studying about soil animals in Vietnam.

Centipedes (Myriapoda: Chilopoda)

In 2013, on the base mainly of the literature, the centipede (Chilopoda) fauna of Vietnam was introduced by Tran, Le, Nguyen [25]. As a result, a total of 71 species belonging to 26 genera and 13 families of four orders, namely Scolopendromorpha, Geophilomorpha, Lithobiomorpha and Scutigeromorpha, has been registered from Vietnam (Table). Four genera, *Tonkinodentus, Alluropus, Anopsobiella* and *Megalacrus*, are monotypic, and twenty-two species as well as subspecies are known only in Vietnam.

Millipedes (Myriapoda: Diplopoda)

In 2004, the millipede (Diplopoda) fauna of Vietnam was firstly reviewed by Enghoff, Henrik, Golovatch and Nguyen Duc Anh (2004) (after Enghoff, et al., 2004 [26]). As a result, a list of 136 millipede species belonging to 74 genera and 28 families were introduced (Table).

Springtails (Insecta: Collembola)

Being one of the main components of soil microarthropods (Microarthropoda), springtails or collembolans as well as oribatid mites are subject of numerous research works in almost every region all over the world. In Vietnam, the study on the collembolans fauna are insufficient [2, 3, 17].

Faunal-ecological studies on collembolans fauna have been carried out continuously by Vietnamese specialists [27-29]. Untill the present, the collembolan fauna (Apterygota: Collembola) of Vietnam are represented by 132 species belonging to 62 genera and 18 families (Table).

Ants (Insecta: Hymenoptera)

The ant fauna (Hymenoptera: Formicoidea: Formicidae) of Vietnam was firstly investigated by Bingham (1903), Santchi (1920) and Karawajew (1935). Based on their study results, the ant fauna of Vietnam was recorded to have about 160 species. The recent studies of Dlussky and Radchenko (1988), Radchenko (1993) and Bui Tuan Viet (2002a, 2002b, 2005) have introduced the ant fauna of Vietnam with 307 species recorded, belonging to 74 genera and 9 subfamilies (Table) (after Viet Bui Tuan, 2005 [30]).

Termites (Insecta: Isoptera)

Bathellier, in 1927, firstly studied Indochina's termite fauna (Blattodea: Isoptera), including Cambodia, Laos, and Vietnam. After this study, the termite fauna of North and South Vietnam have been investigated by Nguyen Duc

Kham (1969) and Nguyen Tan Vuong (1997). Vu Van Tuyen (1982) is one of the Vietnamese leading specialists on termites and has contributed great achievements in termite control (1994, 2004, 2010) (after Nguyen Duc Kham, et al., 2007 [31]).

In the study by Q.M. Vu, H.H. Nguyen, R. Smith (2007) on the termites (Isoptera) of Xuan Son National Park, a lowland and lower mountain evergreen and limestone forest in northern Vietnam, 15 species in 8 genera and 2 families were recorded. Termitidae was the dominant family with 6 genera and 12 species. The genus *Odontotermes* with five, contained the largest number of species. Five species were new records for northern Vietnam: *Odontotermes maesodensis* Ahmad, 1965, *Nasutitermes ovatus* Fan, 1983, *Pericaptitermes latignathus* (Holmgren, 1913), *Pericaptitermes nitobei* Shiraki, 1909 and *Bulbitermes laticephalus* Ahmad, 1965. The inventory included eight fungus-growing species: *Macrotermes barneyi* Light, 1924, *Ma. annandalei* (Silvestri, 1914), *O. yunnanensis* Tsai et Chen, 1963, *O. hainanensis* Light, 1924, *O. formosanus* Sharaki, 1909, *O. maesodensis* Ahmad, 1965, *O. graveli* (Silvestri, 1914) and *Microtermes pakistanicus* Ahmad, 1965. Five species, *M. barneyi*, *O. yunnanensis*, *O. hainanensis*, *O. formosanus* and *M. pakistanicus*, occurred in all habitat types. Six species identified are considered special pests because their activities weaken earthen structures. They are as follows: *M. pakistanicus, M. barneyi*, *M. annandalei*, *O. yunnanensis*, *O. hainanensis* and *O. formosanus* (after Vu, Nguyen, Smith, 2007 [32]).

Up to 2007, Nguyen Duc Kham, et al. have presented a list of 101 termite species known from Vietnam, belonging to 33 genera and four families [31] (Table).

Earthworms (Annelida: Oligochaeta)

Vietnam's earthworm fauna was firstly investigated by Edmond Perrier (1872 & 1875) with a description of *Perionyx excavatus* Perrier, 1872, and then with the second species *Amynthas juliani* (Perrier, 1875). Additionally, earlier there was a record of 2 species, namely *Metaphire posthuma* (Vaillant, 1868) (as *Perichaeta affinis* Perrier, 1872) and *Pheretima houlleti*.

Recently, from studies of Thai (1985) through today (T. Tung Nguyen, D. Nguyen Anh, T.T. Nguyen Binh, Robert J. Blackemore, 2016), Vietnam's earthworm fauna has been recorded with 212 species, belonging to 24 genera and 8 families [33, 34].

The oribatid mites (Acari: Oribatida) fauna of Vietnam

Introduction

The case study of the oribatid mites (Acari: Oribatida) fauna of Vietnam has been carried out during the period of 1977 until now [9]. The investigation on the oribatid mites (Acari: Oribatida) of Vietnam started in 1967, with identifications of 33 oribatid species recovered from Vietnam. All were new for the fauna of Vietnam, and included 29 species and 4 genera that were new for science (Balogh & Mahunka, 1967). The study results obtained indicated that oribatid mites of Vietnam are very diverse, and they have a bioindicator potential (Vu, 1990, 2000; Vu, et al., 1985, 1987, 1995, 2002; Vu, et al., 2010, 2011, 2012, 2013; Dao, Vu, 2010, 2013; Nguyen, Vu, 2011, 2012, 2013, [2, 5, 14-16, 18-20]).

Ecological studies based on the oribatid mite community structure have also been conducted according to landscape, altitudinal zonations, soil and habitat type, and season. They were carried out in a number of national parks (NP) Xuan Nha (province of Son La), NP Xuan Son (Phu Tho), NP Tam Dao (Vinh Phuc), NP Cuc Phuong (Ninh Binh), NP Ba Vi (Ha Noi), NP Cat Ba (Hai Phong), in uplands and the Delta of the Hong river, NP Ben En (Thanh Hoa), NP Phong Nha - Ke Bang (Quang Binh), as well as in some sites in Central and Southern Vietnam (Vu, 2004, 2006, 2008; Vu, et al., 2002, 2003, 2009; Vu, Nguyen, 2000; Dao, Vu, 2011; Ermilov, Anichkin, 2013; Minor, Ermilov, 2015 [2, 7, 8, 15, 17-20, 23, 24]).

In general, the studies on the Oribatid mites of Vietnam can be divided into 3 main periods as follows:

1. 1967-1986: This is the period when a total of 73 species have been recorded from 33 known species. In 1967, 33 oribatid species of Vietnam were identified (Balogh & Mahunka, 1967) (after Vu Quang Manh, 2015b [9]). All these species were recorded as new for Vietnam, including 29 species and 4 genera new for science. In 1980, Vu Quang Manh found that, the soil arthropods, Oribatida and Collembola, are much diversified and still poorly known in Vietnam. This author has identified 73 oribatid species of northern Vietnam, including 39 species recorded new for the Vietnam's fauna, and 7 species new for science.

2. 1987-2007: This is the period when a total of 150 species have been recorded from 73 known species. In 2007, in his study titled '*Fauna of Vietnam T. 21. Acari: Oribatida*' Vu Quang Manh presented 150 oribatid species known in Vietnam, with 44 species recorded new for the

fauna.

3. 2008-2014: This is the period when a total of 320 species have been recorded from 150 known species. The oribatid mite fauna of Vietnam has been recorded with 320 species and sub-species, belonging to 60 families and 163 genera. Among them, 111 species (34.68% of the total) have been described as new for science, and recorded only in Vietnam.

Results and discussions

Based on the studies carried out in Vietnam during the period of 1979 until now, and based on the oribatid materials obtained throughout the country [9], the most important results obtained are as follows:

1. Up to December 2014, the oribatid fauna of Vietnam is represented by 320 species (including four subspecies) belonging to 163 genera, 64 families (including two subfamilies) and 30 superfamilies. It is highly diversified, with a high number of species with limited distribution; 34.68% of the total number are probably endemic species. One hundred and fifty-five (155) species, representing 48.44% of the total oribatid fauna, were recorded for the first time for the fauna of Vietnam. The oribatid fauna of Vietnam occupies 3.09% (320 vs. 10,342 species), 13.05% (163 vs. 1,249 genera) and 38.0% (62 vs. 163 families) of the World oribatid fauna.

2. According to the number of families, genera, species and subspecies recorded, the systematic structure of the oribatid fauna of Vietnam is diverse. However, the number of genera per family, as well as the number of species and subspecies per genus, is not high. Almost all the families consist of one or 2-3 genera (42.2% and 39.1%, respectively, of the 64 families and subfamilies). A majority of the genera are represented by one species (68.10% of the 163 genera). Only one family is represented by more than 10 genera, i.e. the family Oppiidae Grandjean, 1954, with 23 genera. Only two genera are represented by more than 10 species: *Galumna* Heyden, 1826 and *Pergalumna* Grandjean, 1936, represented by 13 and 11 species, respectively. It is shown that *P. arboriseta* Jeleva et Vu is clearly a species distinct from *P. hirsutus* (Aoki 1961) (after Vu Quang Manh, 2015 [9]).

3. The zoogeographical structure of the oribatid fauna of Vietnam is highly diversified. It consists mostly of Oriental species represented by 60.3% (193 species out of 320 species recorded). Other zoogeographical elements represented are Palaearctic-Oriental species (12.2%), cosmopolitan species (10.6%), Afrotropical (Ethiopical) species (6.9%), Australian-Oriental species (5.0%), Neotropical-Oriental species (3.8%), Nearctic-Oriental species (0.9%) and Pacific-Oriental species (0.3%). A substantial part of the oribatid fauna of Vietnam - 111 species, representing 34.68% - consists of species with distribution restricted only to the country. These are probably endemic species.

4. The oribatid fauna in Vietnam is grouped into three main zoogeographical regions. There are differences between these regions of the country, and even between different sub-regions of these three parts. The three main zoogeographical regions of Vietnam are the following: (A) The region between (I) Northwest, (II) Northeast, (IV) Red River Delta, (V) Red River Delta: NP Cat Ba Island, (VI) North Central; (B) The region between (III) Red River Delta: Uplands and (VII) Central North: NP Phong Nha - Ke Bang, and (C) The region between (VIII) Southern - Mekong River Delta: NP Bu Gia Map, (IX) Southern - Mekong River Delta: NP Cat Tien.

5. From the North to South of Vietnam, the distribution of the oribatid fauna can be divided into six zoogeographical zonations, as follows:

(i) Region between (I) Northwest and (II) Northeast (North Vietnam) of Vietnam, with eight characteristic oribatid species including (1) *Papilacarus arboriseta* (Jeleva et Vu, 1987), (2) *Nothrus baviensis* (Krivolutsky, 1998), (3) *Nothrus montanus* (Krivolutsky, 1998), (4) *Gibbicepheus baccanensis* (Jeleva et Vu, 1987), (5) *Leobodes monstruosus* (Jeleva et Vu, 1987), (6) *Perxylobates brevisetus* (Mahunka, 1988), (7) *Xylobates monodactylus* (Haller, 1884), and (8) *Scheloribates cruciseta* (Jeleva et Vu, 1987).

(ii) Region of Red River Delta (IV) (North Vietnam) of Vietnam, with four characteristic oribatid species including (1) *Kokoppia dendricola* (Jeleva et Vu, 1987), (2) *Perxylobates vietnamensis* (Jeleva et Vu, 1987), (3) *Scheloribates praeincisus* (Berlese, 1916), and (4) *Lamellobates ocularis* (Jeleva et Vu, 1987).

(iii) Region of NP Cat Ba Island (V) of the Red River Delta (North Vietnam) of Vietnam, with two characteristic oribatid species including (1) *Scheloribates laevigatus*, and (2) *Fissicepheus elegans* (Balogh et Mahunka, 1967).

(iv) Region between (III) the Uplands of the Red River Delta and (VII) NP Phong Nha - Ke Bang: Central North (North Vietnam and Central North Vietnam) of Vietnam, with four characteristic oribatid species including (1) *Tectocepheus cuspidentatus* (Knulle, 1954),

(2) *Austrachipteria phongnhae* (Ermilov et Vu, 2012), (3) *Scheloribates praeincisus* (Berlese, 1916), and (4) *Galumna kebangica* (Ermilov et Vu, 2012).

(v) Region of (VI) NP Ben En: North Central (North Central Vietnam) of Vietnam, with six characteristic species including (1) *Papilacarus benenensis* (Vu, Ermilov et Dao, 2010), (2) *Setoxylobates foveolatus* (Balogh et Mahunka, 1967), (3) *Perxylobates thanhhoaensis* (Ermilov, Vu, Trinh et Dao, 2010), (4) *Xylobates lophotricus* (Belese, 1904), (5) *Galumna tenensis* (Ermilov, Vu et Nguyen, 2011) and (6) *Pergalumna granulatus* (Balogh et Mahunka, 1967).

(vi) Region between (VIII) Southern - Mekong River Delta: NP Bu Gia Map and (IX) Southern - Mekong River Delta: NP Cat Tien (South Vietnam) of Vietnam, with eight characteristic oribatid species including (1) *Arthrodamaeus vietnamicus* (Ermilov et Anichkin, 2011), (2) *Acrotocepheus (Otocepheus) vietnamicus* (Ermilov et Anichkin, 2011), (3) *Unguizetes cattienensis* (Ermilov et Anichkin, 2011), (4) *Galumna levisensilla* (Ermilov et Anichkin, 2010), (5) *Galumna pseudokhoii* (Ermilov et Anichkin, 2010), (6) *Neogalumna seniczaki* (Ermilov et Anichkin, 2010), (7) *Pergalumna indistincta* Ermilov et Anickin, 2011, and (8) *Pergalumna yurtaevi* (Ermilov et Anickin, 2011).

6. The diversity analysis of oribatid communities in various habitat types shows that the most particular and distinctive communities are formed in natural forests; under agricultural intensification and in human-disturbed habitats these communities are changed, with communities in grasslands and shrubs occupying an intermediate position between natural forests and human-affected habitats. The habitat of the grasslands and scrubs can play the role of a transformational ecosystem for reestablishment of the soil oribatid mite community. A tendency for formation of two distinct oribatid communities in the two main soil types studied (alluvial and ferralitic) is detected. It is possible that the soil type plays a major role in determining the species composition of the oribatid communities. Three oribatid species, namely *Tectocepheus velatus* (Michael, 1880), *Scheloribates praeincisus* (Berlese, 1916) and *Lamellobates ocularis* (Jeleva et Vu, 1987), are the most widespread and most persistent species of northern Vietnam. They can be considered as bioindicators of disturbed soil ecosystems.

Future research direction for soil fauna in Vietnam

Recently, the major soil animal groups that have been studied in Vietnam include nine orders (1) spiders (Araneida), (2) scorpions (Scorpionida), (3) oribatid mites

Table. Soil fauna diversity by number of species, genera and families.

Taxa animal classes and orders	Number of species & subspecies	Number of genera & subgenera	Number of families & subfamilies	Total
i.1. Spiders (Arachnida: Araneida)	491	219	43	491/219/43
i.2. Scorpions (Arachnida: Scorpionida)	39	12	8	39/12/8
i.3. Oribatid mites (Acari: Oribatida)	320	163	64	320/163/64
ii.4. Centipedes (Myriapoda: Chilopoda)	71	26	13	71/26/13
iii.5. Millipedes (Myriapoda: Diplopoda)	136	74	28	136/74/28
iv.6. Springtails (Insecta: Apterygota: Collembola)	132	62	18	132/62/18
iv.7. Ants (Insecta: Hymenoptera: Formicidae)	307	74	9	307/74/9
iv.8. Termites (Insecta: Isoptera)	101	33	4	101/54/4
v.9. Earthworms (Annelida: Oligochaeta)	212	24	8	212/24/8
Total: 5 families and 9 orders	**1809**	**697**	**195**	1809/687/195

(Oribatida), (4) centipedes (Chilopoda), (5) millipedes (Diplopoda), (6) springtails (Collembola), (7) ants (Hymenoptera: Formicidae), (8) termites (Isoptera), and (9) earthworms (Oligochaeta). They belong to five animal classes, namely (I) Archnids (Arachnida), (II) Centipedes (Chilopoda), (III) Millipedes (Diplopoda), (IV) Insects (Insecta), and (V) Earthworms (Oligochaeta). Until this moment, the soil fauna diversity of Vietnam is known with 1,809 species and subspecies, belonging to 687 genera and subgenera, and 195 families and subfamilies (Table).

The number of soil animal species identified decreases in the following order: (1) Araneida: 491 > (2) Oribatida: 320 > (3) Hymenoptera: Formicidae: 307 > (4) Oligochaeta: 212 > (5) Diplopoda: 136 > (6) Collembola: 132 > (7) Isoptera: 101 > (8) Chilopoda: 71 > (9) Scorpionida: 39 (Table). The order mentioned above does not mean that the species diversity of those soil animal is different in soil ecosystems, but it is only in relation to the level of research of each soil animal group in Vietnam.

In general, our understandings on soil fauna of Vietnam are insufficient [2, 7, 8, 35, 36]. Therefore, further research on soil biology in Vietnam will include the following five main directions:

1. Study the biodiversity of soil organisms.

2. Study the ecology and function of soil organisms.

3. Study of soil organisms contributes to the conservation and sustainable management of the soil environment.

4. Study soil organisms as indicators of environmental climate change in Vietnam.

5. Study of soil organisms contributes to the training of soil biology specialists.

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