THE PAN-PACIFIC ENTOMOLOGIST
82(3):000–000, (2006)

The termites (Isoptera) of Xuan Son National Park, northern Vietnam

Quang Manh Vu[1,2,*], Hoang Hanh Nguyen[3], & Robert L. Smith[1]
[1]Department of Entomology, University of Arizona, Tucson, AZ 85721
[3]Hanoi Institute of Water Resources and Technology, Chua Boc Str., Dong Da, Vietnam

Abstract. Subterranean termite species, their habitat preferences and nest habits at Xuan Son National Park, a lowland and lower mountain evergreen and limestone forest in northern Vietnam, were investigated in 2002 and 2003. A total of 234 collections were obtained from 588 sampling sites, on 12 transects, among four different habitat types.

Fifteen species in eight genera and two families were recorded. Termitidae was the dominant family with six genera and 12 species. The genus *Odontotermes* with five species contained the most abundant 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. The scrubland/grassland habitat contained 14 species, forest habitats 12 species, cultivated lands eight species and residential areas contained only six species. In forest habitats 56.2% of sample plots yielded termites, in scrubland/grasslands 54.5%, 32% of plots on cultivated land produced termites and in residential habitats only 18% had termites. Six species identified are considered special pests because their activities weaken earthen structures: *M. pakistanicus, M. barneyi*, *M. annandalei*, *O. yunnanensis*, *O. hainanensis* and *O. formosanus*. Nesting patterns of surveyed species are noted with special attention to species that inhabit earthen structures.

Key Words. Termites, Isoptera, Vietnam, Xuan Son National Park.

Introduction

Termites are social insects that play the principal detritivorous role in tropical ecosystems. The Isoptera are especially important in soil formation processes because of their ability to utilize and recycle cellulose and because of the enormity of their biomass and numbers. In addition, tropical soil dwelling termites exert a profound effect on soil structure affecting many soil properties including friability, porosity, aeration, organic content and permeability and water storage capacity. In turn, the physical and chemical features of soil environment and its vegetation cover characteristics that will influence on the species composition, diversity, distribution, nesting and foraging habits of termites (Bathellier 1927, Lee & Wood 1971, Wood 1976, Collins 1983, Dibog et al. 1999, Eggleton et al. 2002).

The termite fauna of Vietnam is rich, ecologically diverse and exhibits broad habitat preferences. It includes a number of economically important species such as those that damage wooden structures and those whose nesting activities compromise the integrity of earthen river dikes and dams (Bathellier 1927, Harris 1968, Nguyen

* vuqm@email.arizona.edu
[2] Permanent Address: Center for Biodiversity CEBRED c/o Faculty of Agro-Biology, Hanoi University of Education, Xuan Thuy Str., Cau Giay, Vietnam; e-mail: vqmanh@vista.gov.vn

1976, Vu 1982). Little is known about the Vietnamese tropical forest termites, especially their nesting habits and their status as pests in northern part (Nguyen & Vu 1985, Nguyen 2003). In Vietnam especially the northern part of the country, river dikes are critically important infrastructures. They are essential for agricultural production of this region's communities. For thousands of years, hundreds of kilometers of river dikes have been maintained to control river flooding. These dikes are traditionally constructed from soil and soil dikes provide ideal habitat for some species of termites. Some of the dike inhabiting species seriously compromise the structural integrity of these constructs resulting in dike failure, flooding and disruption of agricultural and societal activities. Vu (1982) identified 16 termite species especially harmful to earthworks in Vietnam.

To date, there have been few surveys of insects, including termites in Xuan Son National Park. Termites were surveyed in the Phu Tho area, but these works did not cover the park (Nguyen 1976, Vu et al. 1993). Vu et al. (2001) produced a plant and animal resource management inventory of the Xuan Son National Park that included some data on termites.

Here we provide the results of a termite survey conducted during 2002–2003, with some additional work in 2005. The goals of this research were to survey termite species composition, distribution of the termites in four distinct habitats in the study area and to investigate nesting habits of potentially destructive species in the region of the park. We attempted also, to understand the biology of species recorded from the study area, especially those that inhabit the plain river dikes and dams. This part of the work was intended to focus on especially problematical groups and provides some knowledge that might eventually contribute to management strategies for species that damage human resources.

Materials and Methods

Study Area. The forested area of Xuan Son was included in Decision Number 194/CT by the Vietnamese Chairman of the Council of Ministers, which decree established a 4,585 ha nature reserve (1986). The status of the Xuan Son Forest Area was revised from nature reserve to national park in April of 2002. At present the Xuan Son National Park occupies an area 15,048 ha including a strict protection area 11,148 ha, a forest rehabilitation area 3,000 ha and an administration and service area 900 ha. The Park is surrounded by a buffer zone 18,639 ha. Xuan Son National Park is located in Thanh Son District, Phu Tho Province, northern Vietnam, at the extreme southeastern extent of the Hoang Lien Mountains, 45 km southwest of the confluence of the Red and Black Rivers. It is located on 21°03′–21°12′ N latitude and 104°51′–105°01′ E longitude. Elevations at Xuan Son are lower than elsewhere in the Hoang Lien Mountains. The closest point above 2,000 m is 40 km to the northwest. The park ranges from 200 m to 1,390 m above sea level at the summit of Mount Voi. The Park borders Hoa Binh and Son La Provinces. The forested area is located at the end of the Phu Luong Mountain chain. About 40% of the total land area is over 700 m in elevation. Cam Mountain, 1,140 m, is in the northwest and in the southwest is Voi Mountain with two peaks: Voi, at 1390 m and Ten, at 1,250 m. A soil mountain, i.e. the low one without rocky outcroppings, runs along the northeast at an elevation of from 600–700 m. This area contains the two main river systems, the Thang and Chieng.

The native vegetation types at Xuan Son are lowland and lower montane evergreen forest and lowland and lower montane limestone forest. The predominant soil type in the study region is feralite (acrisols), developed from sediments and limestone. Karst topography is found on 1,661 ha, an area representing about 30% of the park. Beds of limestone in the region contain a large number of caves and some of the caves contain rivers. The park is situated in the watershed or the Red River. Average annual temperature in this region is ca. 22.5°C, average annual rainfall is ca. 1,826 mm and the average humidity is ca. 86% (Bird Life International 2004). The study area is covered with trees, shrubs and herbs mainly of families Fagaceae, Sapotaceae, Magnoliaceae, Aceraceae, Ericaceae, Theaceae, Lauraceae. The study area is a slightly disturbed forest. Its tree canopy ranges from 35 to 55%, with average height of ecologically dominant trees about 13.0 m. All of our studied habitats are slightly disturbed, exhibit high plant biodiversity and contain a litter layer >5 cm deep. These habitats are actually natural forests, normally found at elevation of 600–900 m. The three other habitat types are normally distributed at elevations of 400–600 m. Grassland and scrub habitats are covered mainly with grass and shrubs but with some woody trees. These habitats include trees of families Rubiaceae, Euphorbiaceae, Caesalpiniaceae; and herbs and grasses mainly of families Poaceae, Asteraceae and Fabaceae. In these habitats the litter layer was thin, <5 cm deep. These habitats are not natural but are derived from forest loss. Our studied cultivated land is an agricultural field surrounding habitations with food and vegetable plants. These fields are generally annual monocultures with soil structure determined by human agricultural activity. The residential areas in our study contained homes, stables, gardens and some commercial structures.

Termite and Nest Sampling. A total of 588, 10 × 10 m plots were examined for evidence of termites or termite activity. The plots were established regularly at 50 m intervals along 12 transects situated to accommodate each distinctive habitat type. The compass bearing of each transect was selected to traverse the longest linear dimension of each irregularly shaped habitat parcel. Our sampling procedure involved chaining 50 m on the predetermined heading and then laying out each 100 m^2 plot with stakes and string. Once each plot was established we first examined the forest litter, then the soil surface and finally dead wood was examined. When termites were found, they were collected. If the plot contained a termite nest as evidenced by above ground structures, we excavated the nest as described below. Termite samples outside of the nests were taken from flight holes, ''flight waiting chambers'' (galleries near the surface containing alates prepared to depart the colony), granular soil piles and dead wood that contacted soil including dead tree trunks and fallen branches. We favored soldiers because of their value in species determination. Termites were examined in the field, then cleaned and preserved in ethyl alcohol, or in formaldehyde solution.

The presence of termite nests on the plots was evidenced by above ground structures. We collected termites from these structures by boring a 10–15 cm hole in the above ground portions of the nest with a knife. Swarming periods from March to July, provided us the opportunity for to collect large numbers of winged reproductive termites emerging from their nests. Normal swarming occurred from March through July. Subsurface nests were accessed by digging a 20–30 cm trench in selected promising areas of each plot in order to reach galleries and tunnels. If too few specimens were obtained initially, we refilled the trench with the excavated soil

and left the plot undisturbed for a minimum of 24 hrs. Upon our return, the excavated trenches typically contained numerous termites working to repair the nest. Both workers and soldiers could then be collected. When we were finished collecting from nests, we always filled the trench with excavated soil to assure nest stability for possible later sampling on each plot. We observed superficial subsurface nest structure and behavior of on plot nests by digging parallel vertical cuts of 100–200 cm deep and 100–200 cm long. The parallel trenches into the nests were 20 cm apart thus revealing the cross sections of nests.

Species Identification and Data Analyses. Taxonomic determinations were conducted at the Center for Termite Control at the Hanoi Institute of Water Resources and Technology, Vietnam. Determinations were made by consulting keys and descriptions from Bathellier (1927), Ahmad (1958, 1965 & 1968), Roonwal & Sen-Sarma (1960), Roonwal & Chhotani (1962), Roonwal (1969), Harris (1968), Thapa (1981), Li & Ping (1983), Thakur (1983), Li & Xiao (1989), Tho (1992), Huang et al. (2000), Nguyen et al. (2004). We calculated the frequency of occurrence of each species as a percentage of plots that contained that species, i.e. number of occurrences (I) divided by the total number of plots (N).

Results

Species Composition. Table 1 lists 15 termite species identified from the 234 samples collected in the research area. All of the species belong to two families: Termitidae and Rhinotermitidae; and eight genera: *Coptotermes and Reticulitermes* (Rhinotermitidae) and *Bulbitermes, Macrotermes, Microtermes, Nasutitermes, Odontotermes, Pericapritermes* (Termitidae). The family Termitidae comprised the major part of the termite fauna, with six genera and twelve species (ca. 80%). Among the six genera of the family Termitidae, *Odontotermes* is the richest recorded with five species. Another four genera, *Coptotermes, Bulbitermes, Microtermes, Nasutitermes* each contained only one species. Two species belonged to the genus *Pericaptitermes*. The family Rhinotermidae was represented by only two genera and three species.

Comparing our findings with the recent complete list of the known termite fauna from Vietnam (Nguyen et al. 2004), we find that among the 15 species we identified from the Xuan Son National Park, were five species that are new records for the northern part of the country. These five species are *Odontermes maesodensis* Ahmad, 1965, *Nasutitermes ovatus* Fan, 1983, *Pericaptitermes latignathus* (Holmgren 1913), *Pericaptitermes nitobei* Shiraki 1909 and *Bulbitermes laticephalus* Ahmad, 1965. Among the termites identified from Xuan Son National Park, 8 of 15 (ca. 53%) were fungus-growing species. These eight species are *Macrotermes barneyi* Light, 1924, *Ma. annandalei* (Silvestri, 1914), *Odontermes yunnanensis* Tsai et Chen, 1963, *O. hainanensis* Light, 1924, *O. formosanus* Sharaki, 1909, *O. maesodensis, O. graveli* (Silvestri, 1914) and *Microtermes pakistanicus* Ahmad, 1965.

Distribution and Diversity. Table 1 provides the habitat distribution of the identified termite species. Among the fifteen identified species, five are widely distributed, having been recorded in all four studied habitat types. These are *Ma. barneyi, O. yunnanensis, O. hainanensis, O. formosanus* and *Mi. pakistanicus*, with a frequency of occurrence of ca. 8%, 7%, 5%, 3% and 6%, respectively. An analysis of termite species diversity showed that 14 of the identified species from the Xuan Son National Park occurred in grassland and shrub habitat, accounting for 93% of the

Table 1. Termite species and their distribution in the Xuan Son National Park.

		Forest		Grassland and scrub		Cultivated land		Resident area		Total	
	Families, Genera, and Species	I	I/N %	I	I/N %	I	I/N %	I	I/N %	I	I/N %
	Rhinotermitidae										
	Coptotermitinae:										
	1. *Coptotermes*										
1	*C. formosanus*	0	0	0	0	3	1.74	8	5.71	11	1.87
	Heterotermitinae:										
	2. *Reticulitermes*										
2	*R. aflaviceps*	6	4.96	4	2.58	0	0	0	0	10	1.70
3	*R. chinensis*	3	2.48	5	3.23	0	0	0	0	8	1.36
	Termitidae Macrotermitinae:										
	3. *Macrotermes*										
4	*M. barneyi*	22	18.18	8	5.16	15	8.72	2	1.43	47	7.99
5	*M. annandalei*	0	0	3	1.94	3	1.74	0	0	6	1.02
	4. *Odontotermes*										
6	*O. yunnanensis*	8	6.61	19	12.16	10	5.81	5	3.57	42	7.14
7	*O. hainanensis*	5	4.13	13	8.39	8	4.65	3	2.14	29	4.93
8	*O. formosanus*	3	2.48	5	3.23	5	2.91	3	2.14	16	2.72
9	*O. maesodensis*	2	1.65	2	1.29	0	0	0	0	4	0.68
10	*O. graveli*	0	0	7	4.52	5	2.91	0	0	12	2.04
	5. *Microtermes*										
11	*M. pakistanicus*	11	9.09	12	7.74	6	3.49	5	3.57	34	5.78
	Nasutitermitinae:										
	6. *Bulbitermes*										
12	*B. laticephalus*	1	0.83	2	1.29	0	0	0	0	3	0.51
	7. *Nasutitermes*										
13	*N. ovatus*	5	4.13	3	1.94	0	0	0	0	8	1.36
	Termitinae:										
	8. *Pericapritermes*										
14	*P. latignatlus*	1	0.83	1	0.65	0	0	0	0	2	0.34
15	*P. nitobei*	1	0.83	1	0.65	0	0	0	0	2	0.34
	Total species	12		14		8		6		15	
	Occurrence frequency	56.20%		54.48%		31.98%		18.57%		39.80%	

total number of identified species. The number of identified termite species recorded in the other habitats decreases gradually, from the forest habitat, 12 species or 80%, to cultivated land, eight species or 53%, to residential areas, six species or 40%. The frequency of occurrence of termites according to habitat differed from that of the species number. The average frequency of termite occurrence in the total study area was ca. 40%. The highest frequency of occurrence was found in forest habitat, representing ca. 56%. From there it decreased to ca. 54% in grassland and shrub, ca. 32% in cultivated land and ca.19% in residential areas.

Nesting Habits. Our study recorded six of harmful species to earthworks, as identified by Vu (1982), in the Xuan Son National Park: *Ma. barneyi, Ma. annandalei, O. yunnanensis, O. hainanensis, O. formosanus* and *Mi. pakistanicus*. These six species constitute ca. 40% of the total species identified from the Xuan Son area. Included is *O. hainanensis*, which has been recorded with the highest frequency of occurrence in the northern delta dikes and dams. On the basis of our direct field observations, together with Vu (1982), Nguyen (1997) and Nguyen (2003) works, the pest species recorded from Xuan Son National Park can divided into three main groups based on their patterns of nest construction and habits.

The first group includes only the fungus-growing species *Mi. pakistanicus*. This species normally builds shallow subterranean nests by excavating in the ground or the body of a dike. The nest always contained a main chamber, with diameter of ca. 20 cm connected to a number of surrounding small auxiliary tunnels typically not deeper than about 20 cm below the surface. This group, therefore, is not of great concern for soil foundations, dikes and dams.

The second group contains two species: *Ma. annandalei* and *Ma. barneyi*. Termites in this group build much larger and deeper nests than the first group. The main chambers of these nests are 50–80 cm in diameter and lie just below the surface. The surrounding tunnels can be very long, reaching hundred of meters. This termite group is highly destructive to earthen foundations, dikes and dams. These large, deep, complex nests can cause surface subsidence and create depressions in earthen structures above the termites' underground cavities. *Macrotermes annandalei* normally builds its nest above the soil surface, with only part of the nest underground. The above ground portions of these nests may reach several meters wide and high. The material used to build the mounds is transported from the lower soil layers, thus weakening the structure at depth.

The third group is comprised of three species in the genus *Odontotermes*, specifically *O. yunnanensis, O. hainanensis* and *O. formosanus*. These fungus growing termites normally build hypogenous dispersed nests by subsurface excavation. All *Odontotermes* species investigated build similar nests. In the plain area of the northern part of Vietnam, *O. hainanensis* is common and widely distributed (Vu 1982). A mature nest of *O. hainanensis* is composed of a main hemispherical chamber with a diameter of 30–60 cm, infrequently larger. This chamber is located below ground at a depth of one meter or more. The royal pair and the fungus gardens are found in the main chamber. There are many auxiliary chambers and tunnels distributed around the main chamber, with a diameters of 10–15 cm. The number of these auxiliary chambers and tunnels can reach into the hundreds. Due to these nesting habits this third termite group must be recognized as the most serious threat to the integrity of earthen building foundations, dikes and dams in Vietnam.

Discussion

It is not clear to what extent the modest number of species recorded by us from Xuan Son National Park accurately represents the total termite fauna of the northern upland termite fauna of Vietnam. Our data is similar to that reported by Nguyen (1976); the low diversity may be due to the generally high elevation of the park. On the other hand, our sampling approach may have under represented certain species. However, by comparison, in one recent study of termite fauna from Ba Vi National Park, an area of about 11,400 ha, nearby but smaller than the Xuan Son, 41 termite species in three families and 15 genera were reported. These included 15 species first recorded from the northern part of Vietnam (Bui et al. 2003). This is a much larger number than what we encountered from the Xuan Son area during our study. Also the number of recorded termite species found in our study is relatively small compared with the rich assemblages recorded from other tropical rainforests such as those of other southeast Asian countries including Indonesia, Malaysia, Thailand, or of African forests in Cameroon and Nigeria, South America and Australia (Wood et al. 1982, Braithwaite et al. 1988, Constantino 1992, Inoue et al. 2001, Eggleton et al. 2002, Jone & Prasetyo 2002). The reasons for this poor species composition may be multiple. The habitats that we chose to sample in our study may not have been representative of all soil types, vegetation formations or forest types. Also, we did not sample at all elevations. A number of studies in Vietnamese tropical forests show that forest cover, soil types and elevation-caused climate differences play an important role in modifying soil microarthropod community structure, including termite diversity (Tsonev & Vu 1987, Vu & Nguyen 2000, Nguyen 2003, Vu & Nguyen 2004). The Xuan Son National Park encompasses elevations mainly from 300–700 m and about 40% of this total land area is distributed at a height over 700 m, including some mountains above 1,000 m (Bird Life International 2004). Future survey work should include stratified sampling at the higher and lower elevations and perhaps involve a finer grained recognition of habitat types. Furthermore, quadrate sampling may not be the best approach for documenting diversity. When the objective is to document diversity one should hunt for species using field experience and knowledge of species' habitat and niches.

Termite studies in the Malaysian rain forest, the tropical savanna and monsoonal rainforest of Australia, agri-silvicultural systems of southern Cameroon and in a dry evergreen forest of northeastern Thailand have all observed that, in both natural and in human-impacted forest, the cellulose substrate of litter and decayed wood is very important as a termite food resource and habitat (Collins 1983, Dibog et al. 1999, Inoue et al. 2001, Dawes-Gromadzki 2005). Our study area in the Xuan Son National Park was divided into four different types on the basis vegetation formations and land use: forest, grassland and scrub, cultivated land and residential areas. A similar tendency of varied termite species richness according to human land utilization was reported in recent data from Ba Vi National Park, from the Ha Tay province of northern Vietnam. This study revealed that termite species richness was highest in the secondary forest, followed by primary forest and least diverse in forest plantations (Bui et al. 2003). The study results of Brainthwaite et al. (1988) on the structure of termite communities in the Australian tropics also showed evidence that open forest habitats are richest in termite diversity.

We found that termite species richness and densities of termites differed with habitat type in our survey. Studies by Jones & Precetyo (2002) on termite community

structure in tropical forests of Indonesia, found that species composition and diversity of termite assemblages as well as the formation of communities consisting of different feeding and nesting groups are likely to influence pedological processes and patterns of forest litter turnover. The other important factors impacting distribution and species diversity of the termite community must be found in the physical and chemical features of the habitat. In tropical Australia, the contribution of termites to vegetation changes, nutrient cycles and pedological processes have been recognised in a number of studies (Lee & Wood 1971, Lobry de Bruyn & Conacher 1990, McGarry et al. 2000). However, little is known about the physical and chemical aspects of soils as termite habitat in Vietnam. In our study area, a balance as well as differentiations of pedobiological processes, in combination with human impacts, may be important, but apparently not the only factors influencing termite distribution and species richness.

Among the termites we identified were eight fungus-growing species. These species, through their feeding and nesting activities and with their rather wide distribution in the study area, may have considerable impact on soil formation and organic turnover as well as on the soil's microbiota. This view of the impacts of fungus-growing termite species is supported by a number of studies (Wood 1976, Collins 1983, Eggleton et al. 2002, Jones & Prasetyo 2002, Nguyen 2003). In addition, our study of nesting habit revealed that six species of earthen dike inhabiting termites were fungus-growing ones.

In several studies, Vu (1982), Nguyen (1997) and Nguyen (2000) have described a number of termite treatments for earthen dams and dikes of Vietnam. These authors indicated that it was difficult to detect newly built and deeply located small nests, which were initiated by winged termites from the surrounding area to infest the dikes. They also noted the enormous amounts of soil transported every year for construction and agricultural purposes that may represent a significant mechanism for importing termites as well as other soil arthropods (Nguyen & Vu 1985, Tsonev & Vu 1987, Vu et al. 1987, Nguyen 1997). The large volumes of imported earth to be used for building and rebuilding dikes are almost certainly an important source of destructive termite species. The Xuan Son area belongs to the upland and highland areas of northern part of Vietnam, from whence large quantities of soils are taken for a variety of construction purposes. As a consequence of this process, termites may be mechanically delivered both near and far. This might possibly explain why all of the destructive termite species recorded from the Xuan Son National Park are included in the list of economically important termites for the northern river dikes and dams of Vietnam. In other words, the destructive termites species recorded from the delta's dikes and dams may have originated from the northern upland and highland areas, which includes the Xuan Son forest region.

Acknowledgments

This study was supported partly by the Vietnam National Fundamental Program for Life Sciences and the Vietnamese Overseas Training Project 322. The publication was assisted partly by CP Alexander fund. Field work was conducted with collaboration of the Xuan Son National Park Management chaired by its Director, Mr. Tran Dang Lau.

The manuscript has been much improved during the visiting research of the first author at the University of Arizona, Tucson. He wishes to thank Dr. Vu V. T. and

Dr. Nguyen T. V., from the Center for Termite Research and Control, Hanoi Institute of Water Resources and Technology, for helpful comments and checking the termite scientific names. His thanks are due also to Christopher Deegan, a MSc. student, for corrections of the first English draft. Finally we thank two anonymous viewers and the subject Editor of the Pan-Pacific Entomologist, for their critical reviews of the manuscript.

Literature Cited

Ahmad, M. 1958. Key to Indo-Malayan termites. Part I. *Biology* 4(1):33–118.

Ahmad, M. 1965. Termites (Isoptera) of Thailand. *Bulletin American Museum Natural History* 131:1–114.

Ahmad, M. 1968. Termites of Malaysia. *Bulletin of the Department of Zoology University of the Panjab* 3:1–34.

Bathellier, J. 1927. Contribution a l'etude systematique et biologique des termites de l'Indo-Chine. *Faune Colonies Franc* 1:125–365.

Bird Life International. 2004. *Source Book of Existing and proposed protected Areas in Vietnam,* 2nd edition.

Braithwaite, R. W., L. Miller & J. T. Wood. 1988. The structure of termite communities in the Australian tropics. *Australian Journal of Ecology* 13:375–391.

Bui, C. H., V. Q. Nguyen & T. M. Nguyen. 2003. The results of investigation on the composition Termite (Isoptera) at Bavi National Park, Ha Tay province. *Vietnamese Journal of Biology* 25(2A):42–50. (in Vietnamese with English summary).

Collins, N. M. 1983. Termite populations and their role in litter removal in Malaysian rain forests, pp. 311–325. *In*: S. L. Sutton, T. C. Whitmore & A. C. Chadwick (Eds.). *Tropical Rain Forest, Ecology and Management*. Blackwell Scientific Publications, Oxford.

Constantino, R. 1992. Abundance and diversity of termites (Insecta. Isoptera) in two sites of primary rainforest in Brazilian. Amazonia. *Biotropica* 24:420–430.

Dawes-Gromadzki, T. Z. 2005. The termite (Isoptera) fauna of a monsoonal rainforest near Darwin northern Australia. *Australian Journal of Entomology* 44:152–157.

Dibog, L., P. Eggleton, L. Norgrove, D. E. Bignell & S. Hauser. 1999. Impacts of canopy cover on soil termite assemblages in an agrisilvicultural system in southern Cameroon. *Bulletin of Entomological Research* 89:125–132.

Eggleton, P., R. G. Davies, S. Connetable, D. E. Bignell & C. Rouland. 2002. The termites of the Mayombe Forest Reserve, Congo (Brazzaville): Transect sampling reveals an extremely high diversity of ground nesting soil feeders. *Journal of Natural History* 36:1239–1246.

Harris, W. V. 1968. Isoptera from Vietnam, Cambodia, Thailand. *Opuscula Entomlogica* 33:143–154.

Huang, F., Z. Ping, G. Li, S. Shu, X. He & D. Gao. 2000. *Fauna Sinica* 17, Beijing (In Chinese with English summary).

Inoue, T., Y. Takematsu, F. Hyodo, A. Sugimoto, A. Yamada, C. Klangkaew, N. Kirtibutr & T. Abe. 2001. The abundance and biomass of subterranean termites (Isoptera) in a dry evergreen forest of north-east Thailand. *Sociobiology* 37:41–52.

Jones, D. T. & A. H. Prasetyo. 2002. A survey of the termites (Insecta. Isoptera) of Tabalong District, South Kalimantan, Indonesia. *Raffles Bulletin of Zoology* 50:117–128.

Lee, K. E. & T. G. Wood. 1971. *Termites and Soils*. Academic Press, London, pp. 1–251.

Li, G. & Z. Ping. 1983. Four new species of the genus *Macrotermes* from south China (Isoptera. Termitidae. Macrotermiticaes), *Acta Entomologia* 8(2):183–195.

Li, G. & W. Xiao. 1989. Eight new species of the from Guangxi, China (Isoptera. Termitidae. Rhinotermitidae), *Acta Entomologia* 32(4):465–476.

Lobry de Bruyn, L. A. & A. J. Conacher. 1990. The role of termites and ants in soil modification. a review. *Australian Journal of Soil Research* 28:55–93.

McGarry, D., B. J. Bridge & B. J. Radford. 2000. Constrasting soil physical properties after zero and traditional tillage of an alluvial soil in the semi-arid subtropics. *Soil Tillage Research* 53:105–115.

Nguyen, D. K. 1976. *Termite (Isoptera) from the northern part of VietnamScience and Techniques Publishing House*. Hanoi, pp. 1–219. (in Vietnamese).

Nguyen, D. K. & V. T. Vu. 1985. *Termites and their control techniques*. Agricultural Publishing House, Hanoi, pp. 1–185. (in Vietnamese).

Nguyen, D. K., V. T. Le, T. V. Nguyen & V. Q. Nguyen. 2004. *Termite (Isoptera) fauna of Vietnam*. Science and Techniques Press, Hanoi. (in Vietnamese, in press).

Nguyen, T. V. 1997. *Termites (Isoptera) in the southern part of Vietnam and their control*. PhD thesis, Hanoi University of Education, pp. 1–185 (in Vietnamese).

Nguyen, V. G. 2000. The detection of termite-holes in earthen dams and other geotechnical investigation in Vietnam by Ground Penetrating Radar method (GPR), pp. 196–201. *In*: Q. M. Vu, *et al*. (Eds.), *Soil organism resources and sustainable development of soil ecosystem*. Agriculture Publishing House, Hanoi, pp. 1–304 (in Vietnamese with English summary).

Nguyen, V. Q. 2003. *Study on species composition and distribution of the termites from the genus Macrotermes (Isoptera, Termitidae) and bio-ecological characteristics of the species Macrotermes annandalei (Silvestri) from the northern part of Vietnam*. PhD thesis, Hanoi University of Natural Sciences, pp. 1–154 (in Vietnamese).

Roonwal, M. L. 1969. Measurement of termites (Isoptera) for taxonomic purposes. *Journal Zoological Society of India* 21(1):9–66.

Roonwal, M. L. & O. B. Chhotani. 1962. Termite fauna of Assam, Eastern India, *Proceedings National Institute Science* 28(4):281–406.

Roonwal, M. L. & Sen-Sarma. 1960. *Contribution to the systematics of Oriental termites*. Entomological Monograph Indian Country, Agricultural Research 1, pp. 1–147.

Thakur, M. L. 1983. A review of the family Macrotermitidae (Isoptera) from the Oriental region. *Oriental Insects* 17:35–73.

Thapa, R. S. 1981. Termites of Sabah (East Malaysia). *Sabah Forest Research* 12:1–374.

Tho, Y. P. 1992. Termites of Peninsular Malaysia, *Malayan Forest Records* 36:1–224.

Tsonev, I. & Q. M. Vu. 1987. Influence of some main natural and human impacts on the formation of the Oribatid community (Oribatei, Acarina) in the northern part of Vietnam. *Contemporary Achievements of the Bulgarian Zoology* BAS. Sofia:192–196 (in Bulg. with English summary).

Vu, Q. M., M. Jeleva & I. Tsonev. 1987. Oribatid Mites (Oribatei, Acarina) from the plain of the Red river in Vietnam, pp. 601–604. *In*: B. R. Striganova (Ed.). *Soil Fauna and Soil Fertility*. Nauka, Moscow. (in Russ. with English summary).

Vu, Q. M., V. T. Le & V. T. Vu. 1993. Study on Oribatid (Acari, Oribatei), Earthworm (Oligochaeta) and Termite (Insecta. Isoptera) community structures in the soils of Vietnam by application of the trellis diagram methods. *Vietnamese Journal of Biology* 15(4):4–11 (in Vietnamese with English summary).

Vu, Q. M. & T. T. Nguyen. 2000. Microarthropod community structures (Oribatei and Collembola) in the Tam Dao National Park, Vietnam. *Journal of Biosciences* 25(4):379–386.

Vu, Q. M., N. N. Le, D. N. Tran, D. T. Le & D. L. Tran. 2001. Biological resources from the Xuan Son Reserve, Thanh Son District, Phu Tho province. *Scientific Review*. Hanoi University of Education, 1:119–129 (in Vietnamese with English summary).

Vu, Q. M. & X. L. Nguyen. 2004. Soil microarthropod community structures (Microarthropoda) at different climatic altitudes from the Tam Dao National Part, Vietnam. *Vietnamese Journal of Agriculture and Rural Development* 3(39):409–410 (in Vietnamese with English summary).

Vu, V. T. 1982. *Termites (Isoptera) damaging dikes and dams in Vietnam and their management*. PhD thesis, Hanoi University, pp. 1–220 (in Vietnamese).

Wood, T. G. 1976. The role of termites (Isoptera) in decomposition processes, pp. 145–168. *In* J. M. Anderson & A. McFadden (Eds.). *The Role of Terrestrial and Aquatic Organisms in Decomposition Processes*. Blackwell Scientific Publications, Oxford.

Wood, T. G., R. A. Johnson, S. Bacchus, M. O. Shittu & J. M. Anderson. 1982. Abundance and distribution of termites (Isoptera) in a Riparian Forest in the Southern Guinea Savanna Vegetation Zone of Nigeria *Biotropica* 14:25–39.

Received 25 January 2006; Accepted 10 April 2006; Publication date.