

Species composition and damage levels of termites in three World Cultural Heritage sites: Complex of Hue Monuments, Hoi An Ancient Town, and My Son Sanctuary

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Abstract

Many of the historical constructions and relics in Vietnam have rapidly deteriorated due to different causes, including damage by termites which is considered one of the most important reasons. In this study, we conducted a survey to determine the species composition as well as assessing the damage caused by termites in three UNESCO World Cultural Heritage sites in central Vietnam: Complex of Hue Monuments, My Son Sanctuary, Hoi An Ancient Town. The survey yielded a total of 27 termite species (belonging to 12 genera, 7 subfamilies, 3 families) as follows: 25 species (12 genera, 7 subfamilies, 3 families) in the Complex of Hue Monuments, 5 species (2 genera, 2 subfamilies, 2 families) in Hoi An Ancient Town, and 16 species (8 genera, 6 subfamilies, 3 families) in My Son Sanctuary. Among these, we have determined six species as pest for historical construction in the Complex of Hue Monuments; five as pest in Hoi An Ancient Town, and one species, *Odontotermes angustignathus* as pest at My Son Sanctuary. According to our scale for determining damage levels to construction as caused by termites *Coptotermes gestroi* caused most damage in both the Complex of Hue Monuments and Hoi An Ancient Town, the damage levels caused by this species were 0.90 and 0.81 respectively.

Keywords: *Termite, pest species, damage level, Cultural Heritage*

Introduction

The Complex of Hue Monuments, Hoi An Ancient Town, and My Son Sanctuary, are UNESCO World Cultural Heritage sites which were recognized in 1993, 1999, respectively. Although being placed under protection, these heritage sites are still damaged by the harsh tropical climate (e.g. typhoons, flood) and by pests (most are insect species like termites). In the Complex of Hue Monuments and Hoi An Ancient Town, wooden material is the major component in the buildings or constructions, thus, termites (order Isoptera), feeding on cellulose material, are considered the main pests for these structures (Pinniger, 1989).

Until recently, pest management of termite-infested historical relics in Vietnam was mainly aimed for instant effects, by applying chemical insecticides without taking biological or ecological characteristics of termites and the extent of their damage into serious consideration. This situation has allowed termite re-invasion of structures, even in those just treated with chemical insecticides. In order to achieve better success in controlling termites, knowledge of termite species composition and

significantly harmful species is essential. However, the status of termites in these three World Heritage sites is still poorly known. Therefore, we conducted this study to determine species composition and the extent of damage caused by termites in these areas.

Materials and Methods

Our study was conducted at three World Cultural Heritages, namely the Complex of Hue Monuments, Hoi An Ancient Town, and My Son Sanctuary, from 2011 to 2013.

Study Site: The Complex of Hue Monuments is located from 16 °.00' to 16 °.48'N latitude and from 107°47'60" to 108°12'E longitude, with the size of 5 million square metres, in Hue city. Established during the early 19th century, the Complex of Hue Monuments includes Kinh Thanh (Capital City), for official administrative buildings; Hoang Thanh (Imperial City) for royal palaces and shrines; Tu Cam Thanh (Forbidden Purple City) for the royal residences; Dai Noi (Inner City), tombs, pagoda and some others historical architectural structures. The specific architectural characteristics of this place are brick walls and foundation, wooden pillars and roof.

Hoi An Ancient Town is located from 15°15'26" to 15°55'15"N latitude and from 108°17'08" to 108°23'10"E longitude, in Quang Nam province, next to the Thu Bon River. The river annually brings floods into Hoi An. The architectural structures in Hoi An was almost entirely made of wood. It combines traditional Vietnamese, Chinese, Japanese and also Western designs and architecture.

My Son Sanctuary is about 68 km away from Da Nang City to the south, located from 15° 45' to 15° 51'51"N latitude and from 108° 07' to 108° 57'31"E longitude. These are the remains of a series of 72 impressive tower-temples in 13 groups that were the religious and political capital of the Champa Kingdom for most of its existence. Almost all the temples were constructed using bricks except the "B1 tower", which is constructed from stones.

Collecting termites: Termites samples were collected in dry season (from March to May) and rainy season (from September to December). In the Complex of Hue Monuments, we investigated all components inside Hoang Thanh and four tombs outside. In Hoi An, we sampled in 178 houses on 9 streets. We also searched for arboreal termite damage along the streets. In My Son Sanctuary, we collected termites in temple groups A, B, C, D, G, H and E and the surroundings habitat.

Identification of termites: Termites samples were identified to species according to Ahmad (1958, 1965), Akhta (1974), Yupaporn *et al.* (2004), Nguyen Duc Kham *et al.* (2007).

Determining the damage level caused by termites: We determined the damage caused by termites in historical and civil structures according to the following criteria (Tables 1 and 2).

Table 1. Score for damage level of termites in historical structures

No	Criterion	Scores			
		None	Less	Medium	Critical
1	Damage to structural	0	1	2	3
2	Damage to interior	0	1	2	3
3	Damage to ornament	0	1	2	3
4	Damage to management instruments	0	1	2	3

Table 2. Score for damage level of termites in historical structures

No	Criterion	Scores			
		None	Less	Medium	Critical
1	Damage to structure	0	1	2	3
2	Damage to working facilities	0	1	2	3
3	Damage to living facilities	0	1	2	3
4	Damage to working products	0	1	2	3

The damage level by a termite species in a item works was calculated by the following formula: $HA = TC1 + TC2 + TC3+ TC4$ (HA : damage level in each item works; $TC1 \dots TC4$: score in each criterion)

The damage level by a species in one component construction of a heritage was calculated by the following formula: $HTB_A = (H_{A1} + H_{A2} + \dots + H_{Ai} + \dots + H_{An})/n$ (H_{Ai} : Damage level by species A in i item works ($i: 1, \dots, n$); HTB_A : Damage level by species in a construction; n : number of works in a construction.)

The damage level by a species in one heritage was calculated by the formula: $MH_A = HTB_A * T_A$

MH_A : Damage level by species A in one heritage; HTB_A : Damage level by species A in one component construction; T_A : percentage of item works which is damaged by species A

Results & Discussion

Species composition of termites in three heritages

We collected 406 specimens of termites from the three studied sites, and recorded a total of 27 species, belonging to 12 genera, 7 subfamilies, 3 families (Table 3). Most of the species belong to the family Termitidae (17 species, of 8 genera, 4 subfamilies, namely Macrotermitinae, Amitermitinae, Nasutermitinae, and Termitinae). The family Rhinotermitidae contained 7 species from 2 genera, *Coptotermes* and *Schedorhinotermes*. The family Kalotermitidae contained 3 species from 2 genera, *Cryptotermes* and *Neotermes*. In terms of the number of specimens collected, Rhinotermitidae was the most commonly encountered (48.03% of total number of specimens), followed by Termitidae (41.63%), and Kalotermitidae (10.34%).

Table 3. Percentage of termite species from three heritages

No	Species name	Percentage of specimens		
		Complex of Hue Monuments	Hoi An Ancient Town	My Son Sanctuary
	KALOTERMITIDAE	4.93	5.17	0.25
	Kalotermitinae	4.93	5.17	0.25
1	<i>Cryptotermes domesticus</i>	4.19	4.43	
2	<i>Cryptotermes</i> sp.		0.74	
3	<i>Neotermes koshunensis</i>	0.74		0.74
	RHINOTERMITIDAE	20.20	24.38	3.45
	Coptotermitinae	15.52	24.38	1.23
4	<i>Coptotermes ceylonicus</i>	1.23	5.91	0.74
5	<i>Coptotermes curvignathus</i>	0.25		
6	<i>Coptotermes emersoni</i>	1.97	5.91	0.49
7	<i>Coptotermes gestroi</i>	10.59	12.56	
8	<i>Coptotermes</i> sp1.	1.48		
	Rhinotermitinae	4.68		2.22
9	<i>Schedorhinotermes javanicus</i>	1.97		0.99
10	<i>Schedorhinotermes medioobscurus</i>	2.71		1.23
	TERMITIDAE	29.31		12.32
	Macrotermitinae	24.14		9.85
11	<i>Hypotermes makhamensis</i>	2.96		0.99
12	<i>Hypotermes sumatrensis</i>	1.48		0.49
13	<i>Odontotermes angustignathus</i>	4.19		1.97
14	<i>Odontotermes ceylonicus</i>	1.23		0.74
15	<i>Odontotermes hainanensis</i>	8.37		3.45
16	<i>Odontotermes formosanus</i>	1.48		0.00
17	<i>Odontotermes feae</i>	1.23		0.99
18	<i>Odontotermes mesodensis</i>	0.74		0.00
19	<i>Odontotermes proformosaunus</i>	2.22		0.99
20	<i>Macrotermes annandalei</i>	1.23		0.00
21	<i>Macrotermes serrulatus</i>	1.72		0.00
22	<i>Microtermes pakistanicus</i>	1.72		1.23
23	<i>Microtermes obesi</i>			0.49
	Amitermitinae	3.45		1.23
24	<i>Microcerotermes</i> sp.	1.48		0.00

25	<i>Globitermes sulphureus</i>	1.97		1.23
	Nasutitermitinae	1.72		1.23
26	<i>Nasutitermes matangensis</i>	1.72		1.23
	Termitinae	1.72		
27	<i>Termes propinquus</i>	1.72		
Total		54.43	29.56	16.01

The genus *Odontotermes* contained the highest number of species, 7) and accounted for 25.93% of the total number of species, followed by *Coptotermes* (5 species, 18.52%). Other 5 genera (*Cryptotermes*, *Schedorhinotermes*, *Hypotermes*, *Macrotermes*, and *Microtermes*), each contained 2 species; while the other 5 genera (*Neotermes*, *Microcerotermes*, *Globitermes*, *Termes* and *Nasutitermes*), contained 1 species each.

In terms of the numbers, *Coptotermes gestroi* had the highest number of specimens, accounting for 23.15% of the total number of specimens, followed by *Odontotermes hainanensis* (11.82%), *Coptotermes emersoni* (8.37%), *Cryptotermes domesticus*, *Cryptotermes ceylonicus* (7.88%), *O. angustignathus* (chiếm 6.19% tổng số mẫu) and others. *Coptotermes emersoni* and *C. gestroi* were also found at all three heritages.

Termites were more commonly encountered in the Complex of Hue Monuments, with 25 species, 12 genera, 7 subfamilies, 3 families that made up 54.43% of the total specimens. The most popular was *Coptotermes gestroi* (accounted for 10.59% of total specimens, 19.45% of total species in the Complex of Hue Monuments), the second was *Odontotermes hainanensis* (8.37%, 15,38 respectively), *Cryptotermes domesticus*, *Odontotermes angustignathus* (4.19%, 7.70 respectively). Species compositions were different in each component of this heritage: Minh Mang tomb had 14 species, Tu Duc tomb 13 species, Imperial City 8 species, Thieu Tri tomb 3 species, Khai Dinh tomb 2 species.

The habitat variation in the Complex of Hue Monuments resulted in the high species diversity as well as the distribution in each of the component relics. Each relic had their own specific architectural characteristics and habitat characteristics. Khai Dinh tomb was constructed in the side of mountain, main materials were concrete and stone, surroundings were narrow. These conditions lead to the poor number of species in this relic. It was the same in Thieu Tri tomb. Destroyed in Vietnam wars, Thieu Tri tomb has been restored with monotonic vegetation. It was not an appropriate environment for many termites. In contrast, the species of termites in the remaining three relics was more diverse because of wooden structural components and larger green surroundings. Even though, numbers of species in Dai Noi was lower than Tu Duc and Minh Mang tomb. The main reason is the position of Dai Noi, where is on a plain at low elevation.

In Hoi An Ancient Town, we encountered 5 species, belonging to 2 genera, *Cryptotermes* (Kalotermitidae: Kalotermitinae) and *Coptotermes* (Rhinotermitidae: Coptotermitinae). The number of species and specimens of *Coptotermes* (3 species) was larger than *Cryptotermes* (2 species).

Coptotermes gestroi is most frequently encountered in this area (12.56% of total specimens, 42.49% of the number of specimens in Hoi An Ancient Town), followed by *C. ceylonicus* and *C. emersoni* (5.91%, 19.99%, respectively), and *Cryptotermes domesticus* (4.43%, 14.49%, respectively).

In My Son Sanctuary, we encountered 16 species, belonging to 8 genera, 6 subfamilies, and 3 families. The family Termitidae contained 13 species, Rhinotermitidae 2 species (of a single genus, *Coptotermes*), and Kalotermitidae 1 species. *Odontotermes hainanensis* was the most commonly encountered species with 3.45% of the total specimens, followed by *O. augustignathus* (1.97%), *Microtermes pakistanicus* and *Schedorhinotermes medioobscurus* (1.23%). Other species contributed to less than 1% to the total number of specimens.

In Hoi An Ancient Town, the wood-feeding termites (*Coptotermes* and *Cryptotermes*) were dominate in the old wooden houses. However, the density of population in this town is high, as well as the flood state every year that are not advantagous for other termites, especially soil nesting species. In other hand, species in the family Termitidae dominated the My Son Sanctuary. That heritage was constructed from bricks and stones, which is not damaged much by termites and can be the main reason of this situation.

The damage level by termites in each heritage

The damage level by termites in Complex of Hue Monuments: By calculating the scores of damaging levels according to Table 1, we determined the 6 species that damaged the Complex of Hue Monuments. Species and the scores of damage level are shown in Table 4.

Table 4. Species and damage scores in Complex of Hue Monuments

No	Species	Damage scores					
		Dai Noi	Tu Duc tomb	Minh Mang tomb	Trieu Tri tomb	Khai Dinh tomb	Complex of Hue Monuments
1	<i>Cryptotermes domesticus</i>	0.31	0.13				0.21
2	<i>Coptotermes gestroi</i>	1.31	0.88	1.00	0.33		0.90
3	<i>Coptotermes emersoni</i>		0.50				0.07
4	<i>Coptotermes ceylonicus</i>			0.50		0.25	0.14
5	<i>Odontotermes hainanensis</i>		0.13		0.25		0.07
6	<i>Globitermes sulphureus</i>		0.25		1.00		0.24

The extent of damage by termite species in decreasing order are: *C. gestroi*, *G. sulphureus*, *C. domesticus*, *C. ceylonicus*, *C. emersoni* to *O. hainanensis*. *Coptotermes gestroi* was the most common pest, and they were present in 4 relics. *Cryptotermes domesticus*, *C. ceylonicus*, *O. hainanensis*, *G. sulphureus* occurred in 2 relics and *C. emersoni* was found in one relic.

We determined the key harmful species by using the scores of the damage levels. The scores varied among relics. There were 5 harmful species in Tu Duc tomb, in the decreasing order of damaging level: *C. gestroi*, *C. emersoni*, *G. sulphureus*, *C. domesticus*, and *O. hainanensis* (the values of MH are 0.88, 0.50, 0.25, 0.13, and 0.13, respectively). There were two harmful species (*C.gestroi* and *C.domesticus*) in Thieu Tri tomb and Thanh Noi (the values of MH are 1.31, 0.31 respectively). In Minh Mang tomb, *C.gestroi* and *C.ceylonicus* were found with values of MH are 1.00, 0.50 respectively. Compare to others above-mention relics, Khai Dinh tomb was damaged by only *C.ceylonicus* (MH = 0.25).

The damage level by termites in Hoi An Ancient Town: We found 102 item works that were infested by termites (57.0% of total studied item works) and considered 5 species as the key structural pests to structures/building in Hoi An. The values of MH indicated *C. gestroi* (MH = 0.81) as the most harmful species (Table 5).

Table 5. Species and damage level in Hoi An Ancient Town

No	Species	Damage level
1	<i>Cryptotermes domesticus</i>	0.07
2	<i>Cryptotermes</i> sp.	0.02
3	<i>Coptotermes ceylonicus</i>	0.13
4	<i>Coptotermes gestroi</i>	0.81
5	<i>Coptotermes emersoni</i>	0.06

The damage level by termites in My Son Sanctuary: We only found one species termites, *Odontotermes angustignathus*, in tower A, with MA value of 0.14. The other towers and temples have not been infested of termites because of the specific characteristics of architectural structures and the position of this area. They were built of bricks and located in a valley with natural surroundings.

Conclusion

- 27 species belong to 12 genera, 7 subfamilies, and 3 families were recorded in three world heritage sites. In which, 25 species belong to 12 genera, 7 subfamilies, and 3 families in Hue; 5 species, 2 genera, 2 subfamilies, and 2 families occurred in Hoi An; 16 species, 8 genera, 6 subfamilies, and 3 families were recorded in My Son.

- Species composition and damage levels are different in each heritage site and each component relic. We determined 6 damaging species in Hue, 5 species in Hoi An and 1 species in My Son. The main harmful species in Hue and Hoi An was *C.gestroi*, with damage values of 0.90 and 0.81 respectively.

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