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The diversity and distribution of residential termites in the Minahasa Raya Region, North Sulawesi Province, Indonesia

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Abstract. *Manoppo JSS, Putra RE, Dungani R, Ahmad I. 2024. The diversity and distribution of residential termites in the Minahasa Raya Region, North Sulawesi Province, Indonesia. Biodiversitas 25: 39-48.* Termites are major pests in urban settings, particularly due to their preference for wood, despite its ecological importance leading to structural damage to buildings. Studies showed a gap in the North Sulawesi Region, Indonesia, particularly in termite distribution, control, and economic impact in residential zones. This study aimed to (i) gather preliminary data on termite species in Minahasa and North Sulawesi from the literature; (ii) locate termite colonies via house/building surveys and baiting; (iii) map the distribution of identified termite species by Geographical Information System (GIS); and (iv) record environmental characteristics relevant to termite distribution and related damages. The study revealed a diversity of residential termite species in terms of morphological characteristics and habitats. Three termite families were identified: Rhinotermitidae, Termitidae, and Kalotermitidae, encompassing five sub-families and six genera, with the most notable species being *Cryptotermes brevis* Walker 1853, *Odontotermes javanicus* Holmgren, 1912, and *Nasutitermes atripennis* Haviland, 1898 among others. The *Cryptotermes* and *Odontotermes* were the most commonly encountered genera in Minahasa Raya's residential areas.

Keywords: Minahasa Raya, residential termites, termite diversity, termite distribution

INTRODUCTION

Termites (Order: Isoptera) occupy diverse ecosystems, from natural habitats and agricultural landscapes to urban settings (Clement et al. 2021; Rahman et al. 2022). In tropical and subtropical ecosystems, they are abundant soil macro-fauna, crucial for improving soil structure and fertility (Indrayani et al. 2021), and are indispensable in decomposition processes, particularly of wood, although they also feed on grasses, plant litter and organic matter (Bignell 2005; Jouquet et al. 2006; Prastyaningsih et al. 2020; Pie et al. 2021). Their contributions are vital for maintaining many tropical ecosystems' functions (Bonachela et al. 2015; Ashton et al. 2019; Elizalde et al. 2020).

However, in urban areas, termites have become notorious pests due to their affinity for wood (Lee 2002; Rahman et al. 2022). Their infestations lead to economic repercussions, depreciate aesthetic values, damage flora, and target household infrastructure, and historical structure (Novita et al. 2020; Umar and Majid 2020). Particularly problematic are families like Rhinotermitidae and Kalotermitidae. Subterranean termites, for instance, are notorious for undermining structures by forming underground channels, while dry wood termites nest in desiccated timber, identifiable by their fine-grained frass (Bignell and Eggleton 2000; Traniello and Leuthold 2000). Nevertheless, all termites feed on lignocellulose, the primary cell wall component of woody plants, and are consumed in sound wood or at various stages of breakdown. Baits containing cellulose that subterranean termites prefer are required to determine the diversity of termite species in an area. Wood is one of the most easily accessible cellulose-containing materials (Arinana et al. 2020).

In Indonesia, termites are called *anai-anai* and can be found in various environments, including forests, agricultural fields, plantations, and residential or urban areas. Indonesia's warm, humid tropical climate, organic-rich soil, and diverse range of woody plants provide an ideal termite habitat (Davies et al. 2015; Rahman et al. 2022). Indonesia houses approximately 10% of global termite species (Gathorne-Hardy 2002; Nandika et al. 2015). While many studies have explored termite diversity across regions, from Banda Aceh to Biak, the primary focus has been termites in natural habitats rather than urban settings. With wood as Indonesia's primary construction material, termite infestations result in significant economic losses, particularly where local construction relies heavily on timber, such as key economic regions like Sulawesi. In such developing regions, the high intensity of termite infestation on structures is primarily due to the transformation of large forest areas into urban environments. This change in land use, from a robust natural ecosystem to a new, more homogeneous residential landscape, significantly increases the vulnerability to and investment level of termites (Hasman et al. 2019; Subekti and Milanio 2023). Furthermore, the rising abundance of termite infestations can be partly attributed to the simplification of the termites' natural habitat (Lee and Park 2023)

This situation is also seen in North Sulawesi Province, with the capital city of Manado, which is in the northern part of Sulawesi Island. However, comprehensive data on urban termites in Sulawesi remains elusive, with scant information limited to South Sulawesi's Makassar city (Astuti 2013). Consequently, precise identification of termite species is critical.

This information gap hampers urban pest management efforts in devising accurate termite control strategies. Termite management strategies strongly rely on the features and behavior of the termite species that attack urban infrastructure. North Sulawesi, a region undergoing brisk economic progression, is notably devoid of data concerning termite distribution in its natural and urban locales. This study aims to bridge this knowledge gap, offering a springboard for crafting sustainable urban termite management solutions. A cornerstone of these solutions is the meticulous identification and mapping of termite species and their distribution.

MATERIALS AND METHODS

Study site

The study was conducted in the Minahasa Raya Region of North Sulawesi Province, Indonesia, located between latitudes 1º2'43,62''N and 1º36'29,92788''N and longitudes 124º41'9,27''E and 125º7'44,39028''E. The study area's altitude varies from 5 to 767 meters above sea level.

Field collection and observation

Field activities took place from September to December 2022. Our team conducted systematic field observations, focusing on the collection of termite samples and detailed studies of their habitats. Sampling tools and techniques were chosen based on the region's diverse terrains and altitudinal variations. Each collected sample was labeled, documenting the date, location, and specific environmental conditions. Subsequent analyses were performed to study the diversity, behavior, and habitat preferences of the termite species present in the area.

Determination of research locations

The North Sulawesi Province comprises 15 administrative units, including 11 regencies and 4 cities, encompassing an area of 13,892.47 km^2. It is divided into 171 sub-districts and 1,838 villages (BPS Sulawesi Utara 2022). This study concentrated on the Minahasa Raya Region, encompassing the Minahasa District, North Minahasa District, South Minahasa District, and Southeast Minahasa District (Lolowang et al. 2022). Research locations were chosen using a stratified random or multilevel sampling method (Davies et al. 2021), with the initial observations of termite presence guiding the selection process. Following this methodology, 2-3 sub-districts were selected from each district, and 3 villages were chosen from each sub-district. Every study area received a unique code (Zaman et al. 2022). The designated sites were subsequently surveyed, focusing on house structures, resulting in 60 observation posts (refer to Figure 1 and Table 1).

Collection of termites

House-building survey method, this involved searching for termite colonies and collecting samples from potential habitats, such as decayed wood, weathered branches, soil mounds, and litter. The exact locations of these colonies were documented using GPS. Termites were then cleaned, collected, and stored in 70% ethanol (CH_3OH) vials for later morphological identification (Indrayani et al. 2021; Prastyaningsih et al. 2020).

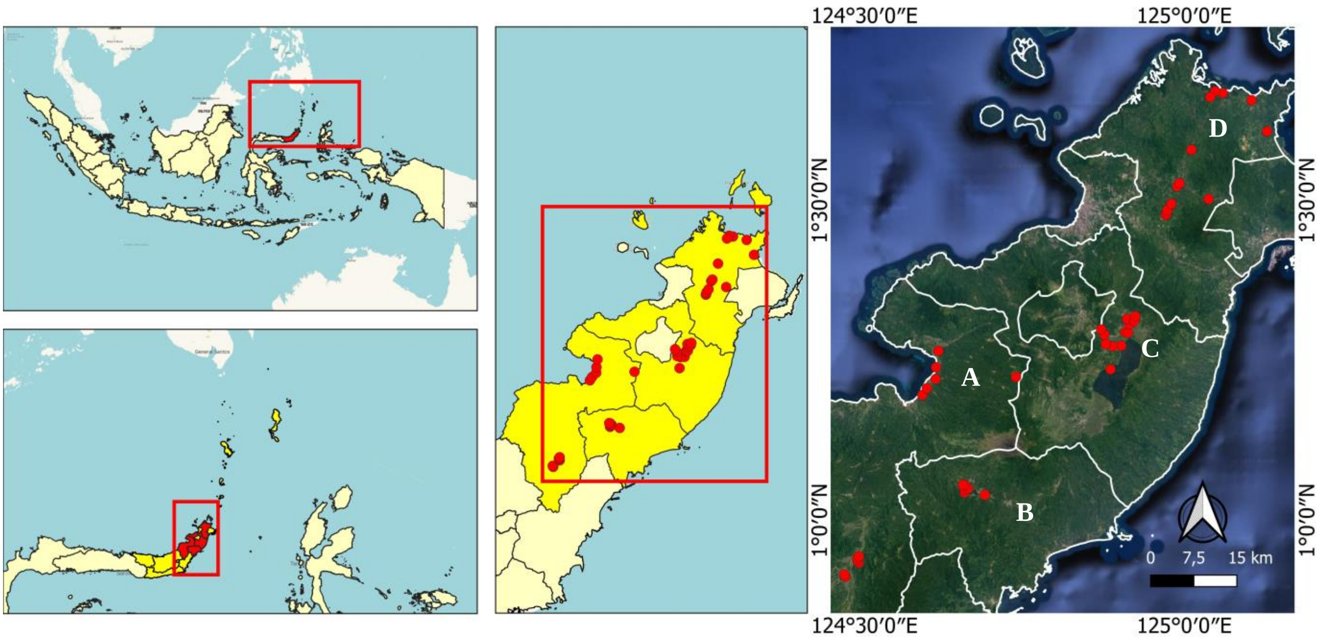

Figure 1. Termite monitoring station map in North Sulawesi Province, Indonesia. A. Southeast Minahasa, B. South Minahasa, C. Minahasa, D. North Minahasa

Baiting method: baits were placed within termite observation stations. The bait is made of a PVC tube (20 cm diameter, 25 cm length; Figure 2) buried halfway into the ground (Arinana et al. 2020). Three pine wood stakes (*Pinus merkusii* Jungh. & de Vriese), each measuring 2×2×20 cm for each tube (Arinana et al. 2016). With 60 observation stations in total, 180 stakes were prepared. These stakes remained in position for 3 months, with monthly inspections for termite infestations. Stakes showing termite activity were removed, and soldier termites were collected and preserved in 70% alcohol (Heriza et al. 2021; Arinana et al. 2022).

Termite identification

Termite species were determined through morphological observations and morphometric measurements, specifically focusing on the soldier caste (Indrayani et al. 2017; Arinana et al. 2020; Umar and Majid 2020). Observations and measurements were undertaken using a Hirox KH-8700 three-dimensional stereomicroscope or equivalent models. Each measurement was meticulously documented. Identification of termite species followed the guidelines presented in specific determination keys (Sornnuwat et al. 2004; Takematsu and Vongkaluang 2012). Photographic and Microscopic Observations: Collected termites were photographed and scrutinized under the microscope. For comprehensive observation, a 10 times magnification was used for the entire insect body, while a 40 times magnification was employed to inspect the head region, encompassing the antennae and mandibles (Wikantyoso et al. 2021). Specific measurements focused on the soldier caste's head, adhering to the standards set by (Takematsu and Vongkaluang 2012). This included measuring the head length (excluding mandibles), the width of the head at the mandible base, the head's maximum width, and the length of the left mandible. Additional measurements included the lengths and widths of the pronotum and postmentum, as well as counting the number of antennal segments (Tho 1992) (Figure 3).

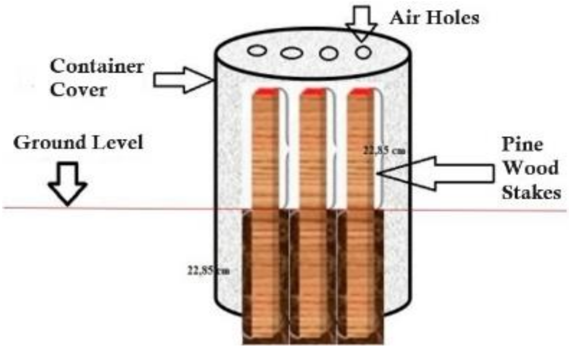

Figure 2. Installation of stakes through the feeding method and modified from (Arinana et al. 2016)

Table 1. Zonation and sampling plot

Code	District	Sub-district	Village
Mitra-01	Southeast Minahasa	Tombatu	Tombatu 2
Mitra-02	Southeast Minahasa	Touluaan	Lobu Atas
Mitra-03	Southeast Minahasa	Touluaan	Lobu Atas 2
Mitra-04	Southeast Minahasa	Touluaan	Toudano Atas
Mitra-05	Southeast Minahasa	Touluaan	Ranoketang Atas 1
Mitra-06	Southeast Minahasa	Touluaan	Ranoketang Atas
Minsel-07 to Minsel-08	South Minahasa	Tompaso Baru	Tompaso Baru Dua
Minsel-09 to Minsel-12	South Minahasa	Tompaso Baru	Karowa
Minsel-13	South Minahasa	Rumoong Atas	Langsot
Minsel-14	South Minahasa	Amurang	Pondang
Minsel-15	South Minahasa	Amurang	Pondang Dua
Minsel-16	South Minahasa	Amurang	Lopana
Minsel-17	South Minahasa	Amurang	Matani Satu
Minsel-18	South Minahasa	Tumpaan	Popontolen
Minahasa-19 to Minahasa-21	Minahasa	Tondano Utara	Tonsealama
Minahasa-22 to Minahasa-24	Minahasa	Tondano Utara	Kembuan
Minahasa-25 to Minahasa-26	Minahasa	Tondano Utara	Sasaran
Minahasa-27 to Minahasa-31	Minahasa	Tondano Selatan	Tataaran
Minahasa-32	Minahasa	Tondano Selatan	Urongo
Minahasa-33	Minahasa	Tondano Selatan	Tounsaru
Minahasa-34 to Minahasa-37	Minahasa	Tondano Barat	Wewelen
Minahasa-38 to Minahasa-40	Minahasa	Tondano Barat	Rerewokan
Minahasa-41 to Minahasa-43	Minahasa	Tondano Barat	Roong
Minut-44	North Minahasa	Dimembe	Tatelu Rondor
Minut-45 to Minut-47	North Minahasa	Dimembe	Tatelu
Minut-48 to Minut-52	North Minahasa	Dimembe	Matungkas
Minut-53 to Minut-54	North Minahasa	Dimembe	Lumpias
Minut-55 to Minut-56	North Minahasa	Dimembe	Klabat
Minut-57	North Minahasa	Likupang Timur	Likupang Satu
Minut-58	North Minahasa	Likupang Timur	Wineru
Minut-59	North Minahasa	Likupang Timur	Serawet
Minut-60	North Minahasa	Likupang Timur	Rinondoran

Measurement of climatic factors

Key environmental variables measured included temperature and relative humidity. For this, thermo-hygrometers were used, following methods from (Zanne et al. 2022) and Hasman et al. (2019). Therefore, thermo-hygrometers were placed in the environment around the vicinity of the nesting site for three to five minutes to obtain accurate measurements. These measurements were conducted three times over three consecutive days at the same location and time when termites were observed. The gathered data were then averaged for analysis. Additionally, sunlight intensity was gauged using a lux meter, per the methods described by Arif et al. (2020).

Termite distribution map in Minahasa Raya, North Sulawesi

Upon completion of termite observations and collections, the next step involved mapping the distribution of identified termite species within the Minahasa Raya region of North Sulawesi Province. A Geographical Information System (GIS)-based approach was employed, utilizing ArcGIS software to visualize and communicate the distribution data.

RESULTS AND DISCUSSION

Termite diversity and distribution

This study identified six termite genera from three families and five subfamilies (Figure 4, Table 2).

In this study, only Rhinotermitidae (*Coptotermes*, *Prorhinotermes*, *Schedorhinotermes*) were found in all observation regions, while Kalotermitidae (*Cryptotermes*) were found in only two of the four regions (Figure 5 and Table 3). *Odontotermes* (Termitidae) (found at 19 of 60 stations, 31.7%), *Cryptotermes* (Kalotermitidae), and *Nasutitermes* (Termitidae) were the most commonly encountered termites in the residential areas of the four sub-districts studied. However, *Schedorhinotermes* (Rhinotermitidae) was only found in Minahasa District precisely at three observation stations number 19, 20, and 21 in Tonsealama Village (Figure 5 and Table 3)

Coptotermes *and its distribution*

Termites of the genus *Coptotermes* found in Southeast Minahasa, South Minahasa, and North Minahasa are relatively small. The distinguishing feature of the warrior caste is their dark brown head with sickle-shaped mandibles, curving at the end, with antenna segments ranging between 14 and 16 (Table 2). Typically, their habitat is wood-based structures, with a particular affinity for dry wood.

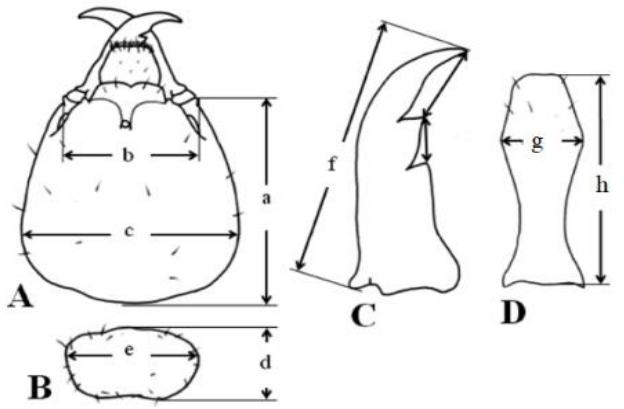

Figure 3. Morphology of termites: A. Head; B. Pronotum; C. Left mandible; D. Postmentum; a. HLWM; b. HWMB; c. MWH; d. LP; e. LP; f. LLM; g. Wpos; h. LPos (Tho 1992; Takematsu et al. 2012).

Figure 4. Types of residential termites found in settlements: A. Rhinotermitidae (*Coptotermes*); B. Rhinotermitidae (*Prorhinotermes*); C. Rhinotermitidae (*Schedorhinotermes*); D. Termitidae (*Odontotermes*); E. Termitidae (*Nasutitermes*); F. Kalotermitidae (*Cryptotermes*)

The warrior caste's features closely match those described by Takematsu and Vongkaluang (2012) for *Coptotermes gestroi* Wasmann, 1896, a sparsely haired head, a slightly hairy or bald pronotum, and a postmentum with some long hairs. The head shape is an elongated oval that narrows anteriorly. The mandible is slightly arched and devoid of marginal teeth. Other features such as a head length (excluding the mandible) of 1.65 mm, a maximum head width of 1.40 mm, and 14-16 antennal segments (Table 2) closely matched the morphology of *C. gestroi* (Scheffrahn and Su 2008; Arif et al. 2020a,b). Further, this species characteristically has a weakly curved mandible, which extends beyond half the head length, beginning its curvature in the apical third of the mandible.

The absence of *C. gestroi* from the main Minahasa region may be related to its environmental requirements. This region lies at a much higher altitude and consequently lower air temperatures than the other three regions. Such high-altitude areas also tend to have lower soil temperatures (Pratiknyo et al. 2018), which might inhibit the activities of subterranean termites like *Coptotermes* (Sattar et al. 2013).

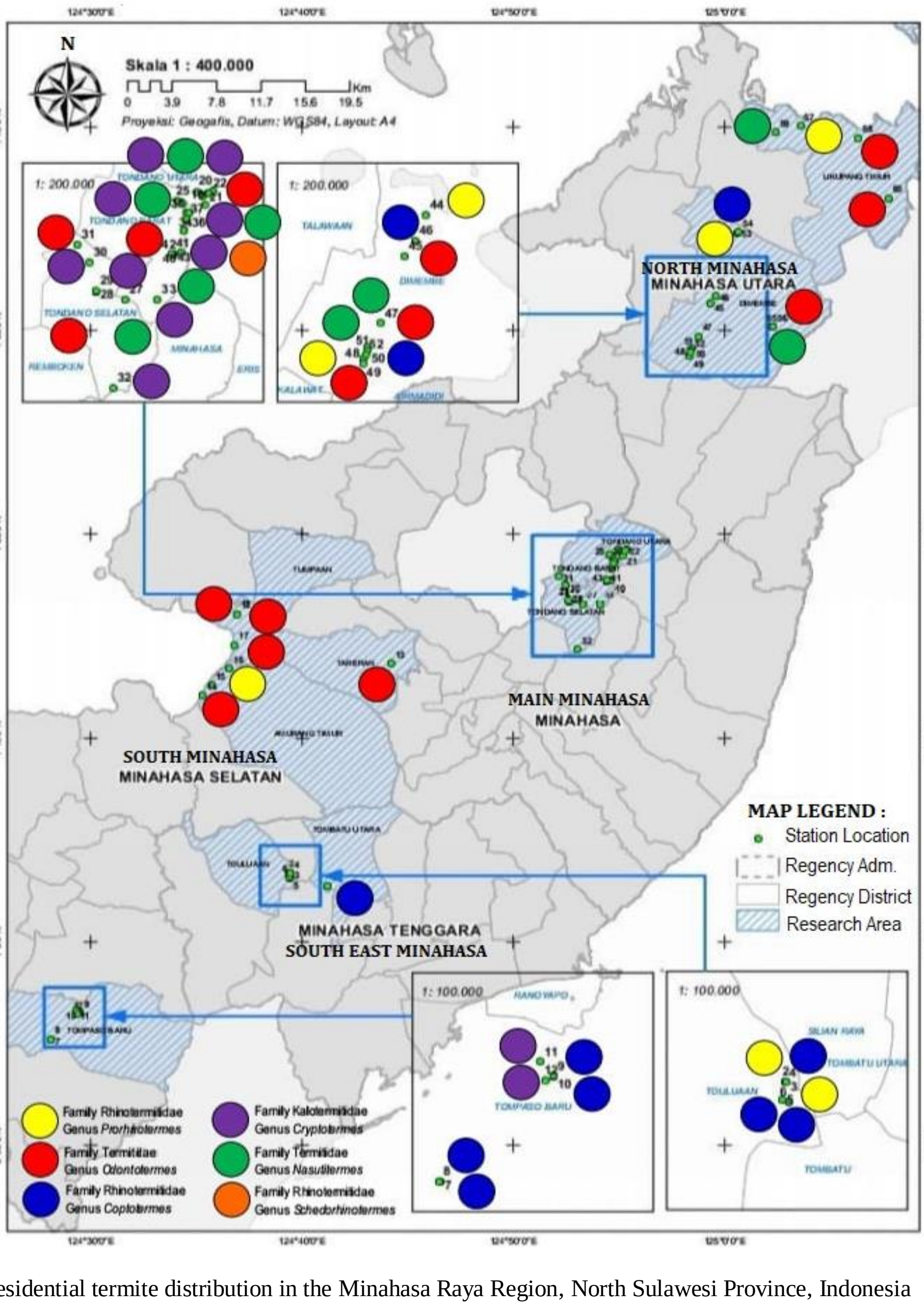

Figure 5. Map of residential termite distribution in the Minahasa Raya Region, North Sulawesi Province, Indonesia

Table 2. Termite genera found in the Minahasa Raya Region of North Sulawesi Province, Indonesia and its biometric

Family	Genus	Species	Types of termite	Measurement of the Head of the Soldier Caste (Mean±SD)								
				HLWM	HWMB	MWH	LLM	LP	MWP	LPos	WPos	NAS
Rhinotermitidae	*Coptotermes*	*C.gestroi*	S	1.65±0.05	0.85±0.04	1.40±0.03	1.20±0.01	0.54±0.01	1.05±0.04	1.02±0.05	0.45±0.04	14-16
Rhinotermitidae	*Prorhinotermes*	*P. flavus*	S	1.48±0.02	0.80±0.03	1.38±0.03	1.16±0.01	0.60±0.03	0.82±0.04	1.10±0.03	0.41±0.03	15-17
Rhinotermitidae	*Schedorhinotermes*	*S. translucens*	S	1.58±0.02	0.83±0.02	1.43±0.02	1.24±0.01	0.77±0.02	0.86±0.02	1.16±0.01	0.44±0.03	19
Termitidae	*Odontotermes*	*O. javanicus*	S	2.40±0.02	1.20±0.01	1.42±0.01	1.10±0.02	0.58±0.02	1.10±0.04	1.15±0.03	0.48±0.03	17
Termitidae	*Nasutitermes*	*N. atripennis*	S	2.35±0.07	1.26±0.03	1.35±0.03	0.50±0.03	0.30±0.03	0.58±0.03	1.06±0.02	0.42±0.02	13
Kalotermitidae	*Cryptotermes*	*C. brevis*	DW	1.05±0.03	0.48±0.02	1.20±0.03	0.57±0.02	0.50±0.03	0.54±0.02	0.60±0.02	0.30±0.02	41579
Kalotermitidae	*Cryptotermes*	*C. dudleyi*	DW	2.30± 0.11	0.49±0.03	1.31±0.07	0.58± 0.03	0.88± 0.05	1.20± 0.07	1.00±0.05	0.30±0.03	41579

Note: S: Subterranean; DW: Dry-Wood (Mean±SD); HLWM: Head Length Without Mandible; HWMB: Head Width at Mandible Base; MWH: Maximum Width of Head; LLM: Length of Left Mandible; LP: Length of Pronotum; MWP: Maximum Width of Pronotum; Lpos: Length of Postmentum; Wpos: Width of Postmentum; NAS: The number of Antenna Segments

Table 3. Termite types observed in each sub-district, with environmental factors

Sub-district	Family	Genus	Species	Type of wood where termites are found	Wood durability grade (Class)	Environmental factors						
						Temp. (℃)	Relative humidity (%)	Altitude (m asl)	Precipit. (%)	Wind speed (km/h)	Air pressure (hPa)	Observation station
SEM	Rhi	*Coptotermes*	*C. gestroi*	*Koordersiodendron pinnatum* (Blanco) Merr. (*kayu bugis*); *P. merkusii* (*kayu pinus*)	Durable (II), Perishable (V)	30-35	60-65	375-380	73-75	5.5-6.5	1008-1009.9	1, 4, 5, 6
		Prorhinotermes	*P. flavus*	*Palaqium obtusifolium* Burck (*kayu nantu/nyatoh);* *P. merkusii* (*kayu pinus*)	Moderately Durable (III), Perishable (V)	30-35	55-60	378-383	73-75	6.0-7.0	1008-1010.0	2, 3
SM	Te	*Odontotermes*	*O. javanicus*	*K. pinnatum (kayu bugis);* *P. merkusii* (*kayu pinus*)	Durable (II), Perishable (V)	25-30	85-90	125-130	73-75	4.5-5.0	1005-1007.7	13, 14, 16, 17, 18
	Rh	*Coptotermes*	*C. gestroi*	*Elmerillia ovalis* Dandy (*kayu cempaka*); *P. merkusii* (*kayu pinus*)	Durable (II), Perishable (V)	30-37	85-90	325-330	73-75	5.2-5.7	1007-1012.5	7, 8, 9, 10
		Prorhinotermes	*P. flavus*	*P. obtusifolium (kayu nantu/nyatoh);* *P. merkusii* (*kayu pinus*)	Moderately Durable (III), Perishable (V)	35-40	85-90	8-13	73-75	5.5-6.5	1003-1007.7	15
	Ka	*Cryptotermes*	*C. brevis*	*P. obtusifolium (kayu nantu/nyatoh);* *Homalium foetidum* (Roxb.) Benth. (*kayu bolangitang*); *P. merkusii* (*kayu pinus*)	Moderately Durable (III), Slightly Durable (IV), Perishable (V)	35-40	85-90	275-280	73-75	5.5-6.0	1000-1005.1	11, 12
M	Te	*Odontotermes*	*O. javanicus*	*K. pinnatum (kayu bugis);* *P. merkusii* (*kayu pinus*)	Durable (II), Perishable (V)	25-30	90-95	700-705	73-75	5.5-6.0	1005-1010.2	21, 24, 26, 28, 31, 35, 38, 42
		Nasutitermes	*N. atripennis*	*H. .foetidum* (*kayu bolangitang*); *P. merkusii* (*kayu pinus*)	Slightly Durable (IV), Perishable (V)	25-30	88-93	692-697	73-75	5.8-6.3	1008-1011.0	20, 23, 27, 34, 37, 39, 43
	Ka	*Cryptotermes*	*C. brevis*	*P. obtusifolium (kayu nantu/nyatoh);* *H. .foetidum* (*kayu bolangitang*); *P. merkusii* (*kayu pinus*)	Moderately Durable (III), Slightly Durable (IV), Perishable (V)	27-32	90-95	700-705	73-75	5.5-6.0	1008-1012.4	19,22,25,29,30, 32,33,36,40, 41
	Rh	*Schedorhinotermes*	*S.translucens*	*Wallaceodendron celebicum* Koord. (*Kayu Latula*); *P. merkusii* (*kayu pinus*)	Slightly Durable (IV), Perishable (V)	25-30	88-93	690-695	73-75	5.5-6.0	1005-1010.8	19, 20, 21
NM	Rh	*Prorhinotermes*	*P. flavus*	*P. obtusifolium (kayu nantu/nyatoh);* *P. merkusii* (*kayu pinus*)	Moderately Durable (III), Perishable (V)	30-35	85-90	180-185	73-75	7.5-8.0	1005-1010.3	44, 48, 53, 57
		Coptotermes	*C. gestroi*	*E. ovalis* (*kayu cempaka*); *P. merkusii* (*kayu pinus*)	Durable (II), Perishable (V)	30-35	87-92	232-237	73-75	8.0-8.5	1005-1009.4	46, 50, 54
	Te	*Odontotermes*	*O. javanicus*	*K. pinnatum (kayu bugis);* *P. merkusii* (*kayu pinus*)	Durable (II), Perishable (V)	28-33	75-80	245-257	73-75	5.8-6.3	1005-1009.1	45, 49, 52, 55, 58, 60
		Nasutitermes	*N. atripennis*	*H. .foetidum* (*kayu bolangitang*); *P. merkusii* (*kayu pinus*)	Slightly Durable (IV), Perishable (V)	28-33	75-80	250-266	73-75	5.5-6.0	1005-1010.2	47, 51, 56, 59

Note: SEM: South East Minahasa; SM: South Minahasa; M: Minahasa; NM: North Minahasa; Rh: Rhinotermiditae; Te: Termitidae; Ka: Kalotermitidae. The soil type of observation areas is mostly Alluvial and Andosol

Prorhinotermes *and its distribution*

Soldier termites of this species were characterized by a vivid brown to orange, oval-shaped head with 15 to 17 antennal segments (Table 2). These termites were found in timber-built structures, desiccated logs, and strategically placed bait stations, as highlighted in Table 3. The specimens of *Prorhinotermes* captured during this study exhibited a yellowish head and pronotum, minimal hair, and a diminutive, rounded fontanelle. The postmentum features sparse hairs confined mainly to the anterolateral margin. Other features include a petite, rounded fontanelle and mandibles resembling a sword with mild curvature (Takematsu and Vongkaluang 2012). Their head length without the mandible (HLWM) had a range from 1.45-1.51 mm, while the Maximum Width of the Head (MWH) had a range from 1.34-1.42 mm (Table 2). Their mandibles, long and reminiscent of a blade, curve subtly, and the antennal has 15 articles. Therefore, drawing upon these characteristics, it was inferred that the soldier termites under study belonged to the species *Prorhinotermes flavus* Bugnion & Popoff, 1910 (Takematsu and Vongkaluang 2012; Indrayani et al. 2022).

Genus Odontotermes *and its distribution*

A significant population of subterranean termites, thought to belong to the genus *Odontotermes*, was observed within the study area. The soldiers of this genus are recognizable by their oval heads ranging in color from dark to light brown or sometimes reddish-brown. A key distinguishing feature of these termites is protruding marginal teeth on the left mandible and 17 segments in their antennae (refer to Table 2). Based on these characteristics, the species was identified as *O. javanicus* (Arif et al. 2019; Arif et al. 2021; Rahman et al. 2022). Typically, the habitats of these termites include dead wood found around residential areas or within strategically placed bait stations.

These termites were found in South Minahasa, Minahasa, and North Minahasa (75% of the total region) and at 30% of total observation stations, regions that exhibit temperatures ranging from 23.81 to 29°C and relative humidity between 76.33 to 91.85% (Table 3) with consistently moist soil conditions, providing an ideal environment for this genus development. These observations are consistent with Nandika et al. (2015), who found that optimal termite development occurred at temperatures between 15 and 38°C and humidity levels between 75 and 90%. However, habitat type, vegetation diversity, and litter availability also impact termite survival (Arif et al. 2019). *Odontotermes* genus was absent from Southeast Minahasa, a phenomenon potentially attributed to the area's lower humidity levels, which ranged between 57 to 61.75% below the optimum humidity of 75 to 95% for this genus.

Genus Nasutitermes *and its distribution*

The collected *Nasutitermes* had a bottle-like head capsule and a short, pointed structure in this research. The average head length measurements (excluding mandible, denoted as HLWM) was 2.35±0.07 mm, and the average maximum head width was 1.35±0.03 mm (Table 2). Based on these characteristics, the soldier termites were identified as *Nasutitermes* (*Havilanditermes*) *atripennis* Haviland (Tho and Kirton 1992; Bong et al. 2012).

Nasutitermes were found only in Minahasa and North Minahasa, with temperatures between 24-29.5°C and humidity levels fluctuating from 76.5 to 90.28%. Additionally, the relative altitude spanned from 258.74 to 695.38 masl (Table 3). The environmental conditions were suitable for *Nasutitermes*, as reported by Mairawita et al. (2022) on the presence of two termite species, *N. havilandi* Desneux, 1904 and *N. matangensis* Haviland, 1898 in West Kalimantan secondary forests (at 100-200 masl), which exhibited temperatures of 23.78-34.64°C and humidity levels between 85.8 and 89.10%, Prastyaningsih et al. (2020) on the highest *N. matangensis* abundance at 31.8°C to 32.5°C with relative humidity levels between 67.5 to 72.9%, and Luna et al. (2023) on the presence of the *Nasutitermes* genus thrives at temperatures of 16-30°C, humidity levels of 50-70%, and altitudes between 1825-2000 masl. Notably, the *Nasutitermes* genus was absent in South Minahasa and Southeast Minahasa. This absence is attributed to declining humidity levels in these areas, dropping from 88.6% to 57%, as showcased in Table 3. This echoes Zukowski and Su's (2017) emphasis on the significance of temperature and relative humidity in termite habitats.

Genus Cryptotermes *and its distribution*

The *Cryptotermes* species is a dry wood termite that infests residential houses, resulting in noticeable wood damage marked by excrements or fine granules. Distinctively, the warrior caste has a darkly hued head, varying from dark brown to blackish-brown or dark reddish-brown. Their mandibles might be rounded or V-shaped, and their antennae typically comprise 11 to 13 segments. They predominantly thrive in community residential spaces, particularly in wooden structures and dry wood piles.

In this study, two *Cryptotermes* types were identified, the first type, suspected to be *C. brevis*, has warriors measuring 4-5 mm in body length. Their heads are phragmotic (plug-like), deeply wrinkled, and black, with a width ranging from 1.2 to 1.4 mm. They possess 13-segmented antennae, relatively small mandibles, and lack the arolium-as is typical of *Cryptotermes* species.

The second type, likely *C. dudleya* Banks, 1918, has warriors between 4.5 and 7 mm body sizes. Their heads are subrectangular, slightly elongated, and feature gentle slopes and dual tubercle pairs. Their mandibles are distinctly elongated and tapering, and their fecal pellets are unique, small, and six-sided.

Urban infrastructures and buildings often fall prey to *Cryptotermes* invasions due to their ability to thrive without soil or direct water contact. They can infest various wooden items, from structural beams to musical instruments.

Genus Schedorhinotermes *and its distribution*

These termites are distinctively marked by two forms of their warrior caste: major soldiers (larger) and minor soldiers (smaller). These characteristics belong to the *Schedorhinotermes* genus (Arif et al. 2020a,b). However, some of the specimens found in this study were dealates or queens, members of the reproductive caste. A diagnostic characteristic of this genus is the pronounced nose or rhinoceros projection on their postclypeus (Scheffrahn 2023). Their heads are moderately larger and sport a bright brown or reddish-brown hue. Antennae are composed of 19 segments. Delving deeper into their morphology, the reproductive caste, or the dealates, showcases a range of measurements. The soldier termites found were identified as *S. derosus* Hill, 1933 (Goverment Australia 2021; Scheffrahn 2023).

These termites were found inhabiting dead wood in gardens and inside bait stations. Notably, the *Schedorhinotermes* genus was only identified at three specific stations -19, 20, and 21- all located in the Minahasa Region. No particular conditions were observed that could be directly linked to the presence of this genus. Therefore, to determine the key factors influencing the presence of Schedorhinotermes, further research should be conducted, focusing on potential influences such as the availability of specific resources or interactions with other organisms.

Although we covered various types of conditions and possible habitats for termites we did not conduct observations on historical and infrastructural area. This is due difficulties on for the permit and access to sampling area on thoses particular areas. Nevertheless, result of this study provided a baseline information for possible distribution of particular group of termites which have specific infestation and colony behavior that allow precision mitigation of termite infestation. Precision mitigation combined with early warning of the possibility of termites infestation may furtherly developed into sustainable termites control program which costumized based on the concrete scientific data.

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REFERENCES

Arif A, Muin M, Larekeng SH, Lestari PI. 2019. Survey and morphological identification of termites (Insecta: Isoptera) in teaching forest of Hasanuddin University, Indonesia. IOP Conf Ser Earth Environ 270 (1): 012001. DOI: 10.1088/1755-1315/270/1/012001.

Arif A, Muin M, Putri G, Hidayah MT. 2021. Termites (Insecta: Isoptera) diversity in forest conseccion areas of PT Inhutani I, Indonesia. IOP Conf Ser Earth Environ 886 (1): 012129. DOI: 10.1088/1755-1315/886/1/012129.

Arif A, Putri G, Lestari PI, Nurqalbi M, Saira A. 2020a. Keragaman rayap Rhinotermitidae (Isoptera, Insekta) di Hutan Pendidikan Universitas Hasanuddin. Perennial 16 (2): 59-67. DOI: 10.24259/perennial.v16i2.11699. [Indonesian]

Arif A, Putri G, Muin M. 2020b. Hazard mapping of subterranean termite attacks in Makassar City, South Sulawesi, Indonesia. Insects 11 (1): 31. DOI: 10.3390/insects11010031.

Arinana, Aldina R, Nandika D, Rauf A, Harahap IS, Sumertajaya IM, Bahtiar ET. 2016. Termite diversity in urban landscape, South Jakarta, Indonesia. Insects 7 (2): 1-18. DOI: 10.3390/insects7020020.

Arinana, Fannani AR, Nandika D, Haneda NF. 2020. Field test on the palatability of the subterranean termites to pine wood with various treatments. Biodiversitas 21 (12): 5763-71. DOI: 10.13057/biodiv/d211237.

Arinana, Rahman MM, Silaban REG, Himmi SK, Nandika D. 2022. Preference of subterranean termites among community timber species in Bogor, Indonesia. J Korean Wood Sci Technol 50 (6): 458-74. DOI: 10.5658/WOOD.2022.50.6.458.

Ashton LA, Griffiths HM, Parr CL, Evans TA, Didham RK, Hasan F, The YA, Tin HS, Vairappan CS, Eggleton P. 2019. Termites mitigate the effects of drought in tropical rainforest. Science 363 (6423): 174-77. DOI: 10.1126/science.aau9565.

Astuti. 2013. Identifikasi, Sebaran dan Derajat Kerusakan Kayu oleh Serangan Rayap *Coptotermes* (Isoptera: Rhinotermitidae) di Sulawesi Selatan. [Disertation]. Universitas Hasanuddin Makassar, Makassar. [Indonesian]

Bignell DE. 2005. Termites as Soil Engineers and Soil Processors. Intestinal Microorganisms of Termites and Other Invertebrates In: König H, Varma A (eds). Intestinal Microorganisms of Termites and Other Invertebrates. Soil Biology, Vol 6. Springer, Berlin, Heidelberg. DOI: 10.1007/3-540-28185-1_8.

Bignell DE, Eggleton P. 2000. Termites: Evolution, Sociality, Simbioses, Ecology. Springer-Science Businees Media Dordrecht, B.V, Dordrecht, Netherlands. DOI: 10.1007/978-94-017-3223-9_18.

Bonachela JA, Pringle RM, Sheffer E, Coverdale TC, Guyton JA, Caylor KK, Levin SA and Tarnita CE. 2015. Termite mounds can increase the robustness of dryland ecosystems to climatic change. Science 12246 (2011): 17658-17659. DOI: 10.1126/science.1261487.

Bong JCF, King PJH, Ong KH and Mahadi NM. 2012. Termites assemblages in oil palm plantation in Sarawak, Malaysia. J Entomol 9 (2): 68-78. DOI: 10.3923/je.2012.68.78.

BPS Sulawesi Utara. 2022. Provinsi Sulawesi Utara Dalam Angka 2022. Badan Pusat Statistik, Provinsi Sulawesi Utara. [Indonesian]

Clement RA, Flores-Moreno H, Cernusak LA, Cheesman AW, Yatsko AR, Allison SD, Eggleton P, Zanne AE. 2021. Assessing the Australian termite diversity anomaly: How habitat and rainfall affect termite assemblages. Front Ecol Evol 9: 657444. DOI: 10.3389/fevo.2021.657444.

Davies AB, Eggleton P, van Rensburg BJ, Parr CL. 2015. Seasonal activity patterns of African savanna termites vary across a rainfall gradient. Insectes Soc 62 (2): 157-165. DOI: 10.1007/s00040-014-0386-y.

Davies AB, Parr CL, Eggleton P. 2021. A global review of termite sampling methods. Insectes Soc 68 (1): 3-14. DOI: 10.1007/s00040-020-00797-y.

Elizalde L, Arbetman M, Arnan X, Eggleton P, Leal IR, Lescano MN, Saez A, Werenkraut V, Pirk GI. 2020. The ecosystem services provided by social insects: Traits, management tools and knowledge gaps. Biol Rev 95 (5): 1418-41. DOI: 10.1111/brv.12616.

Gathorne-Hardy FJ. 2002. The Termites of South East Asia: A Study of Biogeographical Patterns. [Dissertation Thesis] University of London Department of Entomology, The Natural History Museum, Cromwell Road London, United Kingdom.

Goverment Australian. 2021. Inspection of Forest Products for Export. Framework, Practice Statement. Department of Agriculture, Water and The Environment, Australia.

Hasman AE, Muin M and Taskirawati I. 2019. Keragaman jenis rayap pada lahan pemukiman dengan berbagai kelas umur bangunan. Perennial 15 (2): 74. DOI: 10.24259/perennial.v15i2.7637. [Indonesian]

Heriza S, Buchori D, Harahap IS and Maryana N. 2021. Response of termite communities to natural forest conversion. Biodiversitas 22 (11): 5092-96. DOI: 10.13057/biodiv/d221147.

Indrayani Y, Khasanah RU, Anwari S. 2021. Effect of termite activity on soil chemical properties using baiting systems at an Arboretum area in Pontianak, West Kalimantan, Indonesia. Biodiversitas 22 (4): 2125-2130. DOI: 10.13057/biodiv/d220461.

Indrayani Y, Setyawati D, Maryani Y, Simangunsong B. 2022b. A Termite attack on rubber plantation on peat soil: Level of damage and identification of pest species. IOP Conf Ser Earth Environ 976 (1): 012006. DOI: 10.1088/1755-1315/976/1/012006.

Indrayani Y, Setyawati D, Mariani Y, Takematsu Y, Yoshimura T. 2022a. Diversity of termite species at various altitudes in the secondary forest, West Kalimantan, Indonesia. IOP Conf Ser Earth Environ 959 (1): 012014. DOI: 10.1088/1755-1315/959/1/012014.

Indrayani Y, Takematsu Y, Yoshimura T. 2017. Short communication: Diversity and distribution of termites in buildings in Pontianak, West Kalimantan, Indonesia. Biodiversitas 18 (3): 954-957. DOI: 10.13057/biodiv/d180312.

Jouquet P, Dauber J, Lagerlöf J, Lavelle P, Lepage M. 2006. Soil invertebrates as ecosystem engineers: Intended and accidental effects on soil and feedback loops. Appl Soil Ecol 32 (2): 153-164. DOI: 10.1016/j.apsoil.2005.07.004.

Lee CY. 2002. Subterranean termite pests and their control in the urban environment in Malaysia. Sociobiology 40 (1): 3-9.

Lee SH, Park CM. 2023. Exploring the effects of high curvature section distribution and density in termite tunnels on food transport efficiency: A simulation study. Biosystems 231: 1-8. DOI: 10.1016/j.biosystems.2023.104985.

Lolowang, Indira, Iqbal M, Tarigan FA. 2022. Provinsi Sulawesi Utara Dalam Angka 2022. 868. https://sulut.bps.go.id/. [Indonesian]

Luna MD, Scheffrahn RH, Barrios RG, Rodriguez GC. 2023. Termites (Blattodea: Isoptera) of Canada, Continental USA, and Mexico: An identification key to families and genera, checklist of species, and new records for Mexico. Acta Zool Mex 39: 1-30. DOI: 10.21829/azm.2023.3912484.

Mairawita, Herwina H, Rahman T, Janra MN. 2022. Diversity of termite (Insecta: Isoptera) at the forested area of Universitas Andalas, Padang, West Sumatra, Indonesia. IOP Conf Ser Earth Environ 1059 (1): 012085. DOI: 10.1088/1755-1315/1059/1/012085.

Nandika D, Rismayadi Y, Diba F. 2015. Rayap : Biologi dan Pengendaliannya. Universitas Muhammadiyah Press 1: 1-4. [Indonesian]

Novita, Amiruddin H, Ibrahim H, Jamil TM, Syaukani, Oguri E, Eguchi K. 2020. Investigation of termite attack on cultural heritage buildings: A case study in Aceh Province, Indonesia. Insects 11 (6): 1-12. DOI: 10.3390/insects11060385.

Pie MR, Carrijo TF and Caron FS. 2021. The diversification of Termites: Inferences from a complete species-level phylogeny. Zool Scripta 50 (6): 769-79. DOI: 10.1111/zsc.12502.

Prastyaningsih SR, Hardiwinoto S, Musyafa, Koranto CAD. 2020. Diversity of termites (Isoptera) on industrial forest -lantation of Eucalyptus pellita stands of tropical ecosystem in Riau, Indonesia. Biodiversitas 21 (11): 5498-5505. DOI: 10.13057/biodiv/d211158.

Pratiknyo H, Ahmad I, Budiyanto BH. 2018. Diversity and abundance of termites along altitudinal gradient and slopes in Mount Slamet, Central Java, Indonesia. Biodiversitas 19 (5): 1649-58. DOI: 10.13057/biodiv/d190508.

Rahman T, Herwina, Mairawita and Janra MN. 2022. Identification of termites (Insecta: Isoptera) from anthropogenic area in Universitas Andalas campus complex, West Sumatra, Indonesia. IOP Conf Ser Earth Environ 1059 (1): 012084. DOI: 10.1088/1755-1315/1059/1/012084.

Sattar A, Naeem M, ul-Haq E. 2013. Impact of environmental factors on the population dynamics, density and foraging activities of Odontotermes lokanandi and Microtermes obesi in Islamabad." SpringerPlus 2 (1): 1-7. DOI: 10.1186/2193-1801-2-349.

Scheffrahn RH. 2023. The giveaway character of genus *Schedorhinotermes* (Family Rhinotermitidae). Personal Communication.

Scheffrahn RH, Su NY. 2008. Asian Subterranean Termite, *Coptotermes gestroi* (= Havilandi) (Wasmann) (Insecta:Isoptera : Rhinotermitidae) 1. University of Florida IFAS Extension, Florida.

Sornnuwat Y, Vongkaluang C, Takematsu Y. 2004. A systematic key to Termites of Thailand. Kasetsart J Nat Sci 38: 349-68.

Subekti N, Milanio RR. 2023. Termite diversity and abundance based on altitude in Mount Ungaran, Central Java, Indonesia. Biodiversitas 24 (6): 3319-24. DOI: 10.13057/biodiv/d240626.

Takematsu Y, Vongkaluang C. 2012. A taxonomic review of the Rhinotermitidae (Isoptera) of Thailand. J Nat Hist 46 (17-18): 1079-1109. DOI: 10.1080/00222933.2011.651653.

Tho YP. 1992. Termites of Peninsular Malaysia. Edited by Laurence G. Kirton. Forest Research Institute Malaysia, Kepong Kualalumpur. DOI: 10.1017/S0007485300032624.

Traniello J, Leuthold R. 2000. Behavior and ecology of foraging in termites. In: Abe T et al (eds). Termites: Evolution, sociality, symbioses, Ecology. Kluwer Academic Publishes, MA London, UK. DOI: 10.1007/978-94-017-3223-9_7.

Umar WASW, Majid AHA. 2020. Efficacy of minimum application of Chlorfluazuron baiting to control urban subterranean termite populations of *Coptotermes gestroi* (Wasmann) (Blattodea: Rhinotermitidae). Insects 11 (9):569. DOI: 10.3390/insects11090569.

Wikantyoso B, Tseng SP, Himmi SK, Yusuf S, Yoshimura T. 2021. Morphometric analysis of *Coptotermes* spp. soldier caste (Blattodea: Rhinotermitidae) in Indonesia and evidence of *Coptotermes gestroi* extreme head-capsule shapes. Insects 12 (5): 1-24. DOI: 10.3390/insects12050477.

Zaman M, Khan IA, Usman A, Saljoqi AUR. 2022. Species diversity and damage incidence of termites (Isoptera) in different agro-ecological zones of Khyber Pakhtunkhwa, Pakistan. Sarhad J Agric 38 (2): 518-24. DOI: 10.17582/JOURNAL.SJA/2022/38.2.518.524.

Zanne AE, Moreno HF, Powell JR et al. 2022. Temperature sensitivity to temperature determines global wood decay rates. Science 377 (6613): 1440-1444. DOI: 10.1126/science.abo3856.

Zukowski J, Su NY. 2017. Survival of termites (Isoptera) exposed to various levels of Relative Humidity (RH) and water availability, and Their RH Preferences. Fla Entomol 100 (3): 532-538. DOI: 10.1653/024.100.0307.