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*Full Length Research Article*

## Identification of Subterranean Termites and Marine Borers in Ternate City and the Intensity of Damage Resulting from Their Attacks

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### ABSTRACT

Indonesia is the largest archipelagic country, and Ternate is one of its cities with extensive marine areas undergoing rapid infrastructure development, making it prone to ecosystem changes and termite and marine borer attacks. This study aims to identify the species of subterranean termites and marine borers, analyze the intensity of wood damage caused by their attacks, and provide a scientific basis for mitigating wood deterioration in Ternate City. Specimen collection was conducted over three months through field observations and baiting with pine wood (*Pinus merkusii*) across 10 villages (Maliaro, Dufa-Dufa, Sulamadaha, Tobololo, Jati, Gambesi, Malikrubu, Soa, Kastela, and Foramadiahi) and multiple beaches, in accordance with ASTM D1756-08 and SNI 7207:2014 standards. A total of 125 termite baits were installed in the 10 villages, while marine borer baits were installed on two beaches: Jikomalamo Beach and Ake Rica Beach. The research identified five genera of subterranean termites and 18 species of marine borers. Although the overall frequency of subterranean termite attacks on baits in residential areas was low (2.7%), the presence of highly destructive species like *Coptotermes* sp. poses a severe localized threat to buildings. Conversely, marine borers exhibited a 100% attack frequency on submerged baits, resulting in a severe damage intensity averaging 60.8% within just three months. Consequently, Ternate City faces a significant dual threat from localized termite infestations and highly aggressive marine borers, necessitating urgent, targeted mitigation strategies to protect wooden infrastructure.

## 1. Introduction

Indonesia is a vast archipelagic country with a tropical climate, high humidity, and relatively stable temperatures year-round (Paramita and Matzarakis 2023). Ternate City, located in North Maluku, has a coastal tropical environment with high rainfall and temperatures ranging from 23.9 °C to 34 °C (Muhammad et al. 2018). These environmental conditions make wood a commonly used material for traditional fishing villages, piers, jetties, and residential buildings along coastal areas. The combination of high humidity and proximity to the sea increases the vulnerability of wood to biological degradation. Terrestrial residential areas provide favorable soil moisture conditions for subterranean termite activity, whereas coastal structures are exposed to marine wood-boring organisms. These conditions can reduce the durability and service life of wood-based infrastructure. However, studies evaluating the simultaneous occurrence and distribution of both terrestrial and marine wood-destroying organisms in this region remain limited (Ferrer et al. 2020).

In the terrestrial and residential zones of such humid tropical environments, subterranean termites are recognized as among the most detrimental wood-destroying pests worldwide. They live in large underground colonies, build extensive tunnel networks, and continuously consume cellulose-rich wood, leading to serious structural damage (Kusumawardhani and Almulqu 2024; Subekti and Fadhila 2023). In Indonesia, subterranean termite groups from the families Rhinotermitidae and Termitidae, particularly the genera *Coptotermes*, *Macrotermes*, and *Microtermes*, have been reported as major pests of buildings and wooden infrastructure in various urban areas (Arinana et al. 2016). Damage caused by subterranean termites to buildings and construction wood results in significant economic losses and is recognized as a major problem in building management in humid tropical regions (Arinana et al. 2016; Kutana et al. 2025; Nurhadi et al. 2023).

In parallel with the terrestrial threat, marine wood-borers in the coastal zone further endanger timber. Marine borers are a group of marine invertebrates, primarily mollusks and crustaceans, that live in saline and brackish waters. They are known as wood-destroying organisms due to their ability to bore into and damage wooden structures, such as pier piles, ships, and coastal buildings, thereby significantly reducing their service life (Marais et al. 2022; Rajapakse 2016). In Indonesia, an archipelagic country with a very long coastline where approximately 70% of the population lives in coastal areas, many fishing villages and coastal infrastructure still rely on wood (Rahman et al. 2024). This reliance on timber makes them vulnerable to marine borers, which can reduce structural strength and stability (Prabowo et al. 2022).

Recognizing the severe impact of these biodeterioration agents, numerous studies over the last decade have investigated their distribution and the intensity of their attack across various Indonesian ecosystems. For instance, termite hazard mappings and diversity assessments have been extensively conducted in urban areas such as Java (Arinana et al. 2016, 2025) and Sulawesi (Arif et al. 2020). Similarly, research on marine wood-borers has documented their species composition and dual role as both mangrove decomposers and agents of structural biodeterioration in Kalimantan (Diba et al. 2018) and Bali (Ginantra et al. 2022). However, these studies generally focus on specific locations in Kalimantan, Sulawesi, and Nusa Lembongan, leaving relatively little information on the species composition of marine borers in eastern Indonesia, including North Maluku. Ternate, a coastal city in North Maluku Province with a long history of marine resource utilization, the presence of ports and piers, and coastal settlements that frequently use wood, makes it an ecologically highly vulnerable location to marine borer attacks on various wooden structures.

To date, no scientific studies have reported the species composition of marine borers and subterranean termites in Ternate City, nor have they examined their relationships with local environmental conditions, unlike in other Indonesian regions that have been previously studied. Therefore, this research is important to provide a scientific basis for mitigating wood damage, improving construction resilience, and supporting sustainable coastal resource management.

## 2. Materials and Methods

### 2.1. Materials and Study Site

The primary material used for baiting against both termites and marine borers was pine wood (*Pinus merkusii*). This wood species was selected because it is highly preferred by wood-destroying organisms (Arinana et al. 2022). The logs were sourced from Sinarsari Village, Dramaga, Bogor, and processed into boards at the Department of Forest Products Workshop of the Faculty of Forestry and Environment, IPB University. The boards were naturally air-dried until the moisture content reached 20%, then sawn into standard bait samples measuring 2.5 cm × 5 cm × 30 cm for marine borers (SNI 2014) and 2 cm × 2 cm × 46 cm for termites (ASTM 2008). After the sample surfaces were smoothed with sandpaper, they were oven-dried at 103 °C for 24 hours, vacuum-packed, and transported to Ternate.

**Fig. 1** shows the distribution of sample villages and beaches for specimen collection. The sample areas in this study were located across five sub-districts in Ternate City. To assess the presence and attack intensity of these organisms, the sampling design was clearly divided into two methods: bait installation and direct observation. The installation points were purposively selected based on uniform criteria: shaded areas with adequate soil moisture, proximity to existing wooden structures or decaying stumps, and avoidance of chemically treated soils.

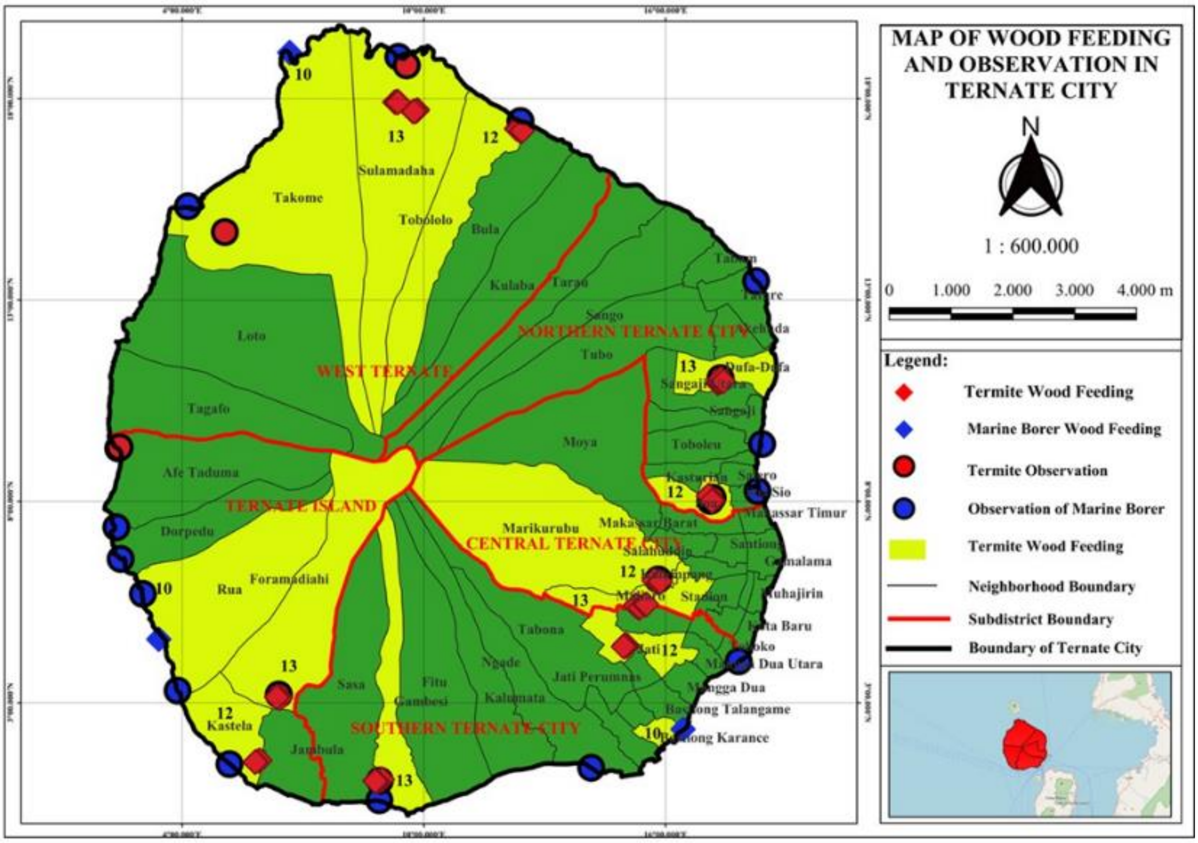


**Fig. 1.** Distribution of sample villages and beaches for specimen collection.

For subterranean termites, bait wood was installed exclusively in 10 designated sample villages: Dufa-dufa, Soa, Maliaro, Malikrubu, Jati, Gambesi, Foramadiahi, Kastela, Sulamadaha, and Tobololo. In each of these locations, soil samples were collected to analyze pH, organic carbon content and soil texture. Conversely, direct observations to identify active termite infestations on buildings and trees were conducted not only in the primary sample villages but also in adjacent areas, such as Tafure and Taduma, to ensure a comprehensive assessment of species diversity in the residential environment.

Similarly, the sampling for marine borers utilized both baiting and direct observation. Bait wood assemblies were installed at two randomly selected beaches: Ake Rica and Jikomalamo. Concurrently, direct observations of infested, naturally submerged wood debris were conducted at six beaches: Tolire, Rua, Gam Lamo, Tafure, Tobololo, and Gambesi. During both bait installation and observation, water quality parameters, including salinity, temperature, and pH, were measured at these locations using a water quality tester.

*2.2. Collection of Termite and Marine Borer Specimens*

Termite specimens were obtained using both installation and observation methods. The wooden baits were installed vertically into the soil in the yards of residential homes or public facilities (such as parks and fields) in each sample village, to a depth of 25 cm (**Fig. 2**). To maximize the probability of infestation and account for environmental variations, sampling locations were purposively selected based on visual indicators of potential termite habitats, such as proximity to existing wooden structures, decaying stumps, or previous records of termite activity. A total of 12–13 bait stakes were installed per location, for a total of 125 units. After three months, the baits were retrieved and examined for the severity of termite damage. The damage was confirmed to be caused specifically by termites (rather than other biological agents such as fungi) based on the presence of live termite specimens, mud tubes, and characteristic feeding galleries (e.g., hollowed-out sections following the grain of the wood). The level of damage was assessed using the wood damage rating classification in ASTM D1758-08 (ASTM 2008). Additionally, field observations involved examining buildings and trees within the sample villages. If signs of termite attack (tunnels) were found, the tunnels were dismantled, and the termites inside were collected.


**Fig. 2.** Termite bait wood installation.

The collection of marine borer specimens was carried out in two ways: baiting (SNI 2014) and direct observation (Goodell and Nielsen 2023). Baiting was conducted at two sample beaches. The test samples were assembled (SNI 2014) and then submerged at predetermined locations in the sea. One bait wood assembly was installed at each sample beach (**Fig. 3**). After three months, the assemblies were retrieved and cleaned, and the marine borer specimens attacking the wood were collected. Meanwhile, the direct observation method involved collecting damaged wood along the coast to observe marine borer attacks; the specimens found inside the wood were removed with tweezers.

Finally, all collected live specimens of both termites and marine borers, whether obtained from baits or direct observation, were immediately placed in bottles containing 70% alcohol for preservation.

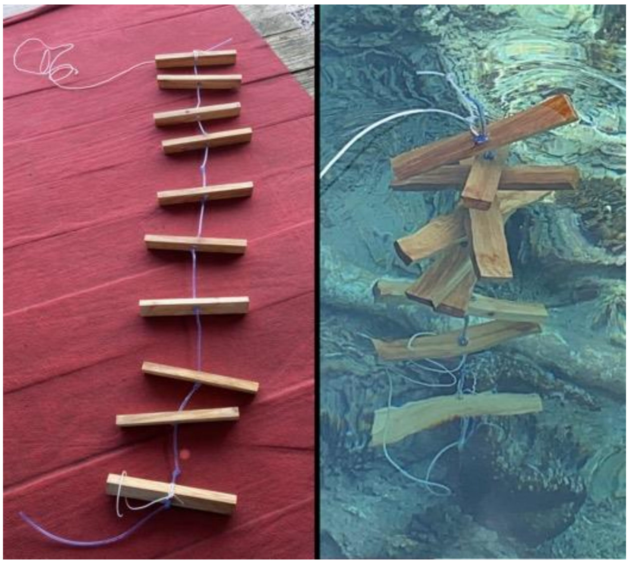

**Fig. 3.** Bait wood assembly for trapping marine borers.

### *2.3. Identification of Termites and Marine Borers*

Termite (soldier caste) and marine borer specimens were photographed using a Dino-Lite Digital Microscope (AM2111 Series, AnMo Electronics Corporation, New Taipei City, Taiwan). The termites were identified to the species level based on specific morphological characteristics, such as the shape of the head capsule and mandibles. Termites were identified to the species level, as reported by Nandika and Arinana (2024). Meanwhile, Turner (1966) described the morphological identification of marine borers.

### *2.4. Frequency of Termite and Marine Borer Attacks*

The frequency of attack on the bait wood is the ratio of the number of units attacked by termites or marine borers to the total number of units. Attack frequency was calculated using the field survey method described by Arinana et al. (2025) and subsequently classified into six categories, as presented in **Table 1**.

**Table 1.** Classification of termite attack frequency on wooden baits (Arinana et al. 2025)

| Class | Frequency (%) | Description |
|---|---|---|
| 1 | 0 | No attack |
| 2 | 1–10 | Very low |
| 3 | 11–20 | Low |
| 4 | 21–30 | Moderate |
| 5 | 31–40 | High |
| 6 | > 40 | Very high |

### *2.5. Intensity of Bait Damage*

The intensity of bait damage due to termite attack was determined as the percentage loss of the wood's cross-sectional area, in accordance with ASTM D1758-08 (ASTM 2008). Because termite degradation is often irregular, the damaged cross-sectional area was quantified using structured visual estimation by comparing the samples against standard grading charts. The damage intensity was subsequently classified into seven classes **(Table 2)**. Conversely, the intensity of bait damage from marine borer attack was measured as the percentage of damaged surface area, in accordance with SNI 7207:2014 (SNI 2014). Similar to the termite assessment, the damaged surface area caused by marine borers was quantified by visual inspection of exposed surfaces. This damage intensity was classified into five classes (**Table 3**).

**Table 2.** Classification of damage to wooden bait caused by termite attack (ASTM 2008)

| Value | Damage intensity |
|---|---|
| 10 | No attack, 1–2% minor damage allowed |
| 9 | Penetration of 3% of the cross-section |
| 8 | Penetration of 3–10% of the cross-section |
| 7 | Penetration of 10–30% of the cross-section |
| 6 | Penetration of 30–50% of the cross-section |
| 4 | Penetration of 50–75% of the cross-section |
| 0 | Penetration >75% of the cross-section |

The damage intensity for both termite and marine borer attacks was calculated using Equation 1 (SNI 2014):

$$Damage\ intensity(\%) = \frac{a}{b} \times 100\% \quad (1)$$

where *a* is the damaged area (measured as the cross-sectional area for termites, or the surface area for marine borers, in $cm^2$), and *b* is the initial total area of the respective measured section ($cm^2$).

**Table 3.** Classification of wood resistance to marine borers (SNI 2014)

| Class | Resistancy | Damage intensity (%) |
|---|---|---|
| I | Very resistant | < 7.0 |
| II | Resistant | 7.0–27.0 |
| III | Moderately resistant | 27.1–55.0 |
| IV | Not resistant | 55.1–80.0 |
| V | Very poor resistance | > 80.0 |

### *2.6. Analysis of Soil Characteristics*

Soil analysis was performed to determine the soil characteristics and content at the research locations. Soil samples, weighing a minimum of 1 kg, were taken from the 10 sample villages at depths of 0–20 to 0–25 cm using a crowbar (Arinana et al. 2022; Ge et al. 2019). Subsequently, the samples were analyzed at the Indonesian Center for Biodiversity and Biotechnology (ICBB) Laboratory in Bogor. The analysis included determining soil texture (percentages of sand, silt, and clay) using Pipette-Gravimetry, measuring soil pH via potentiometry, and quantifying organic carbon (C-organic) content using the Walkley and Black method with a Shimadzu UV-1900i UV-Vis spectrophotometer (Shimadzu Corp., Kyoto, Japan).

### *2.7. Measurement of Air Temperature and Humidity in Residential Environments*

Air temperature and humidity data were measured and recorded using an LCD Digital Temperature Humidity Data Logger Meter Model GSP-6 (Elitech Technology, Inc., Milpitas, CA, USA). The data were recorded in the device's memory daily for three months, from August to November 2025. However, it should be noted as a methodological limitation that the logger was placed in only one of the sample villages (Maliaro) in Ternate City.

### *2.8. Measurement of Seawater Temperature, pH, and Salinity*

Data on the temperature, pH, and salinity of seawater at the two marine borer baiting locations were collected once a month: at installation, during the first and second monitoring periods, and at bait retrieval. Measurements were taken using a digital multiparameter water quality tester (EZ9909SP, generic OEM, Shenzhen, China).

### *2.9. Data Analysis*

Data analysis was conducted quantitatively and qualitatively. Quantitative data were processed using Microsoft Excel. Qualitative data were presented as images and narratively explained based on field observations.

## 3. Results and Discussion

### *3.1. Termites Identification*

The research results show that five termite genera (**Fig. 4**), comprising both subterranean and arboreal species, were found across the sample villages using observation and baiting methods. To improve clarity, the distribution of these termite species across sampling locations and methods is summarized in **Table 4.** Notably, *Nasutitermes* sp., which is typically arboreal or wood-nesting rather than strictly subterranean, was found using both observation and baiting methods across multiple sub-districts.

**Table 4.** Distribution of identified termite species based on sampling methods and locations in Ternate City

| Termite species | Sampling method | Location (village - sub-district) |
|---|---|---|
| *Nasutitermes* sp. | Observation | Tafure (North Ternate), Taduma (Ternate Island), Soa (North Ternate), Sulamadaha (West Ternate), Malikrubu (Central Ternate) |
| *Nasutitermes* sp. | Baiting | Dufa-dufa (North Ternate) |
| *Microcerotermes* sp. | Observation | Gambesi (South Ternate) |
| *Macrotermes* sp. | Observation | Foramadiahi (Ternate Island) |
| *Coptotermes* sp. | Baiting | Malikrubu (Central Ternate) |
| *Odontotermes* sp. | Baiting | Foramadiahi (Ternate Island) |

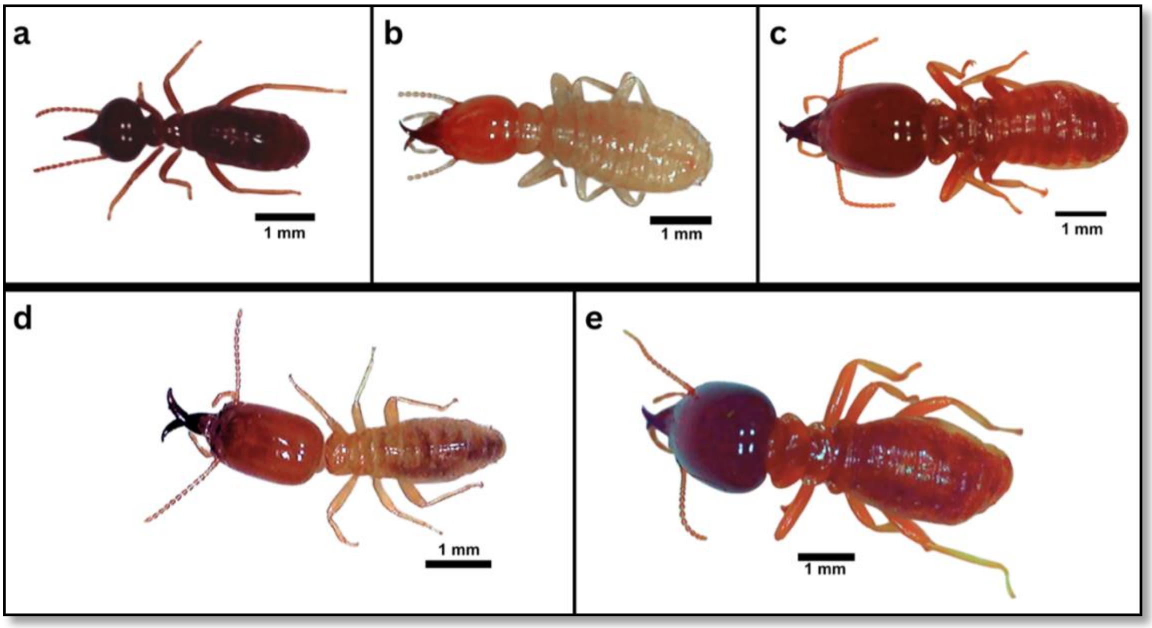


**Fig. 4.** Termite specimens attacking the wooden baits: (a) *Nasutitermes* sp., (b) *Coptotermes* sp., (c) *Macrotermes* sp., (d) *Microcerotermes* sp., and (e) *Odontotermes* sp.

The identification of these genera was primarily based on the distinct morphological diagnostic features of the soldier caste. For instance, *Coptotermes* sp., identified from baiting in Malikrubu Village, possesses an oval- to pear-shaped head, a large fontanelle at the front of the head that can secrete a milky-white defensive fluid, and saber-shaped mandibles devoid of marginal teeth. *Coptotermes* sp. is a group widely reported as the most destructive termite globally. Termites from this genus, particularly *Coptotermes formosanus* and *Coptotermes gestroi*, are known to have extremely large colonies, an ability to forage up to tens of meters from the nest, and a significantly higher rate of wood consumption compared to other genera like *Nasutitermes*, *Macrotermes*, *Microcerotermes*, and *Odontotermes* (Andika et al. 2025).

In this study, *Coptotermes* sp. was identified as the only species attacking the baits in Malikrubu Village. The environmental conditions at this location pose a specific ecological challenge that highlights the adaptive nature of this genus (Nurhadi et al. 2023). Soil analysis from Malikrubu revealed a predominantly sandy texture (68.5% sand), a slightly alkaline pH (7.65), and relatively low organic carbon content (0.92%). Typically, high sand content leads to rapid drainage and sharp fluctuations in moisture, which can severely restrict the foraging capabilities of many moisture-dependent subterranean termites (Richardson and Sun 2023). However, *Coptotermes* is globally recognized for its highly aggressive foraging behavior, extensive tunnel networks, and exceptionally large colony sizes (Pournou 2020). These distinct biological advantages likely enable the *Coptotermes* population in Malikrubu to overcome the limitations of the sandy, well-drained soil. By maintaining protective, moisture-retaining mud tubes that connect their deeper subterranean nests directly to above-ground wood sources, they sustain their foraging activity. Consequently, despite localized edaphic conditions that might deter less robust species, the aggressive biological profile of *Coptotermes* enables it to successfully colonize and cause severe structural damage in this residential microhabitat.

Another species identified, *Nasutitermes* sp., is easily distinguished by its pear-shaped head that extends into a prominent snout (nasus), which secretes defensive chemicals and by the absence of functional mandibles. While often generalized with soil-dwelling pests, *Nasutitermes* is primarily arboreal or wood-nesting, adapting well to both natural trees and residential coastal environments in Ternate. The other genera identified also exhibited characteristic features that support their ecological roles.

*Macrotermes* sp. is morphologically distinct due to its notably large body size and robust mandibles. This species, belonging to the subfamily Macrotermitinae, is symbiotically associated with the fungus *Termitomyces* and is known for building complex nest structures and for being a major decomposer of lignocellulose in tropical ecosystems. However, some species may also act as pests (Patel et al. 2019).

*Microcerotermes* sp., identified from Gambesi Village, has a relatively small body size with soldiers characterized by an elongated head and slender mandibles. This group generally nests in soft or decaying wood and can cause gradual damage to building structures (Arinana et al. 2025).

Furthermore, the genus *Odontotermes*, found in Foramadiahi Village, is morphologically distinguished in the soldier caste by its robust mandibles, most notably by a characteristic marginal tooth on the inner edge of the left mandible (Krishna et al. 2013). Ecologically, this genus is known as a soil termite that processes organic matter and breaks down wood through cooperation with symbiotic fungi. Some of its species are also recorded as important pests in agricultural and forestry ecosystems in tropical Asia (Dao et al. 2025).

The variation of termite genera found in Ternate City indicates the high diversity of termitofauna in the humid tropical environment. Environmental factors such as high humidity, the availability of wood substrate, and soil conditions support the existence of diverse subterranean termite populations. Ecologically, termites play an important role in the decomposition of organic matter and nutrient recycling. However, several groups, such as *Coptotermes* and *Macrotermes*, still require attention due to their potential to damage buildings and cultivated plants.

### *3.2. Marine Borer Identification*

The research also identified 12 species of marine borers through direct observation across six locations: Tolire Beach, Rua Beach, Gam Lamo Beach, Tafure Beach, Tobololo Beach, and Gambesi Beach. Furthermore, seven species of marine borers were collected using the baiting method at two locations: Ake Rica Beach and Jikomalamo Beach (**Fig. 5**).

**Figs. 5** and **6** show that the coastal areas of Ternate harbor a biological community that plays a significant role in wood bioerosion, particularly marine wood-boring organisms. The most dominant groups belong to the family Teredinidae, including *Teredo navalis*, *S. obtusa*, *L. pedicellatus*, and *Spathoteredo spatha*, as well as species of the genus *Bankia* (*Bankia carinata*, *B. gouldi*, *B. campanellata*, and *B. bipalmulata*), and *Nausitora dunlopei* and *Nausitora oahuensis*. Overall, 18 species/taxa were identified using both observation and baiting methods. These organisms are known globally as the most aggressive wood-destroyers in marine environments due to their ability to bore into wood using pallet structures and excavate long tunnels, which drastically decrease the wood's mechanical strength (Pournou 2020). Research by Harbo et al. (2025) indicates that shipworms can bore through wood at several centimeters per week and destroy wooden pier structures within months in environments with high salinity and warm temperatures, such as the waters of Ternate.

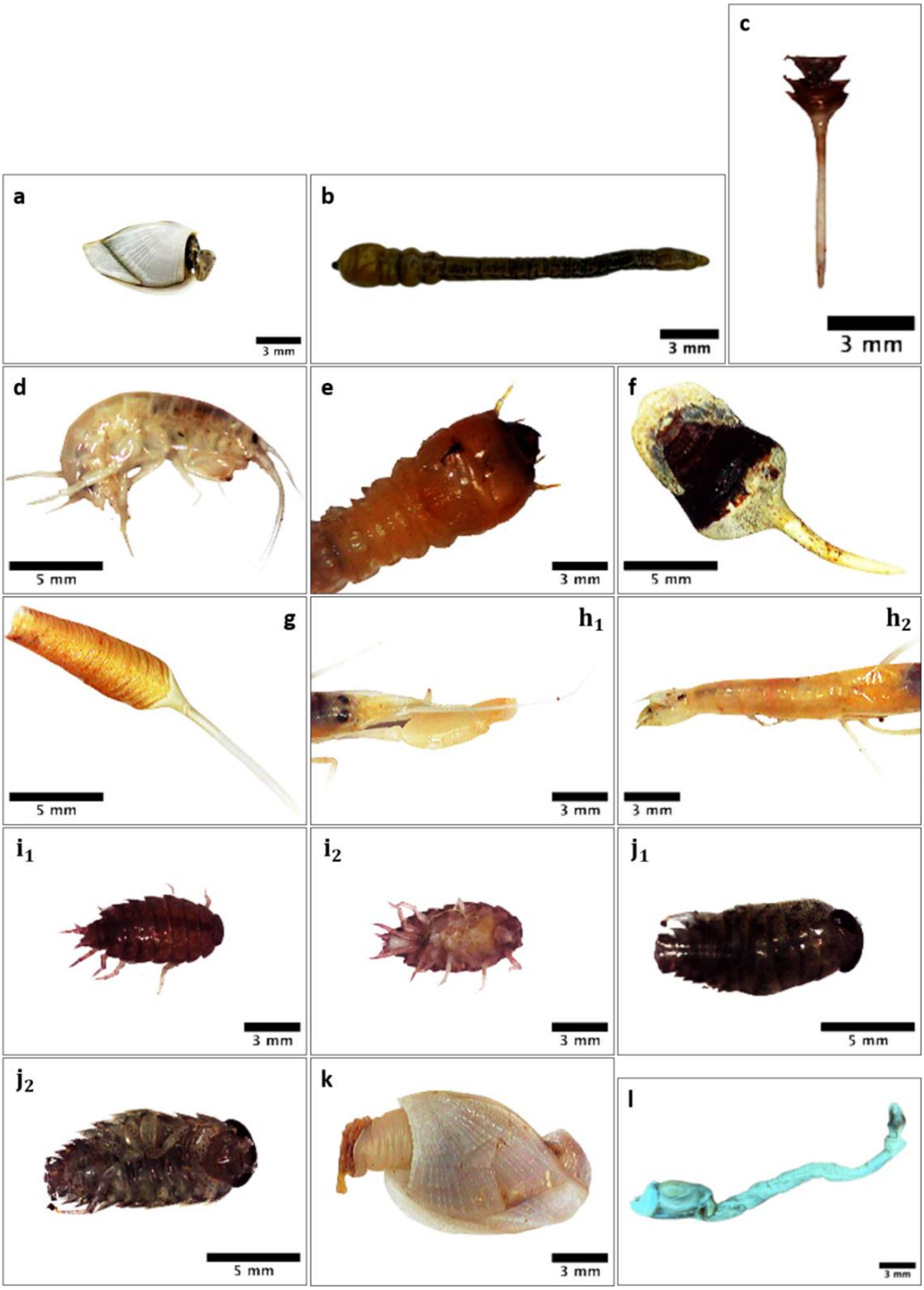


**Fig. 5**. Marine borer specimens from Ternate City. Locations: Tolire (TL), Rua (RU), Tafure (TF), Gambesi (GB), Gam Lamo (GL), and Tobololo (TB). Views: (1) head/front, (2) tail/rear. (a) *Lepas pectinata* (TL); (b) *Phaeonops* sp. larva (RU); (c) *Bankia carinata* (TF); (d) *Tropichelura insulae* (GB); (e) *Cenoloba obliteralis* larva (GL); (f) *Spathoteredo obtusa* (TF; 1, 2); (g) *Bankia gouldi* (TF; 1, 2); (h) *Synalpheus neomeris* (TF; 1, 2); (i) *Porcellionides pruinosus* (TF; 1, 2); (j) *Ligia hawaiensis* (TF; 1, 2); (k) *Amigdoscalpellum elegans* (TB); (l) *Lyrodus pedicellatus* (TF).

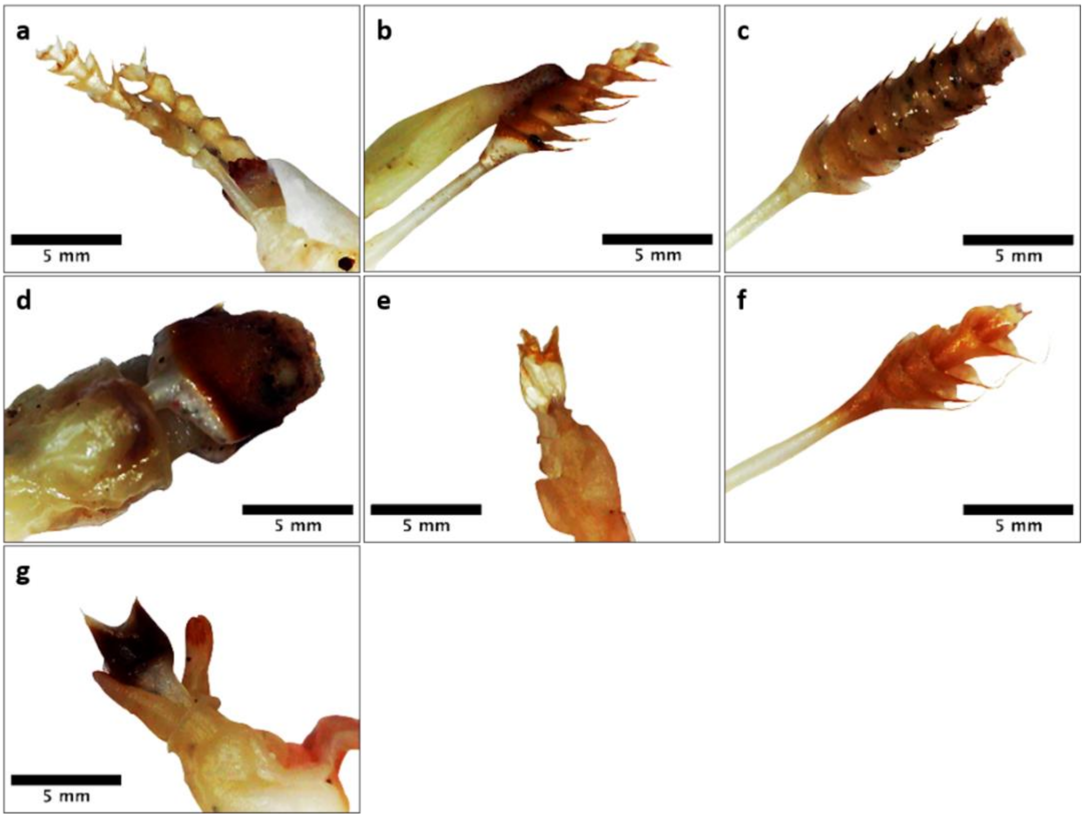


**Fig. 6.** Marine borer specimens collected using baiting methods in Ternate City. Locations: Ake Rica Beach, Rua Village (AR) and Jikomalamo Beach, Takome Village (JK). (a) *Bankia campanellata* (AR); (b) *Bankia carinata* (AR); (c) *Spathoteredo spatha* (AR); (d) *Nausitora dunlopei* (JK); (e) *Nausitora oahuensis* (JK); (f) *Bankia bipalmulata* (JK); (g) *Teredo navalis* (JK).

The presence of *Teredo navalis* in locations such as Jikomalamo is significant, as this cosmopolitan shipworm has caused extensive damage to piers and other wooden marine structures worldwide. The research by Palanti et al. (2022) also reinforces the idea that shipworm recruitment occurs more rapidly in warm waters, where experimental wood panels can show significant damage within five years. This aligns with field data from Ternate, particularly at Ake Rica Beach and Jikomalamo Beach, where baiting identified various species of *Bankia*, *Nausitora*, and *Teredo*. This indicates that these areas have an extreme risk of damage if not properly protected.

In addition to the Teredinidae group, the discovery of *Tropichelura insulae* at Gambesi Beach indicates secondary wood-borer activity. Cheluridae typically collaborate with isopods such as Limnoria, expanding cavities created by shipworms and accelerating wood decay. In other locations, such as Tolire, Rua, Gam Lamo, and Tobololo beaches, the most frequently observed organisms are fouling biota, including *Lepas pectinata* and *Amigdoscalpellum elegans*, as well as supralittoral organisms, including *Ligia hawaiensis* and *Porcellionides pruinosus*. Although fouling organisms do not bore into the wood directly, their presence can increase the substrate's vulnerability to shipworm attack. López (2026) states that biofouling can trap moisture, create micro-cracks, and make the wood surface more easily penetrable by shipworm larvae. This explains why these locations, despite not showing high numbers of shipworms at the time of observation, still face a high risk of borer colonization if there is continuous contact with pier wood.

### *3.3. Frequency of Termite and Marine Borer Attacks on Wooden*

The research results show that the frequency of termite attacks on the bait in Ternate City was 2.7%, classified as Class 2 (very low) according to **Table 1**. This percentage was calculated cumulatively across all sites, where only three out of 125 installed samples were attacked. It is important to note that while direct observations revealed a widespread spatial distribution of termites across multiple villages, their actual infestation on the standardized baits was highly clustered. A spatial comparison across the 10 sample villages reveals that attacks were recorded exclusively in Dufa-Dufa, Gambesi, and Malikrubu, while the remaining seven villages recorded no attacks. This fragmented pattern suggests that in residential urban environments like Ternate, subterranean termite foraging is highly patchy. The presence of attacks is likely driven by specific microhabitat suitability, such as Gambesi's high organic carbon content or Dufa-Dufa's moisture-retaining silt-clay fractions, rather than by a uniform citywide distribution. This contrasts with studies by Arinana et al. (2023, 2025) and Nurhadi et al. (2023) in Bogor, West Java, where attack frequencies reached 38%, 70%, and 39.4%, respectively. The low frequency of termite attacks in Ternate City is suspected to be due to an insufficient baiting period. Similarly, in the study by Arif et al. (2020), subterranean termites in Makassar did not begin attacking until after a six-month baiting period. Conversely, the frequency of marine borer attacks reached 100%, meaning that all installed baits were attacked and classified as Class 6 (very high). This difference in frequency reflects differences in habitat dynamics, organism physiology, and food availability across the two distinct environments.

Subterranean termites exhibit foraging behavior influenced by humidity, soil structure, and ecological interaction with vegetation in settlements. Termite activity in terrestrial habitats often varies temporally and is influenced by local environmental factors (e.g., temperature and humidity), which explains the low frequency (Arinana et al. 2022). Conversely, marine borers are ecologically adapted to saline aquatic environments and are known to attack submerged wood intensively. These organisms include various taxa such as shipworms (*Teredo* spp.) and borer crustaceans like *Limnoria* spp., which actively bore into and consume wood for shelter and nutrition beneath the sea surface (marine wood borers) (Zabel et al. 2020). This vulnerability is exacerbated by the physiological characteristics of marine borers, which can enter wood tissue through very small larvae and subsequently develop into large populations within the wood, often leading to severe structural degradation even when the exterior surface appears intact (shipworm damage) (Hernández and Angelini 2019). Overall, this empirical data aligns with the research profile: termite attacks in settlements can be very low due to local ecological factors, while marine borers show a strong predisposition to attack submerged wooden structures.

### *3.4. Intensity of Wood Bait Damage*

The research results indicate that most wooden baits in the 10 sample villages had a damage intensity score of 10, indicating no termite attack. This pattern is consistent with the findings of Arif et al. (2020), who reported that in most observation stations in Makassar City, the baits did not experience termite attacks and were classified as having low intensity based on the ASTM D1758-08 standard (ASTM 2008), even though the area was ecologically still considered to have the potential for subterranean termite attack. In that study, only a small portion of the stations showed high attack intensity, while the majority of locations remained in the low-intensity or no-significant-attack category.

A comparison of damage intensity across the 10 sample villages reveals stark spatial variations that help explain the observed differences. While seven villages exhibited no significant attack on the baits (Score 10), severe localized damage was observed exclusively in three locations: Dufa-Dufa (Score 8), Gambesi (Score 6), and Malikrubu (Score 0) (**Fig. 7**). This discrepancy can be explained by the highly localized distribution of specific termite genera and their interaction with the varying soil microclimates. Based on the ASTM D1758-08 standard (ASTM 2008), a damage level with penetration > 75% is classified as severe damage (score 0), which is generally associated with the activity of aggressive subterranean termite species, such as *Coptotermes* and *Schedorhinotermes*. The severity of these attacks is ecologically supported by local soil parameters: Dufa-Dufa's higher silt-clay fraction acts as an essential moisture buffer, while Gambesi's high soil organic carbon content provides an optimal, nutrient-rich microenvironment that accelerates decomposition. Specifically, in Malikrubu Village, *Coptotermes* sp. was identified attacking the baits, resulting in a very severe score (Score 0). While Malikrubu features sandy soil with rapid moisture fluctuations, the extremely aggressive foraging behavior and large colony size of *Coptotermes* allow it to overcome these limitations to inflict massive structural damage. This finding aligns with the report by Arif et al. (2020), which states that even if termite attack frequency in a region is relatively low, the presence of active termite colonies in specific locations can cause severe, localized wood damage.


**Fig. 7.** Damage to wooden baits caused by termites: (a) *Nasutitermes* sp. in Dufa-Dufa Village, North Ternate Sub-district, (b) *Microcerotermes* sp. in Gambesi Village, South Ternate Sub-district, (c) *Coptotermes* sp. in Malikrubu Village, Central Ternate Sub-district.

Furthermore, **Figs. 8** and **9** show the attack intensity on the baits. The specific attack intensity was 63.45% at Ake Rica Beach and 58.12% at Jikomalamo Beach, yielding an average of 60.8%. This indicates a moderately severe marine borer attack; thus, it is classified as Class IV (not resistant to attack) under SNI 7207:2014 (SNI 2014), with a baiting period of only three months. Visually, the bait wood from Ake Rica Beach (**Fig. 8**) exhibits more extensive damage compared to Jikomalamo Beach (**Fig. 9**), which corresponds with the higher attack intensity recorded at that location. The classification for bait damage intensity in the SNI standard is applicable for a six-month baiting period, so it is suspected that if the baiting period were extended to six months, the intensity of the marine borer attack in Ternate City would be higher than 60.8%. This anticipated increase aligns with the level of biological degradation of the wood: the higher the percentage, the more severe the level of marine organism attack on the wooden structure. For example, research on wood in the Black Sea region showed that colonization by organisms such as *Teredo navalis* can significantly alter the chemical composition and structure of the wood over several months of marine exposure, thereby accelerating material deterioration (Can and Sivrikaya 2020).


**Fig. 8.** Damage to wood caused by marine borers at Ake Rica Beach, Rua Village, Ternate Island Sub-district.

*3.5. Soil Characteristics*

The soil analyzed in the 10 sample villages in Ternate City (**Table 5**) was dominated by a sandy loam texture with a neutral to slightly alkaline pH range (6.92–8.04) and low to medium organic carbon content (0.29–3.52%). Such edaphic conditions are important for explaining the termite findings on the wooden baits (**Fig. 4**), because texture controls water retention and the ease of constructing tunnels/nests (Yu et al. 2023), while organic carbon reflects the availability of organic matter as a direct or indirect energy source (through litter and microbial activity) (Adekiya et al. 2023), and pH affects nutrient dynamics and microbial communities that are part of the decomposition network (Barrow and Hartemink 2023). A cross-disciplinary review of soil interaction with termites emphasizes that the physicochemical properties of the soil (including texture and composition) limit termite activity. In contrast, termite activity can modify the hydraulic/structural properties of the soil and the distribution of organic matter at the microhabitat scale.


**Fig. 9.** Damage to wood caused by marine borers at Jikomalamo Beach, Takome Village, West Ternate Sub-district.

In Dufa-Dufa Village, the termite found was *Nasutitermes* sp. (**Fig. 4a**). The Dufa-Dufa soil had a sandy-loam texture with 55.5% sand, 36.4% silt, 8.1% clay, a pH of 6.92, and an organic carbon content of 1.77% (**Table 5**). The combination of a substantial silt-clay fraction totaling 44.5% potentially increases micro-moisture stability compared to highly sandy soil, thereby supporting the foraging activity of termites, which are sensitive to desiccation. An experimental study by Jin et al. (2020) also showed that the presence of clay material under low moisture content can increase the "vigor" (survival and body water status) of termites and influence their habitat preference, confirming the role of fine fractions as a moisture buffer. With a neutral pH and a medium organic carbon content, the Dufa-Dufa environment provides reasonable conditions for decomposer activity and bait utilization by *Nasutitermes*, which is ecologically known to be adaptive to habitats with lignocellulose sources and relatively adequate moisture.

In Malikrubu Village, the species found was *Coptotermes* sp. (**Fig. 4b**). Malikrubu soil had high sand content (68.5%), 5.1% clay, a pH of 7.65, and an organic carbon content of 0.92% (**Table 5**). Physically, the sand dominance indicates rapid drainage and sharper moisture fluctuations; however, *Coptotermes* is a subterranean termite known to be capable of building tunnel networks to explore food sources and maintain connectivity with the nest under various soil conditions, as long as a wood source (bait) and moist microhabitats below the surface are available (Garg et al. 2023; Jin et al. 2020).

In Gambesi Village, the species found was *Microcerotermes* sp. (**Fig. 4d**). The Gambesi soil had a sandy loam texture (65.5% sand, 30.2% silt, 4.3% clay), a pH of 7.52, and high organic carbon content (3.16%) (**Table 5**). The higher organic carbon content indicates greater input of litter/organic material and/or better stabilization of organic material; this condition is relevant because wood- and litter-feeding termites interact strongly with decomposer microbial communities, both in the soil environment and in their digestive tracts. Recent microbiological studies on wood-feeding termites (including *Microcerotermes*) confirm that their ability to degrade lignocellulose is supported by a gut microbial consortium whose function is closely linked to the food substrate (wood/litter) and the surrounding environment (Xie et al. 2024). Thus, the high organic carbon content in Gambesi can be viewed as an indicator of a more "productive" habitat for decomposition and foraging by *Microcerotermes* on the baits.

In Foramadiahi Village, the species found was *Odontotermes* sp. (**Fig. 4e**). Foramadiahi soil had a sandy-loam texture with 66.4% sand, 21.1% silt, the highest clay content (12.5%), a pH of 7.63, and an organic carbon content of 0.95% (**Table 5**). Although the surface soil organic carbon content is relatively low, the higher clay fraction at this location potentially increases water retention. This clay serves as a binding material for structural construction, a crucial factor for the Macrotermitinae group (including *Odontotermes*), which builds nesting/chamber systems that maintain humidity (Shanbhag et al. 2017). Additionally, *Macrotermes* sp. in Foramadiahi Village (**Fig. 4c**) is very well known as an "ecosystem engineer" (Muvengwi et al. 2016).

**Table 5.** Soil characteristics in the 10 sample villages in Ternate City

| No | Sample village | pH | Organic carbon (%) | Sand (%) | Silt (%) | Clay (%) | Texture |
|---|---|---|---|---|---|---|---|
| 1 | Maliaro | 7.34 | 0.29 | 57.40 | 32.20 | 10.50 | Sandy loam |
| 2 | Dufa-Dufa | 6.92 | 1.77 | 55.50 | 36.40 | 8.10 | Sandy loam |
| 3 | Sulamadaha | 7.02 | 3.52 | 53.40 | 45.20 | 1.40 | Sandy loam |
| 4 | Tobololo | 8.04 | 2.46 | 63.30 | 27.70 | 8.00 | Sandy loam |
| 5 | Jati | 7.05 | 2.15 | 50.70 | 40.80 | 8.50 | Loam |
| 6 | Gambesi | 7.52 | 3.16 | 65.50 | 30.20 | 4.30 | Sandy loam |
| 7 | Malikrubu | 7.65 | 0.92 | 68.50 | 26.40 | 5.10 | Sandy loam |
| 8 | Soa | 7.57 | 2.55 | 56.70 | 35.00 | 8.30 | Sandy loam |
| 9 | Kastela | 7.00 | 1.19 | 91.10 | 7.50 | 1.40 | Sand |
| 10 | Foramadiahi | 7.63 | 0.95 | 66.40 | 21.10 | 12.50 | Sandy loam |

In the remaining six sample villages (Maliaro, Sulamadaha, Tobololo, Jati, Soa, and Kastela), no termite attacks on the wooden baits were recorded during the study period. Although their soil characteristics largely fell within similar ranges of sandy loam textures (except for Kastela, which was predominantly sand) and adequate pH levels (**Table 5**), the absence of bait infestation in these locations might be attributed to micro-environmental factors, limited local colony foraging ranges, or the presence of alternative, naturally abundant wood sources nearby.

### *3.6. Temperature and Humidity in Residential Environments*

**Fig. 10** shows the fluctuation of air temperature and humidity in Ternate City from August 31 to November 25, 2025. The air temperature in Ternate City's residential environment, ranging from 23.9 °C to 36.6 °C with an average of 28.9 °C, is hotter, particularly at the upper end, compared to the previous study by Arinana et al. (2025) in Bogor City (25.3 °C to 31.5 °C). Coupled with the extremely high humidity in Ternate (71.0%–99.9%, averaging 90.7%), similar to that of Bogor (67.6%–91.9%; Arinana et al. 2025), these conditions create a thermally intense tropical environment for termites. This high humidity supports the overall activity of subterranean termites. Yet their attack frequency was very low, at 2.7% in Ternate's residential areas, likely due to localized soil conditions and microhabitat variation. Nevertheless, when active colonies are present, particularly those of the aggressive *Coptotermes* sp., severe localized damage can occur, with material losses exceeding 75% at affected sites. Consequently, the residential infrastructure in Ternate City remains highly vulnerable to rapid structural degradation wherever termite colonies establish themselves in these optimal microclimates.

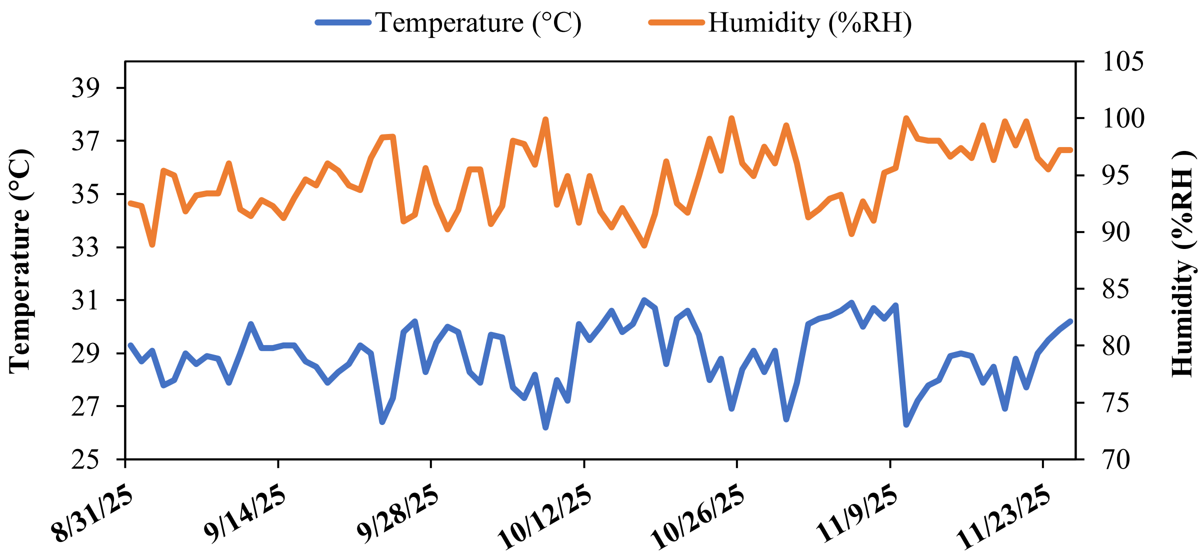


**Fig. 10.** Fluctuation of air temperature and humidity in Ternate City from 31 August to 25 November 2025.

### *3.7. Seawater Temperature, pH, and Salinity*

The results of seawater environmental parameter measurements, salinity, temperature, and pH, at the two bait installation locations, Jikomalamo Beach and Ake Rica Beach (**Table 6**), reveal the specific abiotic conditions driving the 100% marine borer attack frequency observed in this study. A direct comparison between the two beaches shows distinct environmental profiles. Jikomalamo Beach maintained highly stable conditions throughout the August to November 2025 period, with salinity fluctuating narrowly between 34–35 ppt, a gradual increase in temperature from 27 °C to 30 °C, and consistently alkaline pH levels (8.08–8.4). In contrast, Ake Rica Beach experienced wider environmental fluctuations, characterized by a broader temperature range (25–31 °C), a noticeable drop in pH to 7.04 in October, and a significant salinity spike reaching 38 ppt in September. This range reflects typical tropical marine water conditions suitable for marine organisms, including marine borers. Recent studies (Bersoza and Angelini 2019; Harbo et al. 2025; Pournou 2020) indicate that marine borers, particularly those from the Teredinidae and Pholadidae families, generally thrive optimally at salinities of 30–40 ppt and temperatures of 25–32 °C.

**Table 6.** Measurement of temperature, salinity, and pH at two bait installation locations

| Beach location | Parameter | | | Date |
|---|---|---|---|---|
| | Salinity (ppt) | Temperature (°C) | pH | |
| Jikomalamo | 34 | 27 | 8.1 | 31 August 2025 |
| Ake Rica | 34 | 25 | 8 | |
| Jikomalamo | 35 | 28 | 8.12 | 29 September 2025 |
| Ake Rica | 38 | 26 | 8.8 | |
| Jikomalamo | 35 | 30 | 8.08 | 27 October 2025 |
| Ake Rica | 34 | 31 | 7.04 | |
| Jikomalamo | 34 | 30 | 8.4 | 24 November 2025 |
| Ake Rica | 35 | 31 | 8 | |

The relatively small salinity difference between the two locations indicates that salinity is not the main limiting factor for the presence of marine borers. However, the increase in salinity to 38 ppt at Ake Rica Beach in September 2025 may favor the dominance of *Bankia* and *Teredo* species, as López (2026) and López et al. (2024) reported that the genus *Bankia* is highly tolerant of full marine salinity. These findings are consistent with the current study, which identified *Bankia campanellata*, *B. bipalmulata*, and *B. carinata* at this site.

The measured water temperature was within the optimal range for the growth and metabolic activity of marine borers. The temperature increases up to 31 °C in October and November at Ake Rica Beach, potentially accelerating the rate of wood boring, because warmer temperatures increase enzymatic activity and the consumption of the wood substrate by teredinids (Pournou 2020; Thatje and Hall 2016). This condition may explain the high diversity of marine borer species observed through baiting, which yielded 7 species from just 2 installation sites over a brief 3-month period. This level of diversity is remarkably high when compared to the 12 species found through direct observation, which required extensive searching across six different coastal locations.

The pH value of the waters at both locations ranged from neutral to weakly alkaline. This relatively stable pH supports the calcification process and the survival of marine borer larvae. Research by Ferreira et al. (2024) indicates that an extreme drop in pH can inhibit teredinid growth, but pH values within 7–8.5 are still well tolerated. Thus, the pH conditions at Jikomalamo Beach and Ake Rica Beach are conducive to the colonization and development of marine borers.

The correlation between the environmental parameters and the marine borer findings at the research locations indicates that the physicochemical conditions of the waters at both beaches are highly conducive to the colonization of marine wood-destroying organisms. The discovery of species such as *T. navalis*, *B. carinata*, and *N. dunlopei* at the Jikomalamo location suggests that the waters there have strong circulation and sufficient oxygen. Furthermore, the presence of *T. navalis* in the high-salinity waters of Ternate is particularly noteworthy. While this species is globally recognized for its high tolerance of low-salinity (brackish) environments, its successful colonization in these hypersaline tropical conditions highlights its remarkable physiological plasticity. It confirms its status as a highly adaptable cosmopolitan species (Borges et al. 2014).

Overall, our data demonstrate that specific microenvironmental variations between the locations dictate the species composition, yet both environments remain exceptionally conducive to marine borer attacks. Salinity spikes and warming trends are primary drivers shaping the localized diversity and aggressive boring rates of the Teredinidae family in Ternate City.

## 4. Conclusions

This study shows that Ternate City harbors a diverse array of subterranean termites and marine borers capable of damaging wood in terrestrial and coastal environments. The subterranean termites found consist of five genera: *Nasutitermes*, *Coptotermes*, *Macrotermes*, *Microcerotermes*, and *Odontotermes*. The frequency of termite attack on baits was classified as very low, but in specific locations, especially those attacked by *Coptotermes* sp., very severe wood damage occurred. Conversely, the attack of marine borers on the baits in the coastal area was classified as very high, with an attack frequency reaching 100% and an average damage intensity of 60.8% within three months. Marine borer species were dominated by the Teredinidae family, known for its aggressive destruction of marine wood. The soil and water conditions in Ternate City generally support the presence of both organisms. Consequently, wood degradation in Ternate City is significantly more prone to marine borers than to subterranean termites. Furthermore, the findings of this study provide critical baseline data for the development of future wood preservation strategies and the construction of more durable maritime infrastructure in tropical regions.

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**Author Contributions**

F.L.: Investigation, Formal Analysis, Data Curation, Visualization, Software, Writing – Original Draft Preparation; A.A.: Conceptualization, Methodology, Supervision, Project Administration; A.F.: Validation, Resources, Writing – Review and Editing; U.M.: Investigation, Formal Analysis; R.A.: Writing – Review and Editing.

**Conflict of Interest**

The authors declare no conflict of interest.

**Declaration of Generative AI and AI-Assisted Technologies in the Manuscript Preparation**

During the preparation of this work, the authors used Gemini AI to translate and paraphrase the sentences. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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