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Identification of the pest outbreak in the coastal mangrove ecosystem of Mahakam Delta, East Kalimantan, Indonesia

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Abstract. *Harmonis, Haqiqi MT, Fahroni MFA, Jefry, Gunawan S, Sekedang MA, Rahmat D, Azhar NF, Putra MOPS, Kusuma FD, Hapsari MT, Muhammad FA, Diana R, Sudarmadji T, Amirta R, Ariyanto, Saud OR, Sofyan FPM, Fajriansyah, Asngari AMS, Bulo YS, Salman I, Rizaldi R, Lubis KM. 2024. Identification of the pest outbreak in the coastal mangrove ecosystem of Mahakam Delta, East Kalimantan, Indonesia. Biodiversitas 25: 829-835.* Mangrove ecosystems are considered the most essential areas in the wetland since they sequester carbon more efficiently than terrestrial ecosystems. Thus, they have received significant attention as a nature-based solution to achieve the Naturally Determined Contributions in the commitment to global climate change mitigation. Currently, the degradation of mangroves has been linked to serious threats, including pest outbreaks. Our primary objective was to assess the pest outbreaks that occurred in the coastal mangroves of the Mahakam Delta, Indonesia. This study was conducted in two areas in Tanjung (R1 and R2) and one area in Pulau (R3). A total of 19 observation plots with a size of 10×10 m^2 were made. The water quality was further measured to identify the natural conditions affecting the outbreaks. In the present study, it was found that significant disturbance of the mangrove plants occurred due to invasions by *Amphibalanus amphitrite* Darwin, 1854 and *Sphaeroma terebrans* Spence Bate, 1866. The dangerous attack from *S. terebrans* has only been found at the R1 site, where we found environmental conditions such as high dissolved oxygen (DO), high total dissolved solids (TDS), and high salinity. In this area, it could affect the death of adult *Avicennia alba* Blume and *Sonneratia alba* Sm. The results obtained from this study are expected to provide preliminary data to design the best management practices in order to enhance the effectiveness of the mangrove rehabilitation strategy in the Mahakam Delta.

Keywords: Blue carbon, coastal wetland, Mahakam delta, mangrove, pest invasion

INTRODUCTION

Mangrove forests are dynamic intertidal ecosystems generally confined to the tropical and subtropical zones along the coastline areas (Zhang et al. 2021). This type of forest is discovered at the latitudes of 30o N and 30o S (Teka et al. 2019; Swangjang and Panishkan 2021). They have been reportedly found in excess of 100 countries on five different continents (Hamilton and Casey 2016). Due to their location at the interface between land and sea, mangroves possess unique varieties of salt-tolerant vegetation, which taxonomically comprise only 70 true plant species (Polidoro et al. 2010; Ragavan et al. 2016; Thatoi et al. 2016; Ragavan et al. 2018; Chowdhury et al. 2023). Nevertheless, they provide a significant contribution to purifying the environment and mitigating the influence of climate change because of their excessive carbon sequestration capability compared to other wetland ecosystems (Chen et al. 2023). It is well known that coastal ecosystems can sequester carbon ten times more efficiently than terrestrial forests (Kida and Fujitake 2020). Mangroves are able to be an ecological barrier with various irreplaceable ecosystem services, such as producing food, trapping sediment, controlling erosion and flooding, providing a breeding environment for some marine organisms, maintaining water quality, preventing wind and waves, and protecting the shoreline for coastal megafauna (Lee et al. 2023; Wang et al. 2023). More importantly, they are also recognized as an effective barrier to reducing nitrogen pollution (Nie et al. 2023).

In terms of blue carbon, mangrove ecosystems are considered the most efficient carbon sinks, even though they cover only 0.5% of the total coastal area (Alongi et al. 2014; Jin et al. 2019; Liu et al. 2022). Mangrove vegetation contributes to the high capture of carbon dioxide (CO_2) from the atmosphere, although the vegetation quantity is much lower than the plant biomass on land (Zhong et al. 2023). The high carbon storage in mangroves has been reported in their soil sediments (Cui et al. 2021). Therefore, these phenomena will promote their crucial contribution as one of the natural-based solutions for climate change mitigation worldwide. The blue carbon has received significant interest from many countries globally as a strategy to realize their Nationally Determined Contributions, particularly by maintaining and rehabilitating the mangrove ecosystems (Carnell et al. 2022). Furthermore, the growing interest in carbon markets also affects the significant contribution to the mangrove restoration (Sidik et al. 2018).

Indonesia is the home of the world's biggest mangrove zones (Setyadi et al. 2021). The existing area includes 3.1 million hectares, which is equal to around 20% of the total mangrove forest in the world (Quevedo et al. 2023). However, significant degradation in Indonesian mangrove ecosystems has been reported. According to data from the Ministry of Environment and Forestry (2019), mangrove cover was destroyed by 430,000 ha from 1985 to 2019, while its deforestation rate reached 12,647 per year. The remarkable reduction of woody vegetation in mangroves has negatively enhanced acidification and coastal erosion (Ilman et al. 2016). Thus, their essential ecological functions will be potentially lost. Besides human activities such as aquaculture, urbanization, and industrialization (Zhao et al. 2022), one of the serious threats comes from pest outbreaks. The severe outbreak of the teak defoliator, *Hyblaea puera* Cramer 1777, disturbed carbon sequestration around the coastal zones (Nakhawa et al. 2023). The outbreak of bagworm, *Pteroma plagiophleps* Hampson, 1892, has been reported to be one of the challenges in the plantation of mangroves (Lelana et al. 2022). It could be seen from a one-year *Rhizophora apiculata* Blume plantation in Lubuk Kertang Village, North Sumatera, that it attacked the leaves, influencing the lower photosynthesis process (Basyuni et al. 2019). Risnasari et al. (2021) stated that the sea worm (*Teredo navalis* Linnaeus 1758) was a marine organism that could destroy woody vegetation in mangroves. The most dominant pest in Indonesia is crabs (Crustaceae) (Arifanti et al. 2022), although some pests were also found, including barnacles and insects (Mohti et al. 2014).

Mahakam Delta, which is located in East Kalimantan Province, Indonesia, can potentially be one of the buffer zones for the new Indonesian National Capital City. Since the city promotes a forest city concept, the protection of the mangrove sustainability is very important. However, the disturbance of the mangrove ecosystems in Mahakam Delta due to the pest outbreaks has been observed, particularly in certain coastal areas. Herein, we conducted a study about the pest investigation in order to provide preliminary data to find the best strategy for its restoration in the future. The main scope of this study identified the pest species found and their attacked plant species, the signs and symptoms, the intensity of the outbreak, and natural conditions enhancing the outbreak phenomenon.

MATERIALS AND METHODS

Study sites

The present study was conducted at a shoreside mangrove forest ecosystem located in Muara Jawa, Kutai Kartanegara, East Kalimantan, Indonesia. This area has a monthly rainfall of around 217 mm. We conducted observation in this place, which was divided into three sites based on its different abiotic conditions: two areas in Tanjung (R1 and R2) and one area in Pulau (R3) (117°15'37.56"-117°16'15.63" E and 0°53'5.34"-0°53'16.56" S), as can be seen from Figure 1.

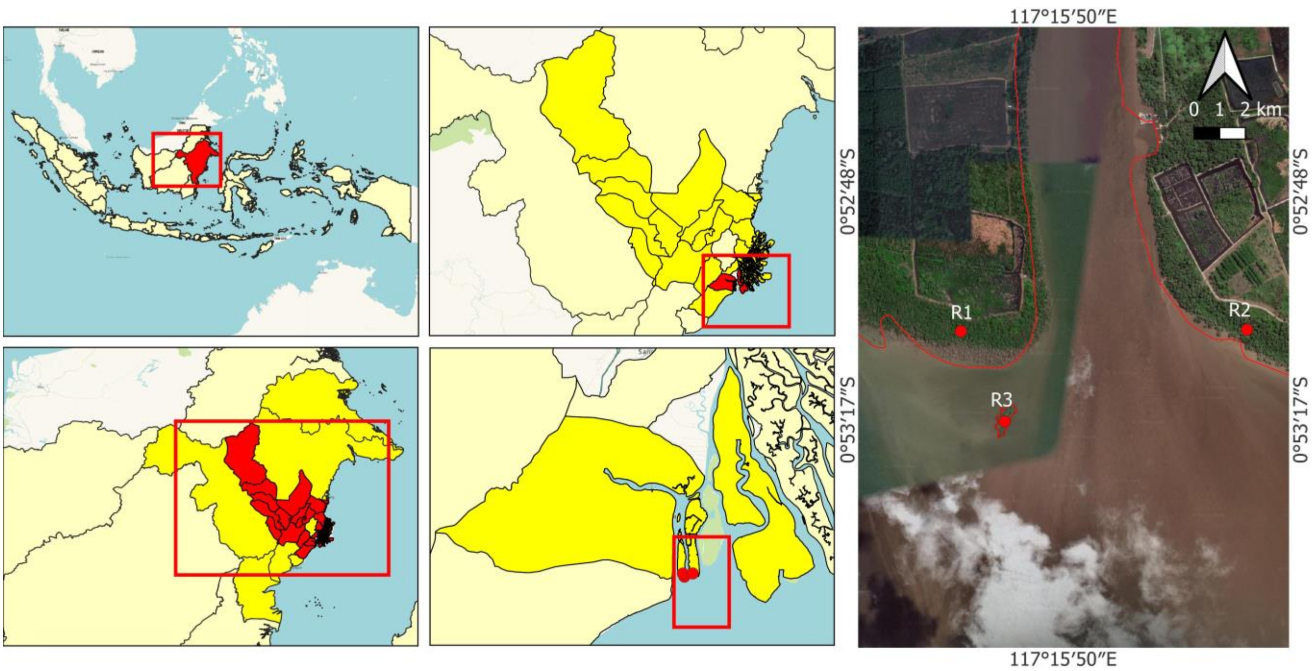

Figure 1. Research locations at the shoreline mangrove ecosystem of Muara Jawa, Kutai Kartanegara, East Kalimantan, Indonesia

Sampling procedure

The identification of the pest outbreak was carried out using sampling plots with a size of 10×10 m^2. The R1 site consisted of the highest number of sampling plots with 9 plots since it was noted as the largest area (4.79 ha), followed by the R2 (3.30 ha) with 6 plots and the R3 (0.44 ha) with 4 plots. The distance of each plot was adjusted to 10 m. Every animal found in the research sites that caused damage to the plant was defined as a pest. The pest species were collected for further identification in the laboratory, according to Abbott and Morris (1995). Mangrove trees in each sampling plot were also recorded. Their diameter was measured at the breast height (1.3 m), while the plant height was calculated using a clinometer. Their attack height from the sea level was also measured. The intensity used some ratings, including healthy, languish, and death, based on the information listed in Table 1.

To understand the natural phenomenon increasing the outbreak, the dissolved oxygen (DO), total dissolved solids (TDS), salinity, pH, and temperature were also measured in the morning and evening using a digital multi-water quality meter (Lutron WA-2017SD, Taiwan).

Data analysis

The calculation of the frequency and intensity of the outbreak followed Haneda and Suheri (2018) with a slight modification.

$$\text{Frequency}=\frac{X}{Y}\times 100\% \quad (1)$$

$$\text{Intensity}=\frac{X_1Y_1+X_2Y_2}{XY}\times 100\% \quad (2)$$

Where:
X : Sum of the plant observed
Y : The highest score
X_1 : Sum of the plant having the score of 1
X_2 : Sum of the plant having the score of 2
Y_1 : Value of the score of 1
Y_2 : Value of the score of 2

The influence between the natural phenomenon observed by water quality data and the intensity of the pest outbreak was evaluated using a simple linear regression generated by SPSS statistic software (IBM Corp., USA).

RESULTS AND DISCUSSION

Identification of pest outbreaks

The identification of the presence of all pests was carried out using sampling plots distributed to research sites. A total of 7 pest species were successfully identified, namely *Amphibalanus amphitrite* Darwin, 1854, *Litharium kurodai* Kosuge, 1962, *Littoraria articulata* R.A.Philippi, 1846, *Melayonchis annae* Dayrat, 2017, *Nerita undata* Linnaeus, 1758, *Sphaeroma terebrans* Spence Bate, 1866, and *Telescopium telescopium* Linnaeus, 1758 (see Table 2 and Figure 2). Thus, the appearance of those pests could be stated as a sign. The mangrove plant species growing at the study site were identified as *api-api hitam* (*Avicennia alba* Blume), *api-api* (*Avicennia lanata* Ridl), *perepat* (*Sonneratia alba* Sm.), *rambai padi* (*Sonneratia caseolaris* (L.) Engl.), and *pedada* (*Sonneratia ovata* Backer). Their height and diameter averages are displayed in Table 3. It could be seen that only *A. alba* was grown in all study sites, while *A. lanata* and *S. alba* were grown only in the R1. S. caseolaris and S. ovata could be found both in the R1 and R2 study sites. According to Priosambodo et al. (2019), mangrove plants having a diameter of less than 10 m could be characterized as being in the sapling stage. Therefore, *S. ovata* grown in all study sites was still recognized as the sapling. A similar condition was also observed in *S. caseolaris* at the study site in R2. In general, the majority of plants in the study sites could be characterized as mangrove trees due to their diameters of more than 10 cm (Priosambodo et al. 2019). It was also evidenced that there were no seedlings recorded in the area studied.

Table 1. The score of the plant based on its condition

Rating	Plant condition	Percentage of the pest attack	Score
Healthy	The pest attack was not found	0 %	0
Languish	• The stems and leaves possessed a green and fresh condition without significant attack from pests	1-25 %	1
	• The stems and leaves changed color from green to yellow	26-50 %	
	• The stems and leaves changed color to become darker with partially fallen leaves	51-75 %	
Death	All the leaves were fallen, the stems possessed a black color with brittle characteristics, and there was no sign of life	76-100 %	2

Table 2. Taxonomy of all pests found in the research sites located in Mahakam Delta, Indonesia

Phylum	Class	Order	Family	Genus	Species
Arthropods	Crustacea	Sessilia	Salanidae	Amphibalanus	*Amphibalanus amphitrite*
Mollusca	Gastropoda	Gastropoda	Triphoridae	Litharium	*Litharium kurodai*
Mollusca	Gastropoda	Littorinimorpha	Littorinidae	Littoraria	*Littoraria articulata*
Mollusca	Gastropoda	Systellommatophora	Onchidiidae	Melayonchis	*Melayonchis annae*
Mollusca	Gastropoda	Cycloneritida	Neritidae	Nerita	*Nerita undata*
Arthropods	Isopod	Malacostraca	Sphaeromatidae	Sphaeroma	*Sphaeroma terebrans*
Mollusca	Gastropoda	Caenogastropoda	Potamididae	Telescopium	*Telescopium telescopium*

It has been found that not all of the pests at the study sites had a serious influence on the damage to the mangrove plants. For instance, *L. kurodai*, *L. articulata*, *M. annae*, *N. undata*, and *T. telescopium* were presented in small quantities with little plant damage. On the other hand, the excessive quantity of *A. amphitrite* and *S. terebrans* had been seen to significantly affect the disruption to the plants. The flooded plant parts, such as the stem and root, were fully covered by *A. amphitrite*. The average stem height attacked by this type of barnacle on the *A. alba*, *A. lanata*, *S. alba*, *S. caseolaris*, and *S. ovata* plants was 1.73 m, 1.74 m, 1.78 m, 1.57 m, and 1.85 m, respectively (Table 4). Concerning these values, it could be stated that the attack of the barnacle might be related to the height of sea level that occurred in these areas. This phenomenon was also found in other mangrove forests, especially in the coastal area. Luthfi et al. (2020) reported that barnacles sometimes acted as the main contributor to the mortality of mangrove plants. Their presence on the stems, roots, and leaves could reportedly inhibit the photosynthesis rate and reduce the growth of juvenile individuals (Chen et al. 2022). The damages due to the barnacle outbreaks could cause the death of young plants (Risnasari et al. 2021). Therefore, in this study, it might be the reason why no seedlings were found in the observed areas since the invasion of the *A. amphitrite* was massive.

The frequency and intensity of the invasions of *A. amphitrite* and *S. terebrans* that attacked mangrove plant species in the Mahakam Delta are summarized in Table 4. It has been observed that the outbreak of *A. amphitrite* was found in all mangrove species with a frequency value of 100%. On the other hand, the intensity differed based on the species attacked. *S. alba* had the highest value (58.82%), followed by *S. ovata* (56.00%). *A. lanata* and *S. caseolaris* were found to possess a similar value (50.00%), while *A. alba* received the lowest value (25.00%). In the meantime, the attack of *S. terebrans* on the species of *A. alba*, *A. lanata*, *S. alba*, *S. caseolaris*, and *S. ovata* resulted in frequency values of 10%, 100%, 100%, 63.15%, and 0%, respectively. Furthermore, the intensity values revealed 5%, 50%, 58.82%, 31.57%, and 0%. Interestingly, we found that *S. terebrans* were not present in the *S. ovata* plant. It might indicate the ability of this plant species to adapt to the habitat of *S. terebrans*. More importantly, we further classified the frequency and intensity according to the research site (Figure 3). It could be seen that *S. telebrans* was only found at the R1 site, which affected the deaths of some plants of *A. alba* and *S. alba*. The invasion of *A. amphitrite* was found at other sites, but no mortality was detected. Thus, it was evidenced that the presence of *S. telebrans* could potentially contribute to the dangerous degradation of the mangrove forest, although the attacked plant was recognized as a tree. The specific symptoms of the *S. telebrans* included the presence of holes in the flooded stems and roots and the significant fall of leaves (Figure 4). On the other hand, the living plants raised new shoots located at their lower stems.

Table 3. Diameter and height of the mangrove plant in the research sites

Plant species	Plant diameter (cm)			Plant height (m)		
	R1	R2	R3	R1	R2	R3
A. alba	11.09 ± 4.86	11.37 ± 4.05	16.04 ± 4.31	5.30 ± 2.43	7.04 ± 1.69	10.00 ± 1.90
A. lanata	15.18 ± 0.80	None	None	6.67 ± 0.58	None	None
S. alba	15.96 ± 2.55	None	None	5.82 ± 2.02	None	None
S. caseolaris	12.42 ± 5.60	9.63 ± 0.11	None	6.17 ± 2.42	9.50 ± 0.71	None
S. ovata	7.32 ± 5.40	8.88 ± 1.56	None	5.40 ± 3.6	6.71 ± 1.50	None

Notes: Plant without diameter and height information indicated that the plant species was not found at such research area. R1: Tanjung 1; R2: Tanjung 2; R3: Pulau baru

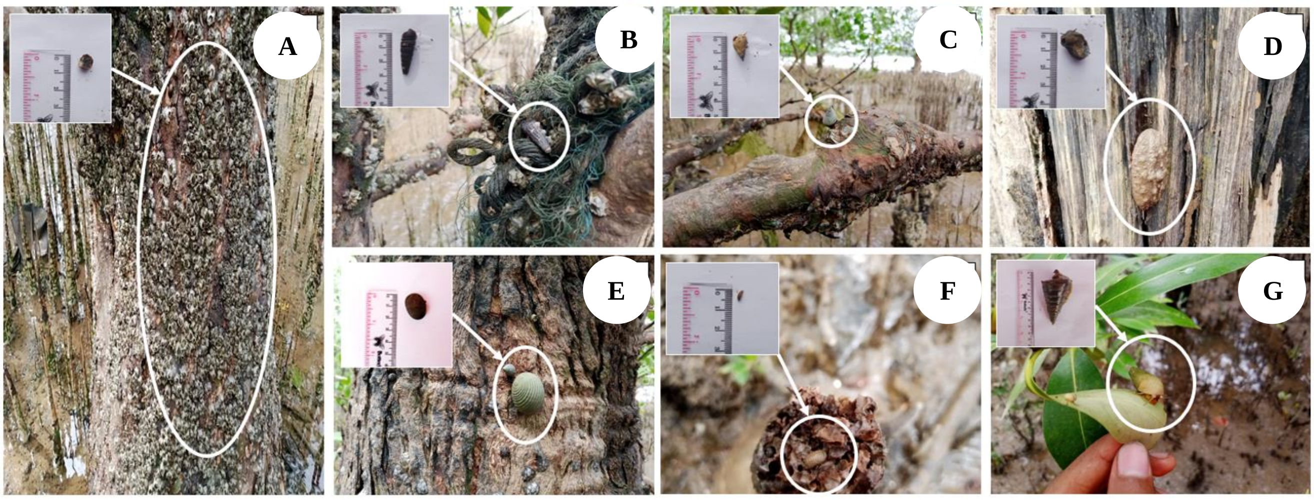

Figure 2. The appearance of A. *Amphibalanus amphitrite*; B. *Litharium kurodai*; C. *Littoraria articulata; D. Melayonchis annae*, E. *Nerita undata*; F. *Sphaeroma terebrans*; and G. *Telescopium telescopium*

The invasion of a marine wood-borer isopod, *S. terebrans*, has been distributed globally in tropical mangroves with a wide range of salinity (Thiri and Yang 2022). The burrowing activity of this species is virtually impossible to eradicate, as it was recorded in the serious attack on mangrove forests in Florida (Talley and Crooks 2007). It was found within the aerial roots of *Rhizophora mangle* L., reducing root production and increasing root atrophy (Brooks and Bell 2005). However, some plant species in China, including *Lumnitzera racemose* Willd., *Excoecaria agallocha* L., and *Ceriops tagal* (Perr.) C.B.Rob., have been reported to be free from invasion even when grown in the habitat of this isopod (Xin et al. 2020). In this study, we found that the invasion was not detected on *S. ovata*, which demonstrated that this species might be suitable to be planted in the Mahakam Delta or other areas with similar *S. terebrans* outbreaks.

Environmental conditions

We further measured the water properties in relation to the investigation of the natural conditions that enhanced the pest outbreak in the Mahakam Delta. The data can be seen in Table 5. The dissolved oxygen (DO) ranged from 28.3 to 36.4 ppm, the total dissolved solids (TDS) ranged from 7.70 to 13.74 mg/L, the salinity ranged from 0.41 to 0.77 ppm, the pH ranged from 7.35 to 7.90, and the temperature ranged from 28.6 to 29.1oC. According to Diba et al. (2021), these quality values could support the growth of marine organisms, especially temperature and pH. However, it was noted that *S. terebrans* was only found to attack the mangrove plants at the research site of R1. The difference was observed since the R1 site possessed higher dissolved oxygen (DO), higher total dissolved solids (TDS), higher salinity, slightly higher pH, and slightly higher temperature. Therefore, we concluded that these abiotic conditions might be suitable for the habitat of *S. terebrans*. The influence of the water properties on the intensity of pest outbreaks was further assessed using a simple linear regression (Table 6). This investigation was only carried out during the outbreak of *A. amphitrite*, since the outbreak of *S. terebrans* was only found at the R1 research site. It has been observed that DO, temperature, and salinity could result in a strong influence, with the coefficient of determination of 0.95, 0.90, and 0.80, respectively. The high influence was obtained from DS, with a coefficient of determination of 0.79. On the other hand, it could be seen that pH was considered to have a very low influence since it possessed the lowest coefficient of determination value (0.14).

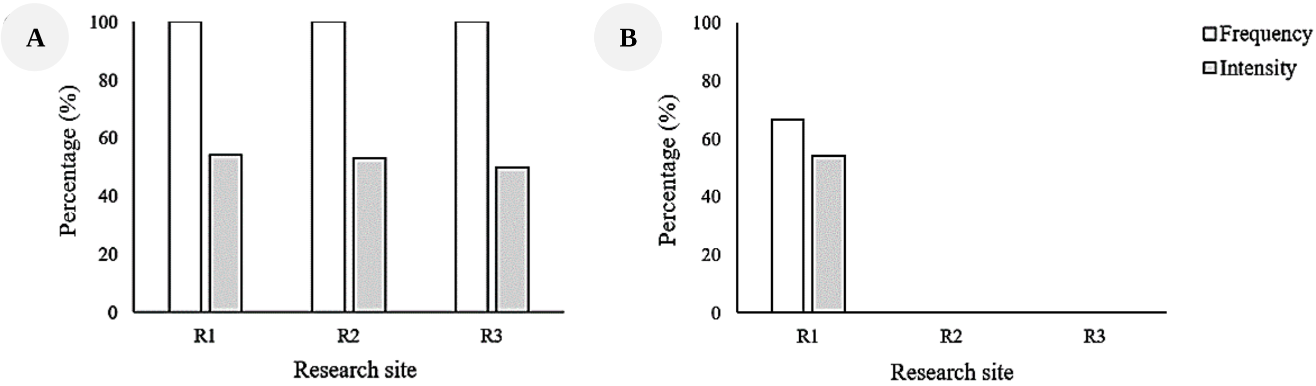

Figure 3. Frequency and intensity in the research sites due to A. *Amphibalanus Amphitrite*; and B. *Sphaeroma terebrans* invasions

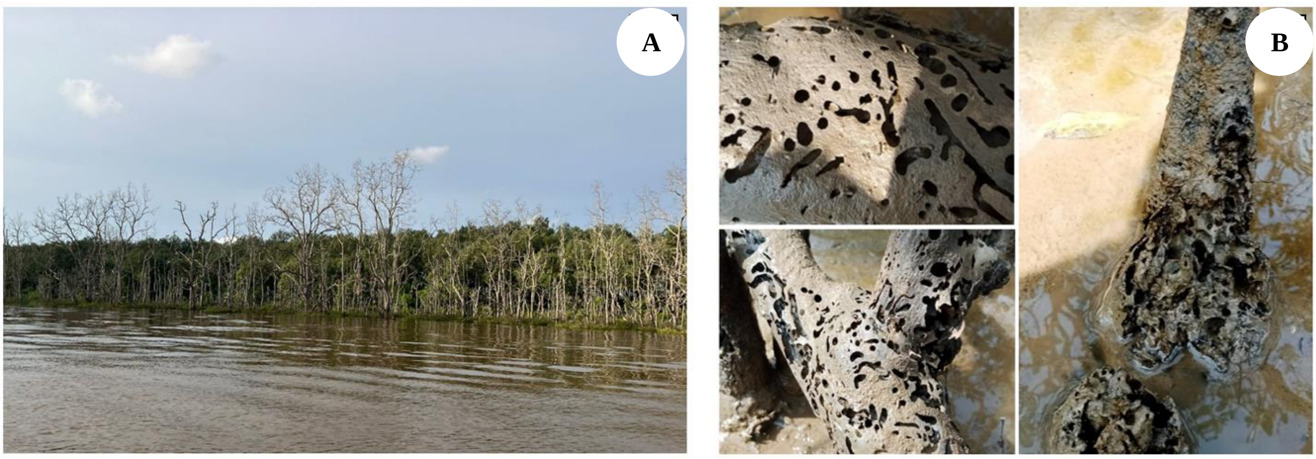

Figure 4. The damage of mangrove plants in the research site of R1 due to *Sphaeroma terebrans* invasion: A. Fallen leaves; and B. Stem holes

Table 4. Frequency and intensity of all mangrove plants attacked by *Amphibalanus amphitrite* and *Sphaeroma terebrans*

Plant species	*A. amphitrite* invasion		*S. terebrans* invasion		Height attacked (m)
	Frequency (%)	Intensity (%)	Frequency (%)	Intensity (%)	
A. alba	100.00	25.00	10.00	5.00	1.73 ± 0.71
A. lanata	100.00	50.00	100.00	50.00	1.74 ± 0.03
S. alba	100.00	58.82	100.00	58.82	1.78 ± 0.50
S. caseolaris	100.00	50.00	63.15	31.57	1.57 ± 0.26
S. ovata	100.00	56.00	0.00	0.00	1.85 ± 1.63

Table 5. Water physico-chemical properties in the research sites

Research site	DO (ppm)	TDS (mg/L)	Salinity (ppt)	pH	Temperature (°C)
R1	36.4 ± 1.56	13.74 ± 2.00	7.7 ± 0.25	7.90 ± 0.26	29.1 ± 0.14
R2	32.2 ± 0.33	9.36 ± 0.20	5.1 ± 0.02	7.35 ± 0.18	28.8 ± 0.14
R3	28.3 ± 0.83	7.70 ± 3.19	4.1 ± 0.17	7.59 ± 0.05	28.6 ± 0.28

Table 6. Influence of the water quality on the intensity of the *Amphibalanus amphitrite* outbreak

Parameter	Coefficient of correlation (R)	Coefficient of determination (R-Square)	Influence on the intensity
DO	0.97	0.95	Strong
Temperature	0.94	0.90	Strong
Salinity	0.89	0.80	Strong
TDS	0.89	0.79	High
pH	0.37	0.14	Very low

Finally, we pointed out that among the pests found in the coastal mangrove ecosystem in the Mahakam Delta, Indonesia, the most significant disruption was observed in the presence of *A. amphitrite* and *S. terebrans*. The attack of *A. amphitrite* was spread on the flooded roots and stems of plant species in all the areas studied, while *S. terebrans* was only detected at the R1 site, where this area had different abiotic conditions. In this area, *S. terebrans* could affect the deaths of some individuals from the plant species *A. alba* and *S. alba*. Therefore, we stated that these species might not be suitable for plantation projects in habitats of this pest type. Nevertheless, it was also observed that S. ovata was considered the only species that was free from the invasion of *S. terebrans*. Concerning this condition, it will be important to select seedling mangrove species that can survive based on the suggestions in the literature in order to restore such an ecosystem. One of the other important things is building engineering constructions to inhibit the attack of *A. amphitrite*, which commonly kills juveniles. In general, the data obtained from this study will be used to design best practices for future management strategies in mangrove rehabilitation and restoration in the coastal area of the Mahakam Delta, Indonesia, or other places with similar situations.

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