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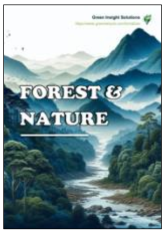

RESEARCH ARTICLE

Marine Borer Resistance of Resak Wood (*Vatica* sp.): Assessing Durability Across Different Immersion Depths

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ABSTRACT

Wood submerged in brackish and marine environments is highly susceptible to degradation by marine borers, which can compromise its structural integrity over time. Resak wood (*Vatica* sp.), widely used in boat construction, is frequently exposed to seawater, making it vulnerable to such bio-deterioration. This study aimed to assess the intensity of marine borer attacks on resak wood at different immersion depths (5 cm, 25 cm, and 50 cm) over three months in the estuary of Mempawah River, Mempawah Regency. Test samples (2 cm × 5 cm × 30 cm) were deployed, and data were analyzed using a Completely Randomized Design (CRD) with five replications, totaling 15 samples. The results revealed that resak wood exhibits high natural durability and is classified as durability class I, indicating strong resistance to marine borer infestations. The recorded weight loss percentages were 1.48% at 5 cm depth, 1.81% at 25 cm depth, and 2.69% at 50 cm depth, with statistical analysis confirming a significant effect of immersion depth on weight loss. This suggests that while resak wood is highly resistant, degradation intensifies with increasing submersion depth. Four marine borer species were identified in the estuarine waters of the Mempawah River: *Limnoria* sp., *Balanus* sp., *Nereis* sp., and *Teredo* sp. Their presence highlights the potential threat to submerged wooden structures in the region. Despite its durability, prolonged exposure and greater immersion depth may gradually reduce the structural performance of resak wood. Further long-term studies are recommended to evaluate its resistance under diverse environmental conditions and to explore protective treatments that could enhance its durability in marine applications.

1. Introduction

Indonesia is a maritime country, and 75% of its territory is ocean and consists of islands. Transportation such as wooden ships, docks, piles and buildings at sea are mostly made of wood, making them very important (Debataraja et al., 2021). The wood used is inseparable from attacks by marine borers. Marine borers are invertebrates that can dig into and damage wood exposed to the marine environment (Rozani and Salmiah, 2015).

Shipway et al., (2018) stated that marine borers are a group of wood-eating bivalves that cause damage to wooden structures on docks and ports. The value of the loss reaches millions of dollars each year. Weigelt et al., (2016) stated that wood damage due to marine borers, besides drilling wood, also consumes wood. Wood that has been soaked for three months in coastal waters has been severely attacked by the Pholadidae and Teredinidae families from the Mollusca phylum. The damage caused by marine borers has economic and ecological impacts on coastal areas. Knowledge about the durability of a type of wood is important so that damage caused by marine borers can be minimized.

Durability is an important property of wood because it is closely related to the service life of the wood. A short service life is very detrimental because the costs incurred are not balanced with its service life. The durability of a type of wood can be used as a consideration in deciding whether the type of wood needs to be preserved or not when used for certain purposes. The natural durability of wood is determined by extractive substances that are toxic to wood-damaging factors, so the natural durability of wood will vary according to the variation in the amount and type of extractive substances. The more extractive substances in the wood, the more durable the wood (Hunt and Garrat, 1986). Different types of wood have different natural durability (Can and Sivkrikaya, 2020).

Research results by Aksan et al., (2021) regarding the natural durability of jackfruit wood (*Artocarpus heterophyllus*) against marine borer attacks in Donggala Regency based on variations in the axial direction and different sea depth levels (5 cm, 10 cm and 42 cm), reported that the average attack intensity results at the base (0.49%), middle (1.7%), and tip (6.5%). The interaction between the two factors significantly affects the intensity of marine borer attacks. The types of marine borers found in the mangrove waters of Donggala Regency and have been identified are *Littorina obtusata*, *Teredo* sp., and *Trochus niloticus*.

Similar research was also conducted by Ramadhana et al., (2021), reporting that the duration of testing (4 weeks, 8 weeks and 12 weeks) had a very significant effect on wood strength (MOE and MOR) and natural durability of wood (percentage of weight loss) and the types of Malapoga wood and Tea wood were classified as strength class V (five). The results of this study are very useful for the people in Talise Village, Palu City, who work as fishermen because these two types of wood are often used as raw materials for making boats. Most people living around the Mempawah River estuary also work as fishermen.

The people around the estuary of the Mempawah River still produce boats traditionally. The need for wood in making boats is still often used by fishermen and people living on the coast as a means of transportation. The wood used in making boats will often come into contact with seawater, so marine borer attacks may reduce the strength of the wood itself, especially if used for a very long time. Marine borer attacks can reduce the durability of wood, disrupt the sustainability of the traditional ship industry and increase maintenance costs and replacement of damaged ship parts. Therefore, selecting the right raw materials for shipbuilding is important to save costs and reduce the excessive use of wood.

One type of wood that can last a long time when used as a raw material for making ships by the local community is resak wood. The results of the identification of the morphology of this plant include the genus *Vatica* and the family Dipterocarpaceae. Resak wood is known as hardwood, so its durability is also high. Woodworking by cutting and drilling is easy to do with good results, making it suitable as a raw material for making ships. Given the importance of this wood to be developed as a raw material for making ships, it is necessary to research the natural resistance of resak wood to marine borers.

2. Materials and Methods

2.1. Study Area

This research was conducted at the estuary of the Mempawah River, Kuala Secapah Village, Mempawah Hilir District, Mempawah Regency. The test was conducted for 3 months, from February to May 2024. The material used in this study was resak wood (*Vatica* sp.), measuring 2 cm x 5 cm x 30 cm.

2.2. Testing Method

Testing the natural durability of resak wood against marine borers refers to SNI 01-7207-2014 concerning the resistance test of wood and wood products against wood-destroying organisms. The difference in treatment used is the depth of each test sample (BSN, 2014) as follows: a depth of 5 cm below sea level (a1), a depth of 25 cm below sea level (a2), and a depth of 50 cm below sea level (a3). The test sample used was resak wood (*Vatica* sp.), locally used by the community as a raw material for making ships. The number of test samples needed is 15.

The resak wood is dried to air-dry moisture content (12-18%), after which it is cut into test samples measuring 2.5 cm x 5 cm x 30 cm. Then the center of the test sample is drilled with a diameter of 1.5 cm and weighed to determine the initial weight of the test sample.

The test samples with known weights are arranged in such a way as in **Fig. 1**. Then the test samples are inserted into seawater with different depths for each test sample (5 cm depth, 25 cm depth, and 50 cm depth), and the test samples are tied so that the river current does not carry them away. This treatment is carried out 3 times. The placement of the test samples is given a distance of 2 meters for each repetition. Observations are carried out for 12 weeks (3 months). After 12 weeks, the test samples are removed from the seawater and the type of marine borers that attack the test samples is identified. Then, the surface of the test samples is cleaned and dried until the weight is constant. After the weight is constant, the natural durability of the wood is determined based on the surface area attacked and the weight loss of the wood (test sample). Next, the test sample is split on the thick side into two equal parts and the surface area of the split plane is measured and the level of attack and the surface area of the test sample attacked by marine borers are observed. Then, the calculation of the intensity of marine borer attacks is carried out using the following formula (BSN, 2014):

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

where a is the area of the measured section (cm^2), and b is the damaged surface area (cm^2).

The intensity of the attack is observed visually based on the assessment set in SNI 01-1207-2014 (BSN, 2014), as in **Table 1**.

Table 1. Wood durability class based on attack intensity (BSN 2014)

Class	Intensity of attack (%)	Durability
I	< 7	Very High
II	7 – 27	High
III	> 27 – 55	Moderate
IV	> 55 – 80	Low
V	> 80	Susceptible

The natural durability of wood can be determined based on the weight loss of wood before feeding and after feeding, which can be calculated using the following formula:

$$\text{Weight loss (\%)} = \frac{W1 - W2}{W2} \times 100\% \quad (2)$$

where $W1$ is the initial weight of wood (g), and $W2$ is the final weight of wood (g).

The weight loss data was then analyzed using the NWPC (Nordic Wood Preserves Council) standard No. 1.4.2.2/73 as in **Table 2**.

Table 2. Wood durability class based on weight loss (Nordic Wood Preserves Council (NWPC) No. 1.4.2.2/73)

Weight loss (%)	Durability
≤ 1%	High
> 1% – 33%	Moderate
> 33% – 66%	Low
> 66%	Susceptible

The marine borers that attack the test sample are identified by type. Identification of the type of marine borers is carried out by direct and visual observation. In addition to direct observation, a magnification observation tool is also used as a magnifying glass so that the characteristics of the marine borers that attack the test sample can be seen. These characteristics will be adjusted or equated with the characteristics of the type of wood-destroying organisms in previous research results, identification books, and internet browsing results or bold (Sivrikaya, 2018).

2.3. Data Analysis

Data on the intensity of marine borer attacks and weight loss of test samples were then analyzed using, according to Gasperz (1995), the general model of an experiment with a completely randomized design (CRD) as follows:

$$Yij = \mu i + Ti + £ij \quad (3)$$

where Yij is the observation value in treatment i, repetitions j, μi is the general mean value, Ti is the effect of the error on the j repetitions to obtain the i treatment, £ij is the experimental error from treatment i on observation j, i is the number of treatments, and j is the number of repetitions.

After the results of F calculation are obtained, a comparison is made with F table, so that several possibilities are obtained as follows:
a. F Calculation < F Table 0.05, then the treatment has no real effect (non-significant),
b. F Calculation ≥ F Table 0.05, then the treatment has a real effect (significant),
c. F Calculation ≥ F Table 0.01, then the treatment has a very real effect (highly significant).

To find out the real differences between each treatment, a comparison is made using the Honestly Significant Difference (HSD) test so that it can be seen which treatments are different and which are not different (Gaspersz, 1995) as follows:

$$HSD = q\alpha\,(p, n2) \times SY \quad (4)$$

where HSD is the real honest difference, qα value (p, n2)can be seen in table q (with α 5% and 1%), p is the number of treatments, n2 is the DB error, and SY is the Standard error.

The standard error can be calculated based on the following formula:

$$SY = \sqrt{\frac{KTG}{r}} \quad (5)$$

where *KTG* is the mean square error, and *r* is the number of repetitions.

Then compare it with the difference of 2 average treatments to be compared with the HSD value so that several possibilities arise as follows:

a. Average difference> HSD value of 5% then there is a real difference
b. Average difference> HSD value of 1% then there is a very real difference
c. Average difference < HSD value of 5% or 1%, then there is no difference between the two treatments tested

Measurement of the magnitude of variation in data distribution can use the coefficient of diversity (KK), expressed in percentage (%). The coefficient of diversity can be calculated using the following formula:

$$S_Y = \frac{\sqrt{KTG}}{x}\, x\ 100\% \quad (6)$$

where *KTG* is the mean square error and *x* is the average observation results.

3. Results and Discussion

3.1. Weight Loss of Resak Wood after Feeding

Test samples soaked for three months in the Mempawah River estuary showed that marine borer attacks were very low or even non-existent, meaning that the intensity of marine borer attacks was <7%. This is indicated by the wood samples' physical condition, which were only covered in mud and overgrown with moss. Based on these results, resak wood (*Vatica* sp.) is included in the durability class 1 against marine borer attacks in the SNI 01-1207-2014 classification with an attack intensity range of < 7%. The absence of marine borer attacks can be caused by several things, namely wood hardness, wood extractive content, lack of feeding time and marine borer activity at the research location.

Determination of the natural durability of wood against marine borer attacks can also be done by looking at the test sample's weight loss percentage (Ramadhana et al., 2021). **Fig. 1** shows the average weight loss percentage of test samples after feeding, ranging from 1.48 - 2.69%. The highest average weight loss value was found in the test sample fed at a depth of 50 cm. Based on the test results, the resak wood is included in the durability class I - II against marine borer attacks. Resak wood is generally included in the durability class III (Martawijaya et al., 2005). The study's results showed an increase in the durability class of wood. This is in line with research conducted by Aksan et al., 2021, which showed an increase in the durability class of jackfruit wood, which generally has a durability class II - III to a durability class I against marine borer attacks. The lowest average weight loss value was found in the test sample fed at a depth of 5 cm. Analysis of the variance of wood weight loss values can be seen in **Table 3**.

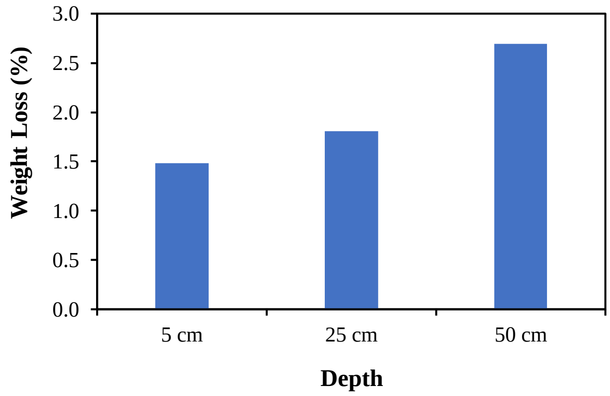


Fig. 1. Weight loss of resak wood after feeding at different immersion depths.

Based on the results of the diversity analysis shown in **Table 3**, it was found that the treatment in the form of different depths significantly affected the value of wood weight loss. Furthermore, to determine the differences in the treatments that had an effect, an HSD test was conducted. The results of the HSD test for wood weight loss can be seen in **Table 4**.

Table 3. Analysis of variance (ANOVA) for weight loss of test samples

Source of diversity	Degrees of freedom	The sum of squares	Middle square	F. count	F. table	
					5%	1%
Treatment	2	3.9357	1.9679	4.7288*	3.89	6.93
Error	12	4.9938	0.4161			
Total	14	8.9295				

Note: * = significant.

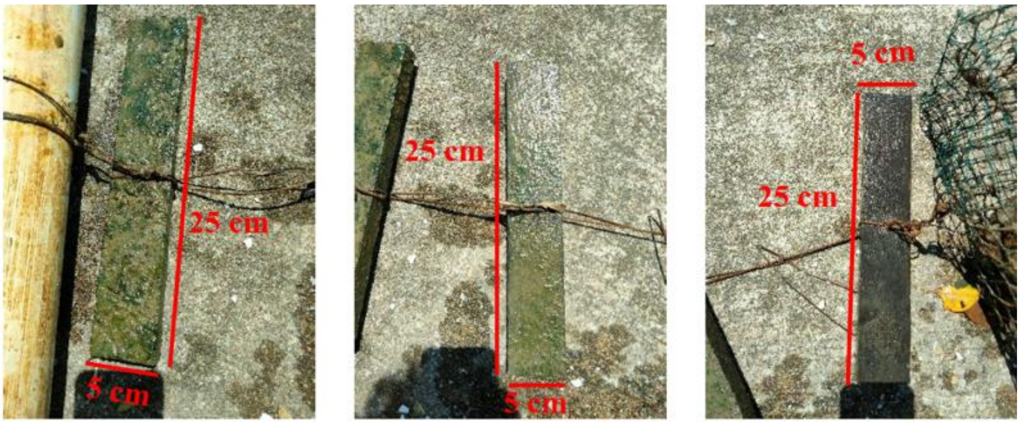
The results of the HSD test in **Table 4** show that treatment a2 was not significantly different from treatments a1 and a3, but treatment a1 was significantly different from treatment a3. The value of wood weight loss tends to increase with increasing depth during feeding due to environmental conditions at the feeding location. Weight loss can occur due to the dissolution of chemical components of wood in the water test sample, namely extractives. Extractives are substances dissolved from wood using neutral solvents such as water or organic solvents (benzene, dichloromethane, ether, alcohol, or a mixture of alcohol and benzene) (Sjostrom, 1995). Extractives that dissolve in water are sugar, dyes, tannins, gums and starch (Sokanandi et al., 2014). The results of research conducted by Aksan et al., (2021) showed that a sea depth of 5 cm was not significantly different from a sea depth of 10 cm, in contrast to a sea depth of 42 cm, which had a significant effect.

Table 4. Honestly significant difference (HSD) test results of weight loss of test samples based on depth differences

Treatment	Average percentage weight loss
a1	1,4818 a
a2	1,8097 ab
a3	2,6946 b
HSD 5% 1,0876	HSD 1% 1,4569

Notes: The averages followed by the same letter are not significantly different, while the averages not followed by the same letter are significantly different.

Based on the results of physical observations of the test samples shown in **Fig. 2**. it is known that each replication in each treatment has a relatively similar physical condition, namely that it is covered with mud and moss. The closer to the surface, the more mud and moss cover the test sample. This is because the test sample closer to the surface still gets enough sunlight, allowing moss to grow and photosynthesize well. The mud and moss that cover the test sample will also close the wood's pores, making the wood’s chemical components dissolve in water more difficult to get out. This is what makes the weight loss of the test sample the deeper the greater. The solubility of the chemical content of resak wood is 1.6% in cold water, 3.6% in hot water and 12.2% in 1% NaOH solution (Martawijaya et al., 2005).



(a) (b) (c)

Fig. 2. Condition of wood samples after testing for 3 months: (a) depth 5 cm, (b) depth 25 cm, and (c) depth 50 cm.

3.2. Types of Marine Borers in the Sea

The study results showed that no marine borers attacked the test samples. Therefore, observations were conducted again to look for marine borers around the research location. The results of the observations in **Fig. 3**. show that marine borers attacked wood and several ships and several types of wood-boring organisms were found in the estuary waters of the Mempawah River, which were successfully identified, namely *Limnoria* sp., *Balanus* sp., *Nereis* sp., and *Teredo* sp.

(a) (b)

Fig. 3. Research location: (a) condition of ships attacked by marine borers, and (b) forms of marine borer attacks found at the research location.

3.2.1. Limnoria sp.

Limnoria sp. in English is called gribbles, and this species causes major damage to marine wood installations. The Limnoriidae family is often found in the North Atlantic and North Pacific oceans, which perforate, attack and destroy submerged wood structures (Quayle, 1992). The classification of *Limnoria* sp. is as follows (Rathke, 1799):

Kingdom : Animalia
Phylum : Arthropoda
Class : Malacostraca
Order : Isopoda
Family : Limnoriidae
Genus : *Limnoria*
Species : *Limnoria* sp.

The body of *Limnoria* sp. consists of three parts: the head, chest and abdomen (**Fig. 4**). The head has a pair of eyes, two pairs of antennae and a set of complex mouth components, the important part of which is the mandible or lower jaw. The chest of *Limnoria* sp. consists of seven segments, each equipped with a pair of legs. Each leg consists of seven segments, the last of which ends with a simple claw. The abdomen has six segments, with the last fused with a flat plate (telson) forming a pleotelson. There are also five pairs of pleopods on the abdomen, which are complementary tools such as covers for swimming and breathing (Quayle, 1992).

Fig. 4. *Limnoria* sp.

3.2.2. Balanus sp.

Balanus sp., commonly called barnacles, are invertebrates that live in the sea, and their life goes through two stages, namely the larval stage, which is planktonic, while the adult stage is attached (**Fig. 5**). This can cause problems for activities at sea. *Balanus* sp. is one of the biofouling organisms that cause damage to coastal buildings and ships, especially on the hull (Mirza et al., 2017). The classification of *Balanus* sp. is as follows (Linnaeus, 1758):

Kingdom : Animalia
Phylum : Invertebrata
Class : Crustaceae
Order : Thoraciceae
Family : Ballonoidae
Genus : *Balanus*
Species : *Balanus* sp.

Fig. 5. *Balanus* sp.

Balanus sp. is a type of Crustacea class with characteristics of white with reddish brown. On each shell, 3-4 white strips are formed from chalk, with a soft side and a blunt gaping top. The dominance of *Balanus* sp is due to the arthropod compounds it releases so that the same *Balanus* sp. will gather and grow until there is a buildup. *Balanus* sp. has the characteristics of a segmented animal hidden in its hard, chalky shell (Cahyanurani et al., 2023).

3.2.3. Nereis sp.

Nereis sp. is a worm that lives in the sea, including invertebrates of the Annelida phylum, and the body has elongated segments (Wibowo et al., 2018). Its body has a capuz and additional tools, divided into many segments (**Fig. 6**). The first segment is called the peristomium, with two pairs of tentacles on each lateral part. It is included in the polychaeta class, which means it has much hair. On the anterior part is a head equipped with eyes, tentacles and a jawed mouth. The body is attractively colored namely reddish brown. The classification of *Nereis* sp. is as follows (Wilson and Ruff, 1988):

Kingdom : Animalia
Phylum : Annelida
Class : Polychaeta
Order : Phyllodocida
Family : Nereidae
Genus : *Nereis*
Species : *Nereis* sp.

Fig. 6. *Nereis* sp.

This type of worm has a layer of longitudinal muscle or circular muscle. The intestines are almost straight, stretching from front to back. There is a blood vessel system and a brain ganglion in the anterior part is located above the digestive tract. Body length is 5 - 10 cm and 2 - 10 mm diameter. Fertilization is internal to form larvae. It moves using parapodia and already has a real coelom, which is limited by the mesodermal helium epithelium. Each segment has a pair of parapodia. Marine worms *Nereis* sp. generally live in estuarine areas with sandy mud substrate conditions, which are shallow and influenced by tides. Marine worms are detritus (eating organic remains) or deposit feeders (sediment eaters) (Hermawan, 2015).

3.2.4. Teredo sp.

Teredo sp. is a shipworm, a highly modified shellfish adapted to drill wood. *Teredo* sp. has a high reproductive ability and is widely distributed according to physiological tolerance and condition factors (Appelqvist et al., 2016). Reproduction of *Teredo* sp. in the adult phase occurs in the roots and trunks of rotting trees (Mohrholz et al., 2015). This species is one of the most widespread marine wood borers in the world and has caused damage to ships, boats, docks, piles, buoys, and seawalls. The classification of *Teredo* sp. is as follows (Linnaeus, 1758):

Kingdom : Animalia
Phylum : Mollusca
Class : Bivalvia
Order : Myida
Family : Teredinidae
Genus : *Teredo*
Species : *Teredo* sp.

Teredo sp. has a body structure resembling a worm in general appearance, while at the anterior end, it has a small shell with two valves that are specialized for drilling through wood (**Fig. 7**). Apart from its slender and worm-like shape, shipworms have shell morphological characteristics. Its head is covered with two white, three-shaped shells used to drill wood. The shell is up to 2 cm long and has concentric protrusions. Inside the shell, there is a hook-like process called the styloid apophysis. The legs are also at the anterior end. The average body size of *Teredo* sp. when it reaches adulthood is 60 cm (Macintosh et al., 2014).

Fig. 7. *Teredo* sp.

3.3. Factors Affecting the Activity of Marine Borers

3.3.1. Salinity

Salinity is the percentage of salt content found in seawater. Salinity greatly affects aquatic organisms by controlling the balance of water and ions between the body and its environment. If salinity conditions fluctuate, the larvae need more energy for their metabolic processes (Jayanti et al., 2022). Salinity measurements are carried out using a refractometer.

(a) (b)

Fig. 8. Water salinity measurement: (a) refractometer, (b) water salinity measurement results.

The salinity of the Mempawah River estuary from the data obtained is 1% - 4%. The intensity value of wood borer insect attacks in the sea is relatively small on the wood fed because organisms such as *Balanus* sp. and *Nereis* sp. release many body fluids to balance the salt content through osmosis. This salinity value still meets the seawater quality standards for the life of organisms in mangrove forests in accordance with the values determined by the Decree of the Minister of Environment No. 51 of 2004. According to Bengen, (2002), the life of biota in the mangrove ecosystem, including marine wood borer worms, can reproduce well at salinity values of 2-38%.

3.3.2. Temperature

Temperature is a physical quantity that states the amount of heat contained in an object. Temperature is one of the most important factors for the life of organisms in the ocean because it can affect the metabolic activity and reproduction of these organisms (Hutabarat and Evans, 2014). Likewise, the temperature factor is very important in regulating the life process and distribution of wood-boring organisms in the sea. In tropical waters, the water temperature does not fluctuate too much, allowing wood-boring organisms in the sea to thrive throughout the year.

From the study results, the temperature in the waters of the Mempawah River estuary ranges between 29-30ºC. The Mempawah River estuary is a tropical area where the intensity of attacks on all types of wood by wood-boring organisms in the sea is relatively light. The study's results showed that the damage to the tested wooden sample boards did not cause significant damage.

Marine organisms are generally polykylothermic, so their distribution follows the geographical differences in ocean temperatures. Biofouling organisms such as *Balanus* sp., *Telescopium* sp., *Nereis* sp., and *Cardisoma carnifex* can live in waters with temperature changes ranging from 15-30°C or estuarine waters to the open sea.

3.3.3. Current speed

Sea water is always in motion. Sea water movements are caused by several factors, such as wind blowing over the sea surface and stirring due to differences in water temperature from two layers, sea level, tides, and others. This seawater movement is called currents, waves, and water mass surfaces.

Current speed can also affect the attachment of wood-boring organism larvae in the sea. The opportunity for larvae to attach will be easier in small current movements, and the incoming water also carries wood-boring organism larvae in the sea, so the larvae can easily attach and make holes for housing and foraging. Attached to wood, the attachment of these organisms often occurs at night.

4. Conclusion

During the feeding process, the test sample did not show any signs of being attacked by marine borers, so the resak wood is included in the durable class I or very resistant to marine borer attacks. The lowest and highest weight loss in sequence were 5 cm depth (1.48%), 25 cm depth (1.81%) and 50 cm depth (2.69%), and this difference in depth had a significant effect on the weight loss value of the test sample. The types of marine borers found in the estuary waters of the Mempawah River that were successfully identified were *Limnorium* sp., *Balanus* sp., *Nereis* sp, and *Teredo* sp.

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