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Environmental Assessment of Fish Farm Areas Using Macrobenthic Mollusk Structures Comparing Coastal and Lake Water Ecosystems: Efforts toward Sustainable Aquaculture

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Abstract: Due to rising global food demand, aquaculture in Indonesia has experienced tremendous expansion, rising from 35% in 2010 to 65% in 2050. However, environmental disruption in aquatic habitats can result from this development. Because their structure strongly correlates with physicochemical water parameters and organic enrichment, macrobenthic mollusks extensively distributed in freshwater and marine habitats, are ideal bioindicators. This study aimed to compare the lake water and coastal ecosystems to evaluate the environmental conditions of fish farming sites using macrobenthic mollusk structures. We identified macrobenthic mollusk communities collected from two sites on Karimunjawa Island in July and September and from three sites in Rawapening Lake in October, November, and December. The ecosystem assessment involved the community structure index, species composition, abundance, and diversity. Analyses of water and sediment properties have determined the relationship between macrobenthic mollusks and environmental factors. The primary influence of ecosystem variation on species distribution is the lack of related species between Karimunjawa and Rawapening. The diversity index of gastropod and bivalve mollusk species of Karimunjawa Island was significantly higher (1.36-2.40) than that of Rawapening Lake (0.68-1.19), where the predominance of two mollusk species—*Littorina* sp. (2192.59 ind.m⁻²) and *Cerithium* sp. (3777.78 ind.m⁻²)—was observed. In Rawapening Lake, *Fillopaludina* sp. (36859.26 ind.m⁻²) was the most prevalent gastropod. At Rawapening Lake, the abiotic factor closely correlated with their abundance was the fine sand substrate ($r = 0.612$; BIO-ENV, PRIMER 6.1.5 software). At Rawapening Lake, the abiotic factor closely correlated with their abundance was the fine sand substrate ($r = 0.612$; BIO-ENV, PRIMER 6.1.5 software). In Karimunjawa, the silt and dissolved oxygen content had the strongest correlation ($r_{\text{value}} = 0.733$; BIO-ENV, PRIMER 6.1.5 software).

Keywords: macrobenthic mollusk, aquaculture, lake, ecosystem.

使用大型底棲軟體動物結構對養殖場進行環境評估，比較沿海和湖泊水生生態系統：
永續水產養殖的努力

摘要：由於全球糧食需求不斷增長，印尼的水產養殖經歷了巨大的擴張，從2010年的35%上升到2050年的65%。然而，這種發展可能會導致水生棲息地的環境破壞。由於大型底棲軟體動物的結構與理化水參數和有機富集密切相關，廣泛分佈在淡水和海洋生境中，因此是理想的生物指標。本研究旨在比較湖水和沿海生態系統，以評估使用大型底棲軟體動物結構養魚場的環境條件。我們確定了7月和9月從卡里蒙賈瓦島的兩個地點以及10月、11月和12月從拉瓦平湖的三個地點收集的大型底棲軟體動物群落。生態系評估涉及群落結構指數、物種組成、豐度和多樣性。對水和沈積物性質的分析確定了大型底棲軟體動物與環境因素之間的關係。生態系變異對物種分佈的主要影響是卡里蒙賈瓦和拉瓦平之間缺乏相關物種。卡里蒙賈瓦腹足類和雙殼類物種的多樣性指數（從1.36到2.40）顯著高於拉瓦平湖（從0.68到1.19），其中兩種軟體動物 - 濱海藻的優勢物種。(2192.59單位/平方米)和凱氏藻。(3777.78單位/平方米)——被觀察到。在拉瓦平湖，菲羅帕魯德納。(36859.26單位/平方米)是最常見的腹足類。在拉瓦平湖，與其豐度密切相關的非生物因素是細砂基質 ($r = 0.612$; 生物環境, 底漆6.1.5軟體)。在拉瓦平湖，與其豐度密切相關的非生物因素是細砂基質 ($r = 0.612$; 生物環境, 底漆6.1.5軟體)。在卡里蒙賈瓦，淤泥和溶氧量具有最強的相关性 (r 值=0.733; 生物環境, 底漆6.1.5軟體)。

关键词：大型底棲軟體動物、水產養殖、湖泊、生態系。

1. Introduction

Aquaculture and technology have been applied for many years worldwide and developed over the past few decades, including in Indonesia's marine waters [1], to enhance aquaculture production, which is critical to Indonesia's economic structure [2]. According to the Food and Agriculture Organization of the United Nations, aquaculture production in Indonesia has supplied more than 8.2% of the global demand in 2022 and has been increasing annually. However, this industry is not yet optimal for Indonesia. Aquaculture using floating net cages is a method of aquaculture support, where aquaculture refers to an open system [3, 4]. The rapid development of aquaculture is a blue revolution, which is an approach to increase global fish production and contribute to meeting human nutritional needs and food security. Using blue water for aquaculture, namely, surface water and groundwater, also significantly contributes to global fish production. However, the Blue Revolution in aquaculture refers to various environmental problems, including habitat destruction, water pollution, eutrophication, biotic depletion, ecological effects, and disease outbreaks [5].

In practice, feed is not always consumed by cultured biota; up to 60% of the food will eventually accumulate or dissolve in the organic fraction on the surface of water bodies until a depth of 25–40 m from the water surface. Dissolved organic compounds may spread, and

sediment particles may suspend depending on the hydrodynamic conditions of the local water body. Some organic matter, especially coarse fractions, can settle at the bottom of water. The deposition of organic matter can accumulate in the lower part of the water body where fish farming occurs. In addition to changes in the physicochemical properties of sediments, they can affect the structural dynamics of macrobenthic communities inhabiting bottom marine water environments [5, 6]. Therefore, more attention should be given to its practice, as it involves biota at relatively high densities and intensive feeding.

Analysis of macrobenthic organisms can determine the quality of aquatic environments. Variations in density and biomass patterns of aquatic organisms at temporal and spatial scales can be used as biological indicators of ecosystem community disturbances [7]. The extent of disturbance can be characterized by changes in species composition or proportions with increasing stages of disturbance and by the relative distribution of species density and biomass. Species composition, abundance, and biomass of macrobenthos are jointly influenced by cage farming, fishing, and the geomorphological characteristics of the cage farming area in lake ecosystems [8]. Therefore, it is necessary to determine the impact of aquaculture activities on the quality of both marine and freshwater ecosystems based on the dynamics of the structural composition of macrobenthos [9–11].

We performed an ecological assessment of fish farm areas using the macrobenthic mollusk structure as a comparative parameter between marine and freshwater ecosystems, constituting a proactive initiative toward promoting sustainable aquaculture. Consequently, it is anticipated that this investigation will establish correlations with environmental science, particularly concerning the application of mollusk structures in evaluating environmental disturbances in marine ecosystems. The exclusive adoption of the mollusk structure within the macrobenthic community inhabiting sedimentary environments is predicated on a deliberate reduction in data complexity and the duration of specimen identification processes, which would be necessary if applied universally across all sampled macrobenthos. This approach should speed up the analysis of data and its interpretation, aiming to make the workflow faster, with the overarching objective of accelerating the workflow without compromising precision in assessing the degree of environmental disturbance.

2. Methods

2.1. Study Sites and Sampling Method

This study used qualitative descriptive analysis. The data used comprised primary data. The sampling sites involved two different ecosystems: Karimunjawa Island (KI), a marine ecosystem, and Rawapening Lake (RL), a freshwater ecosystem. The territorial area of Karimunjawa Island is 107,225 ha, with the majority consisting of oceanic regions spanning 100,105 ha.

Karimunjawa National Park has a collection of 27 islands, each hosting diverse ecosystems. Rawapening Lake is in the tropics, with a warm water temperature and an influx of nutrients flowing from the surrounding river systems. Fig. 1 shows a map of the study sites, with the details below.

Karimunjawa samples were collected for 2 months, July and September. Rawapening Lake samples were collected for three months: October, November, and December. The observed variations were essential for the comparative analysis performed in this study, considering the specific seasons and ecological characteristics of each respective location. At each site, water parameters, such as pH, temperature (°C), dissolved oxygen (DO), salinity, and water current, were recorded using the Water Quality Checker U-50 Horiba. Sediment collection used an Ekman grab by gently dropping them onto the water's bottom surface to prevent any potential collisions with coral formations or debris; hence, sediments could be effectively retrieved. This process was repeated thrice to enhance the accuracy of the collected samples. We used 3-L jars, each properly labeled from every site, to store the sediment and preserve the collected samples in a 10% formalin solution. In the laboratory, all samples were rinsed with a 0.5-mm mesh sieve before being transferred to a sorting tray. This procedure is effective for separating silt, debris, and other objects from the macrobenthos. Macrobenthos samples were examined and counted under an Olympus CX-21 microscope at 400× magnification.

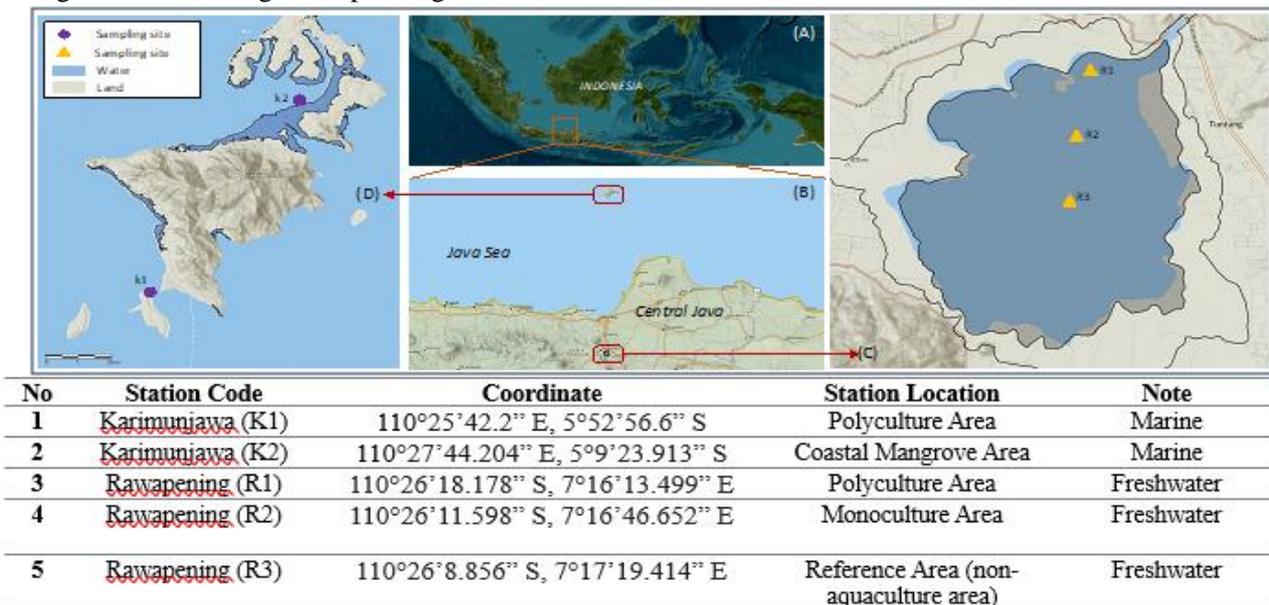


Fig. 1 Map of the study area of the macrobenthic sampling in 2 different locations: (A) Map of Indonesia, (B) Central Java, (C) Rawapening Lake location, (D) Karimunjawa Island location

2.2. Data Analysis

Macrobenthos data were analyzed and inserted into the abundance formula based on the number of individuals per area unit (ind.m^{-2}) (Welch, 1948, in [12]):

$$K = \frac{n \times 10.000}{A \times P} \quad (1)$$

where K is the abundance per square meter (ind.m^{-2}), n is the number of species (i) found (individuals), A represents the transverse area of the Ekman Grab (cm^2), P is the number of samples taken at one sampling site,

and 10.000 is a conversion cm^2 to m^2 .

The index of frequency consists of the number of times a species occurs in a given number of quadrates and is usually expressed as a percentage [13]. The index of frequency or frequency of incidence (FoI) was estimated using the equation (Romimohtarto and Juawana, 2001, in [14]):

$$\text{FoI} = \frac{\text{Ni.St}}{\text{N.St}} \times 100\% \quad (2)$$

where Ni.St is the total number of locations where species I was found, and N.St is the total number of sampling locations.

Frequency value ranges are 0-25% (very rare), 25-50% (rare), 50-75% (moderate), and > 75% (frequent/absolute). The calculation of macrobenthic mollusk diversity used the Shannon–Wiener diversity index (H') [15]:

$$H' = -\sum_{i=1}^S pi \ln pi \quad (3)$$

where pi is the proportion of the (i) species and \ln represents the logarithm of pi .

The Shannon–Wiener diversity index is classified into three levels: $H' < 1$ (low species diversity), $1 \leq H' \leq 3$ (medium species diversity), and $H' > 3$ (high species diversity) [48]. The evenness index (e) analyzed the individual composition of each species in the same sampling area calculated by the following formula [16]:

$$e = \frac{H'}{\ln S} \quad (4)$$

where H' is the Shannon–Wiener index and $\ln S$ is the maximum diversity. The evenness value ranges from 0 to 1. Furthermore, the evenness value follows the next categories: if $0 < e \leq 0.5$, the community is depressed, if $0.5 < e \leq 0.75$, the community is unstable, and if $0.75 < e \leq 1$, the community is stable [49].

The Dominance Index (C) was used to determine community dominance, calculated by the following formula [50]:

$$C = \sum_{i=1}^S \left(\frac{ni}{N}\right)^2 \quad (5)$$

where ni is the number of individuals per species and N is the total number of individuals per species. The dominance index values range from 0 to 1 according to the following categories: if $0 < C < 0.5$, the dominance is low, if $0.5 < C \leq 0.75$, the level of dominance is moderate, and if $0.75 < C \leq 1.0$, the level of dominance is high [17].

Data processing involved the use of Microsoft Excel 2016 and PRIMER v.6.1.5 software, and parametric and non-parametric data analysis. Non-parametric analysis was conducted using PRIMER v 6.1.5 software. Data processed in non-parametric analysis include macrobenthic mollusk community data, sediment substrate composition, sediment chemical content, and water parameters, with BIO-ENV, which refers to the integration of biological and environmental sciences. The validity of species names was also checked.

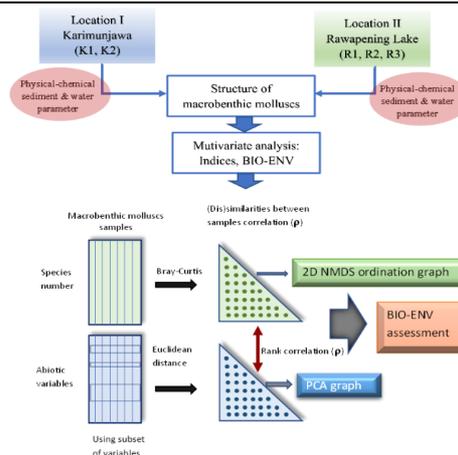


Fig. 2 Flow chart of the research methodology

3. Results and Discussion

3.1. Composition of Macrobenthic Mollusks

A macrobenthic mollusk composition of 3773 ind.m^{-2} , or 48 species spread across 29 families and 11 orders, was discovered in two locations on Karimunjawa Island. In terms of bivalves, 399 ind.m^{-2} were identified, belonging to 13 taxa across 6 families in 4 orders. In comparison with Rawapening Lake from three sites, these consisted of 931 ind.m^{-2} gastropods, representing 9 species from 7 families in four orders. In contrast, the collection of bivalves was quite limited – only 28 ind.m^{-2} taken from one genus (Fig. 3).

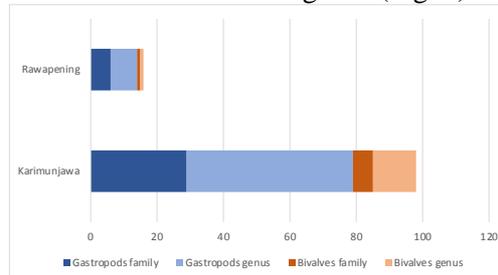


Fig. 3 Taxonomic diversity by family and genus in Karimunjawa and Rawapening

The mean abundance from these two locations differed significantly in terms of abundance (Fig. 4). The Karimunjawa sites had a higher mean abundance with 6210.70 ind.m^{-2} gastropods and 1970.37 ind.m^{-2} bivalves, while the Rawapening sites showed a lower mean abundance with 3288.89 ind.m^{-2} and 103.70 ind.m^{-2} bivalves.

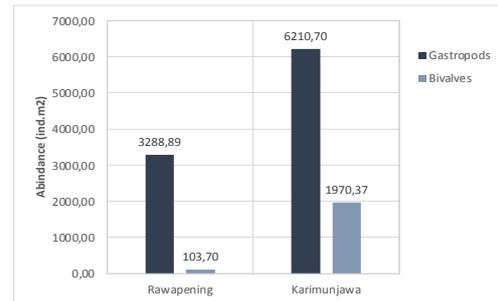


Fig. 4 Mean abundance (ind.m^{-2}) of macrobenthic mollusks in Karimunjawa and Rawapening

The frequency of species observed was based on habitat type, as shown in Table 1. In general, there was no presence of similar species across the two locations (KL and R) (Fig. 5). Such an absence of overlap can be attributed to the major effect of variations in ecosystems and habitats on species distribution. From the Karimunjawa location, two sites (K1 & K2) shared the presence of 8 species of gastropods and 2 species of bivalves. A total of five dominating gastropod species were consistently present throughout all sample sites and across all seasons on Karimunjawa Island (FoI 100%), namely *Fissilabia* sp., *Rissoina* sp., *Cerithium* sp., *Bittium* sp., and *Acteocina* sp. These species were recorded as frequent/absolute (FoI >75%).

In aquaculture site (K1) of Karimunjawa, eight species of gastropods were found to be abundant. Among these species, *Littorina* sp. was observed to be the most dominant throughout all seasons. On July (K1T1), *Littorina* sp. accounted for 20% of the total species, whereas *Fissilabia* sp. accounted for 14%. On September (K1T2), *Littorina* sp. exhibited even greater dominance, comprising 35% of the total species. McQuaid et al. [18] showed that *Littorina* sp., commonly referred to as "sea snail," dominantly inhabits intertidal zones. Supported by [19, 20], it was revealed that *Littorina* sp. exhibits a distribution pattern that extends beyond coral reefs and is also found in seagrass beds within coastal areas and intertidal zones. Tan and Low [21] concluded that the presence of *Littorina* sp. in high numbers can be linked to nutrient enrichment in their habitat. The abundance of *Fissilabia* sp. in [22] revealed that a distribution pattern of *Fissilabia* sp. was observed mostly in the high intertidal zone of rocky environments, sometimes found inhabiting the upper littoral zone and tending to cluster in locations with higher moisture levels during low tide, while actively avoiding areas with intense lights.

In the coastal mangrove site (K2), Karimunjawa area, the most abundant gastropod species recorded is *Cerithium* sp., this species occurs in all seasons. In July (K2T1), this species was abundant for 58% of all species observed, while in September (K2T2), it accounted for 49% of the total gastropod species. *Cerithium* sp. is a member of the marine snail family. According to [23], species of cerithids have herbivorous or detritivores feeding behaviors and inhabit the intertidal zone as well as the shallow waters of tropical and subtropical seas, characterized by sand and mud. According to [24], *Cerithium* prefers mangrove forests and demonstrates a higher competitiveness in terms of resource acquisition and habitat occupancy compared with other species exclusively during high tide periods. We recorded two other species of gastropods found abundant and only appeared in the mangrove forest: *Clypeomorus* sp. and *Pirenella* sp. Isoni et al. [25] showed that *Clypeomorus* sp. inhabits mostly surrounding areas of

mangrove vegetation, specifically in the *Sonneratia* and *Avicennia* mangrove habitats. Further supported by [26], which highlights the presence of mangroves in Karimunjawa, particularly in the Kemujan forest, species identified include *Avicenna marina* and *Sonneratia alba*. Islamy and Hasan [27] revealed that members of the genus *Pirenella* inhabit intertidal sedimentary shores and are often found in association with mangroves. *Pirenella* sp. was found to be associated with algae in the upper intertidal and mid-intertidal zones in mangrove plantations. Regarding bivalves, *Anadara* sp. was frequent in both K1 and K2. According to [28], the genus *Anadara* often inhabits substrates that contain higher nutrient levels within the intertidal zone and inhabits estuary locations with high salinity levels.

In Rawapening Lake that expressed freshwater attributes, four dominant gastropod species were observed over the entire sample area (Table 1, Fig. 5), including: *Filopaludina* sp., *Melanoides* sp., *Ferrisia* sp., and *Pila* sp. one gastropod species was found only at the reference site, and two gastropod species were exclusively found at the monoculture site. *Filopaludina* sp. appeared as the dominant species, with abundance over 60% and a high frequency of occurrence (89%) at all sample sites, as shown in Table 1. However, *Filopaludina* sp. did not exhibit a consistent abundance throughout all seasons. Priawandiputra et al. [29] showed that *Filopaludina* sp. exhibits a high degree of adaptability to diverse habitats, has a wide geographical range in freshwater environments, and possesses filter feeding characteristics. According to [30], *Filopaludina* sp. consumed decomposed organic material for approximately 90% reduction. The second most abundant gastropod (56%) is *Melanoides* sp., which is known to be an invasive species, dominating aquatic ecosystems such as rivers and lakes. According to [31], over 60% of the total microalgal biomass was consumed by *Melanoides* sp., and the feeding dynamics for *Melanoides* sp. are positively correlated with temperature, as the highest temperature increases the consumption efficiency and gut passage time. This species is a good bioindicator and heavy metal accumulator. Saputra et al. [32] showed that *Melanoides* sp. has an adaptive capability to thrive across a broad spectrum of pH levels and is distributed among various substrate types, commonly in rock or mud habitats, and is recognized for its ability to take advantage of environments with eutrophication and environmental stressors. Moreover, [33] showed Rawapening Lake as one of 15 priority lakes in Indonesia that suffers from eutrophication due to erosion from residential and agricultural areas surrounding the lake. Bivalves in Rawapening Lake were only found for 1 species and recorded only in monoculture and reference locations (Fig. 5), namely *Pilsbryocncha* sp. [34]. *Pilsbryocncha* sp. are known for their behavior in filter feeders, frequently seen in

freshwater environments, particularly in lakes, rivers, and aquaculture ponds. Rahmawati et al. [35] showed that *Pilsbryocncha* sp. has the capacity to survive in

aquatic environments characterized by reduced oxygen levels, thrives in sedimentary habitats, and is capable of collecting contaminants.

Table 1 The dominant taxa and frequency of occurrence of macrobenthos mollusk abundance (ind.m⁻²) in Rawapening Lake (RL) and Karimunjawa Island (KI)

Karimunjawa Island (KI)						
Dominant taxa	Aquaculture site (K1)		Coastal mangrove site (K2)		FoI	
	July	Sep.	July	Sep.		
<i>Fissilabia</i> sp.	992,59	488,89	59,26	14,81	100%	
<i>Rissoina</i> sp.	696,30	177,78	237,04	503,70	100%	
<i>Cerithium</i> sp.	681,48	222,22	1392,59	1481,48	100%	
<i>Bittium</i> sp.	311,11	281,48	44,44	133,33	100%	
<i>Acteocina</i> sp.	207,41	311,11	103,70	118,52	100%	
<i>Anadara</i> sp.	14,81	14,81	14,81	-	75%	
<i>Littorina</i> sp.	1022,22	1170,37	-	-	50%	
<i>Cerithidium</i> sp.	148,15	162,96	-	-	50%	
<i>Clypeomorus</i> sp.	-	-	222,22	192,59	50%	
<i>Pirenella</i> sp.	-	-	340,74	503,70	50%	
<i>Acanthocardia</i> sp.	44,44	14,81	-	-	50%	

Rawapening Lake (RL)										
Dominant taxa	Polyculture site (R1)			Monoculture site (R2)			Reference site (R3)			FoI
	Oct.	Nov.	Dec.	Oct.	Nov.	Dec.	Oct.	Nov.	Dec.	
<i>Filopaludina</i> sp.	1970,37	1970,37	2637,04	-	10533,33	1970,37	2637,04	12503,70	2637,04	89%
<i>Melanoides</i> sp.	-	651,85	-	-	1318,52	-	651,85	1970,37	651,85	56%
<i>Ferrisia</i> sp.	-	651,85	651,85	-	-	1318,52	-	2637,04	-	44%
<i>Pila</i> sp.	-	-	651,85	1318,52	-	-	-	1970,37	-	33%
<i>Pilsbryocncha</i> sp.	-	-	-	1970,37	1970,37	-	1970,37	-	-	33%

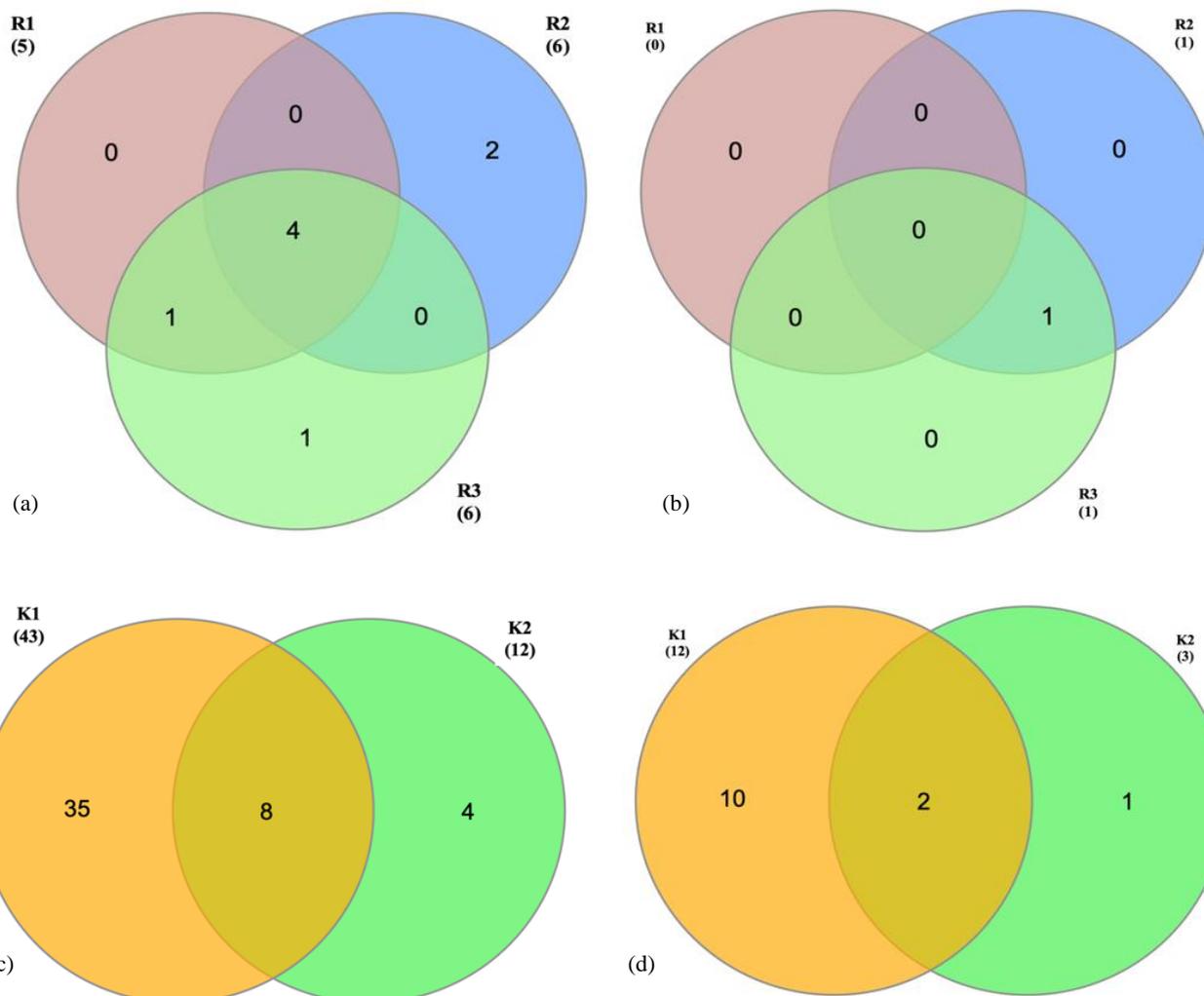


Fig. 5 Genera distribution in (a) Rawapening gastropods, (b) Rawapening bolivals, (c) Karimunjawa gastropods, and (d) Karimunjawa bolivals

3.2. Diversity, Evenness, and Dominance Index

The highest value of diversity index (H') in Karimunjawa was in the aquaculture site in September (K1T2), with a value of 2.40 categorized as medium, while the lowest was in July in the mangrove site (K2T1), with a value of 1.36 categorized as low (Fig. 6). The highest evenness index was in September at the aquaculture site (K1T2) with a value of 0.72, categorized as medium, whereas the lowest was in July at the mangrove site (K2T1) with a value of 0.62, categorized as medium (Fig. 5). The small dominance index values (ranging from 0.09 to 0.33) observed at each station and sample period indicate the absence of any dominating species. Meanwhile, in Rawapening Lake, diversity index (H') was low in all periods ranging from 0.68 to 1.19, the highest value in reference October (R3T1) and lowest value diversity in both aquaculture sites (R1 & R2). The Evenness Index value (e) at all sites was classified as moderate, ranging from 0.58 to 0.98. Dominance index (D) values from all sites indicated low to moderate dominance ranging from 0.48 to 0.65, with the highest value in the reference site in the October period (R3T1).

The recorded differences in the value index between the Rawapening and Karimunjawa sample locations indicate a major difference in quality. The observed rise in diversity value at K1 was believed to be a direct result of aquaculture activities in the area. The operations performed at the aquaculture site introduce organic matter, which serves as a source of nutrition for macrobenthic mollusks. Nurhasballah et al. [36] showed that the presence and variety of macrobenthic mollusks exhibited a positive correlation with the abundance of organic materials available in the area. The diversity in mangrove site (K2) was known to be lower, supported by the fact that recorded in [26] showed that the mangrove forest in Karimunjawa has experienced many anthropogenic disturbances, both

direct and indirect in recent years. The density of mangroves in Karimunjawa tends to be classified as rare to medium density, which had a major effect on the biotic community residing in the region. In Rawapening Lake, places that engage in aquaculture (R1 & R2) exhibit varying levels of diversity, which are generally lower than those in the reference areas (R3). The lowest levels of diversity are seen in areas that practice monoculture (R2: 0.68). The data obtained from the Rawapening site showed that Rawapening Lake exhibited signs of instability, indicating a state of poor or disrupted water conditions. Several factors that are closely related to the life of mollusks, such as substrate and water chemistry can influence such conditions. According to [37], the diversity of mollusks in freshwater is influenced by several abiotic and biotic factors, such as features of local geography, biological interactions, and anthropogenic activities. Thus, environmental conditions with polluted ecosystems tend to have low diversity.

The evenness index at Karimunjawa demonstrates that the ecosystem maintains a steady state, with little impact from disturbances on its overall stability [38], which indicates that the distribution of the number of individuals of each species has an equal value on survival rate. While in Rawapening Lake evenness values were recorded as unstable to stable, the polyculture location had higher evenness when compared to the monoculture locations, which shows that the polyculture location is more stable than the monoculture location.

There was no high dominance in both Karimunjawa and Rawapening. However, Rawapening Lake had *Filopaludina* sp. as the most abundant gastropod species in all areas, surpassing other species. The existence of dominant species indicates differences in the adaptability of each species to the environment.

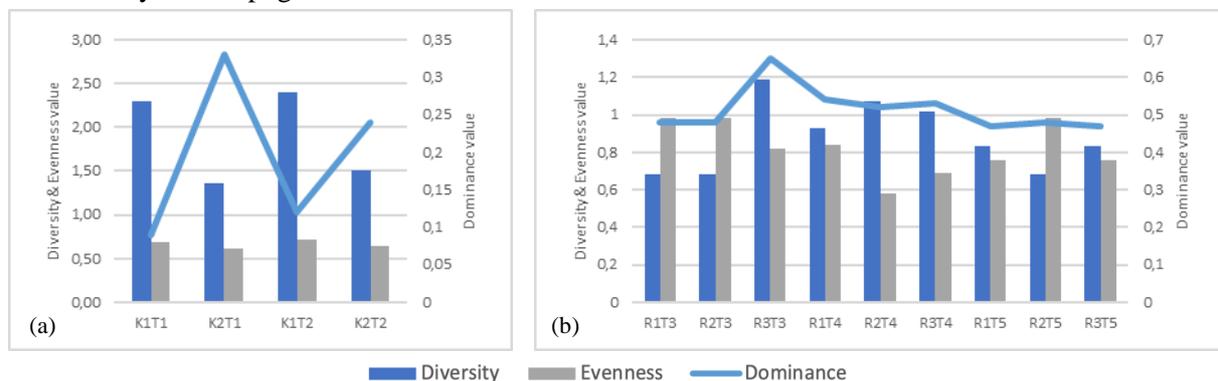


Fig. 6 Diversity, evenness, and dominance index in (a) Karimunjawa and (b) Rawapening

3.3. Water Parameters

The measured physical-chemical properties of water parameters in both locations were temperature, pH, and DO. However, salinity and current speed were only recorded in the Karimunjawa site, while TDS was recorded only in the Rawapening site. Karimunjawa's

highest temperature (25°C), $\text{pH} = 8.07$, and current of $83 \text{ cm}\cdot\text{s}^{-1}$ were recorded in the aquaculture site (K1). The location of this site is located within the intertidal zone, offering a greater expanse for the acquisition of light and water movement flowing from the open ocean, in contrast to the mangrove site, [39] showed a

lack of shades and aquaculture activities which add free minerals to the ecosystem. The mangrove site (K2) had a higher average DO value (9 mg/L) than the aquaculture site (8 mg/L). According to [40], a higher abundance of organisms would decrease the DO level in the water column due to competition between organisms.

In Rawapening, the reference site (R3) had the highest average value for temperature (29.04°C) and pH (7.94), DO averagely highest in the monoculture site (R2: 1.38), while TDS highest in the polyculture site (R1: 133). Based on seasons, DO and TDS significantly decreased in November (T4) and

December (T5) at all sites but were increasingly higher in pH and temperature, as shown in Fig. 7.

In general, the temperature values showed an upward trendline, as seen by the dotted line in Fig. 7. Conversely, the pH redline tended to remain relatively stable, while the DO redline showed a decreasing track. Supported by the research [40], the variable DO also shows a positive correlation with pH and a negative correlation with temperature. From these observations, it can be concluded that the Rawapening area generally experiences higher temperatures and lower DO levels than the Karimunjawa area.

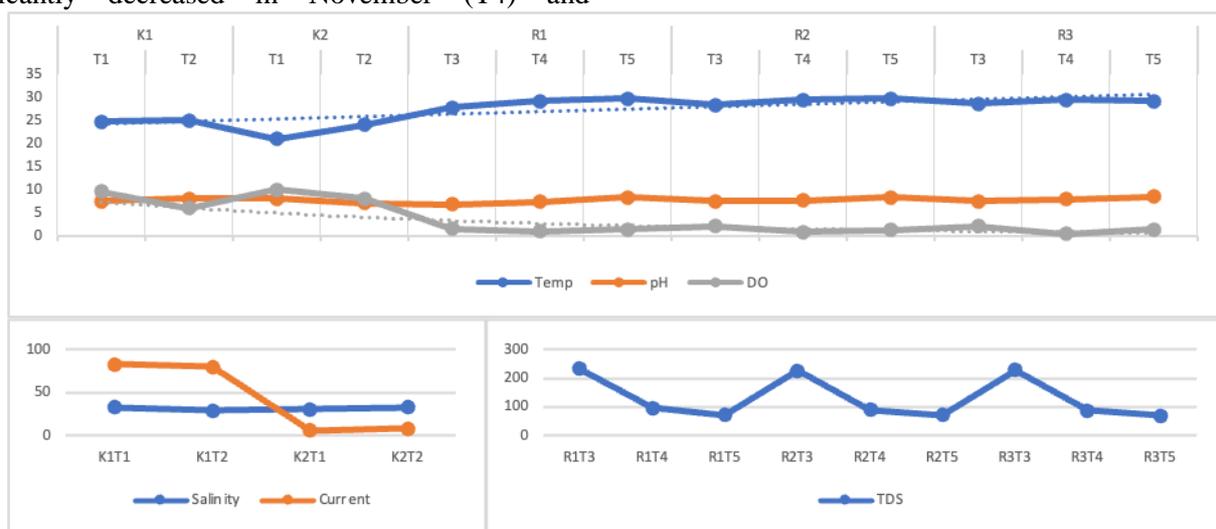


Fig. 7 Comparative data of water parameters in Karimunjawa and Rawapening

3.4. Sediment Properties

The composition of the sedimentary substrate grains in Rawapening includes: gravel, fine sand, coarse sand, silt, and clay, whereas Karimunjawa is composed only of gravel, fine sand, coarse sand, and silt. The particle size and type of substrate is one of the ecological factors affecting organic matter and the spread of macrobenthos [41]. Substrates that have finer grains are more able to accumulate organic matter. This also confirms the data provided in this study, where Rawapening Lake, characterized by silt-clay substrates, has a greater organic matter than Karimunjawa Lake. Grain composition can be seen in Fig. 7, and organic matter is shown in Fig. 8.

The sediments collected from Rawapening are mostly composed of silt-clay, with silt forming around 60% of the composition and clay forming approximately 20% (Fig. 7). The average high content of the silt fraction at the three sampling locations also contributed to the high organic matter content (Fig. 8). According to [42], sediments with a clay texture have a large surface area, so they have a high ability to absorb nutrients and retain water. The substrate in the form of gravel had the smallest percentage at each station, with an average of 0.54%. Waters of Rawapening Lake are lake-type waters that do not have strong water currents; therefore, the particles that settle in the sediment are fine particles. According to [22], the deposition of silt

particles on the bottom of water depends on water currents. If the water currents are strong, the particles that settle are large, and if the water currents are not strong, the particles that settle will be smaller.

The significant variations in sediment composition between Rawapening and Karimunjawa play a substantial role in shaping their biotic distributions. The sedimentary composition of Karimunjawa is mostly composed of fine sand, accounting for approximately 68% of the total composition. Specifically, inside the mangrove area, the dominant composition consists of fine sand (69.58%) and silt (14.05%). Conversely, at the aquaculture sites, the dominant composition was characterized by fine sand (68.66%) and coarse sand (25.10%). The water current at the aquaculture site (K1) shows greater intensity in comparison to the mangrove area, thus producing an important effect on the sediment condition in both locations. According to [43], the sedimentation of silt particles on the bottom of aquatic environments is dependent on the intensity of water currents. In the presence of strong water currents, larger particles are more likely to settle, whereas weaker water currents tend to facilitate the deposition of smaller particles. According to [44], the mangrove environment is a muddy substrate generated by sedimentation, resulting from the accumulation of sediment components that are held by the roots of mangrove plants. The low water

current recorded at the mangrove location may be attributed to the presence of mangrove trees, which can weaken waves [45]. Mangrove trees, when submerged by tides, effectively disperse waves and mitigate tidal currents. This, in turn, reduces hydrodynamic pressures

inside the mangrove, which encourages the deposition of suspended sediment, resulting in an increase in bed elevation. Consequently, this process supports the long-term survival of wetlands among the challenges posed by rising sea levels.



Fig. 8 Sediment properties (%) of Karimunjawa and Rawapening

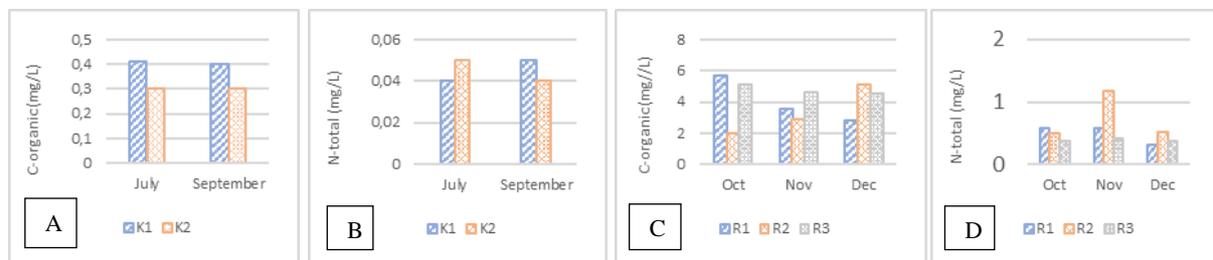


Fig. 9 Organic matter properties (mg/L): (a) Karimunjawa – C-organic, (b) Karimunjawa – N-total, (c) Rawapening – C-organic, and (d) Rawapening – N-total

3.5. Link between Macrobenthic Mollusks and Environmental Factors

BIO-ENV (Primer v 6.1.5) analyzed the level of correlation between the physical–chemical data of sediment and water and the abundance of macrobenthic mollusks. A square root transformation was applied to sediment and water data as abiotic data. The data were then normalized using the Euclidean distance similarity and weighted Spearman correlation value methods. Details of the BIO-ENV analysis results for the Rawapening site can be seen in Table 2, and those for Karimunjawa are shown in Table 3.

Table 2 BIO-ENV analysis regarding the correlation between biotic and abiotic parameters in Rawapening

Correlation value (r)	Coefficient of determination (r ²)	Selected variables	Number of variables
0.5090	25.91%	4, 9	2
0.5083	25.84%	3, 4, 8 – 10	5
0.5083	25.84%	4, 6, 9	3
0.5083	25.84%	4, 6, 8, 9	4
0.5083	25.84%	3, 4, 8, 9	4
0.5083	25.84%	4, 7 – 9	4
0.5076	25.77%	3, 4, 7 – 9	5
0.5076	25.77%	4, 6 – 9	5

Variables No.:

1. Gravel	4. Silt	7. Temp.	10. Salinity
2. Rough sands	5. C-Organic	8. pH	
3. Fine sands	6. N-Total	9. DO	

Table 3 BIO-ENV analysis regarding the correlation between biotic and abiotic parameters in Karimunjawa

Correlation	Coefficient of	Selected	Number of
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value (r)	determination (r ²)	variable	variables
0.612	37.45%	1	1
0.548	30.03%	1, 7	2
0.476	22.66%	4, 6, 8, 10	5
0.473	22.37%	4, 6, 10	4
0.473	22.37%	1, 4, 6, 10	5
0.473	22.37%	2, 4, 6, 10	5
0.473	22.37%	4, 7, 10	5
0.473	22.37%	4, 6, 10, 12	5
0.473	22.37%	4, 6, 10, 11	5
0.471	22.18%	4, 5, 10, 12	4

Variables No.:

1. Temp.	4. TDS	7. Phosphate	10. Fine Sand
2. pH	5. C-Organic	8. Gravel	11. Silt
3. DO	6. N-Total	9. Rough sands	12. Clay

Based on Table 2, the abundance of mollusks in Rawapening has the highest degree of correlation with temperature and fine sediments ($r = 0.548$; $r^2 = 30.03\%$). According to [46], temperature can affect the distribution, species composition, and way of life of intertidal animals. Another variable that is considered positively correlated is the fine sand substrate variable, which always appears at every correlation value. Based on the results of the analysis of abiotic–biotic correlations in Karimunjawa, the main factors influencing the abundance of macrobenthic mollusks were identified as the mud fraction and DO content. This observation was substantiated through careful examination of the interactions between biotic and abiotic parameters, which showed a statistically significant correlation coefficient of 0.509 (Table 2).

According to [43], water currents have a visible impact on the texture of the substrate. Specifically, regions with strong currents tend to have rough substrates, whereas regions with weaker currents show the opposite.

According to [47], gastropods exhibit a marked predilection for fine substrates because of the augmented presence of organic matter relative to their coarse counterparts, including silt, muddy, and sandy substrates. Furthermore, the corroborative evidence presented in [46] underscores the integral role of DO in influencing macrobenthic mollusk dynamics. According to this study, dissolved oxygen plays a pivotal role in metabolic processes, thereby directly influencing the distribution and density of gastropods. Importantly, negative correlation with temperature characterizes the relationship between DO and gastropod parameters, as established by empirical observations.

4. Conclusion

Karimunjawa sites had a greater diversity of macrobenthic mollusks, whereas Rawapening sites showed low diversity. The aquaculture site in Karimunjawa had the highest diversity among all locations, with low dominance, and *Littorina* sp. and *Cerithium* sp. were abundant, indicating nutrient enrichment in their habitats. However, aquaculture sites in Rawapening Lake showed poor diversity and medium dominance, with *Filopaludina* sp. occurring abundantly in all sites, related to the high silt-clay substrates in Rawapening and *Melanoides* sp., indicating a high organic matter to eutrophication in their habitat. Macrobenthic mollusks in Rawapening had the highest degree of correlation with temperature and fine sediment substrates, whereas Karimunjawa had a closer relationship with the silt fraction and dissolved oxygen in their habitat.

This study demonstrates the impact of physicochemical parameters of aquatic environments on the structural composition of macrobenthic mollusks. We propose leveraging partial datasets derived from complete macrobenthic structural data for a more streamlined analysis of environmental disturbances. Furthermore, using partial macrobenthic data collection to determine their level is a solution to make the workflow faster without reducing the accuracy of their assessment.

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