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Diversity and distribution of benthic macroinvertebrates in Krueng Aceh watershed, Aceh Province, Indonesia

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Abstract. *Octavina C, Muchlisin ZA, Satriyo P, Hurzaid A. 2025. Diversity and distribution of benthic macroinvertebrates in Krueng Aceh watershed, Aceh Province, Indonesia. Biodiversitas 26: 601-616.* Krueng Aceh, the densest watershed in Aceh Province, Indonesia, features diverse habitats with rainwater as its main source. However, agriculture, plantations, sand mining, and waste disposal have affected its aesthetics. This study examines the diversity and distribution of benthic macroinvertebrates in Krueng Aceh. Conducted over six months (March-August 2024), it used purposive sampling at 10 stations (upstream, midstream, and downstream). Surber nets sampled upstream and midstream, while PVC pipes were used downstream. A total of 1240 benthic macroinvertebrates were identified across 3 phyla, 5 classes, 29 families, 42 genera, and 49 species. *Hydropsyche angustipennis* dominated hard substrates, while *Tarebia granifera* dominated soft substrates. Most macroinvertebrates exhibited a clustered distribution, with some showing no clear pattern. The diversity index (H') ranged from 0.99 to 3.46 (moderate to high), and the Simpson dominance index from 0.10 to 0.62 (low dominance). Hierarchical Cluster Analysis (HCA) grouped the 10 stations into two similarity clusters. Overall, macroinvertebrate diversity in Krueng Aceh was relatively high, and water quality remained within acceptable standards.

Keywords: Benthic macroinvertebrate, *Hydropsyche*, Krueng Aceh, *Tarebia*

INTRODUCTION

Benthic macroinvertebrates are a group of animals without backbones and are larger than 1 mm (millimeter) in size. These animals often live in the bottom sediment of waters (Singh and Sharma 2020; Kownacki and Szarek-Gwiazda 2022) and include insects, shellfish, snails, and worms (Isroni et al. 2023). One of the important habitats for macroinvertebrates is rivers, which serve as a diverse lotic ecosystem (Buffagni et al. 2003; Hauer and Resh 2017). In addition, rivers play an important ecological role, including controlling floods (Lombardi and Davis 2023), nutrient cycling (Wohl et al. 2015), carbon storage (Raymond et al. 2013), biodiversity (Cumberlidge 2014), and economic value in agriculture, fisheries, and renewable energy sources (Islamy and Hasan 2020; Bursać et al. 2022). However, this ecosystem is the most threatened (Sabater and Elosegi 2014) due to the location and human contact. The common problem experienced is the decline in water quality caused by human activities and nature, such as climate change (Chazanah et al. 2020; Putri et al. 2021; Pratiwi et al. 2023).

One of the watersheds suspected to be experiencing a decline in water quality is the Krueng Aceh watershed. This watershed has the highest density in Aceh Province, Indonesia, with an area reaching 174785.79 ha, (1747.8 km^2). In addition, it is located in 2 administrative areas, namely Aceh Besar District and Banda Aceh City, at the northern tip of Sumatra Island. Geographically, it is located at 5003'41"-5038'10"N and 95011'41"-95049’46"E, and has several sub-watersheds, including Krueng Jreue (Basri et al. 2023), Krueng Keumireu (Jayanti et al. 2019), Krueng Khea (Darwin et al. 2021), Krueng Tereubeh (Syukri et al. 2013), and Krueng Seulimum (Akbar 2018; et al. 2018; Siswanda et al. 2023).

The main water source of Krueng Aceh watershed is rainwater precipitation, which becomes surface and groundwater (Ferijal et al. 2016a; Satriyo et al. 2017). This is supported by the fact that Banda Aceh and Aceh Besar have a tropical rainforest climate with an average annual temperature of around 27°C. Both regions do not have a clear dry season, but there is a period of higher rainfall between October and January, influenced by the northeast monsoon and tropical depression (Ferijal and Fauzi 2024). However, land conversion into agricultural land, plantations, and settlements without considering the principles of soil and water conservation is suspected to have caused significant damage. These include erosion, increased water turbidity, reduced infiltration, and increased surface runoff (Ferijal et al. 2016b; Muis 2019a,b). The damage causes a decrease in groundwater supply, flooding during the rainy season, drought in the dry season, and river shallowing due to sedimentation (Devianti et al. 2021; Saputra et al. 2021; Basri et al. 2023).

Land conversion activities also cause a decline in water quality, such as high attrition (Chairani et al. 2014; Azmeri et al. 2015; Alfaisal et al. 2017), low land productivity, and sedimentation downstream (Aini et al. 2023). Suboptimal water management, including the construction of dams and drainage (Muis et al. 2016; et al. 2017), as well as pressure from heavy metal pollution (Hadi et al. 2018; Putra et al. 2022), are serious threats to benthic macroinvertebrates that inhabit watershed. The existence of this biota is very important in the food chain and river ecosystem, and it determines the productivity of waters (Pawlowski et al. 2020; Singh and Sharma 2020). Several types of macroinvertebrates are often consumed by the community, leading to a high economic value.

According to Pawlowski et al. (2020), the diversity and distribution of benthic macroinvertebrates are closely linked to river quality. High species diversity indicates a healthy river, while low diversity suggests habitat pollution or degradation. Additionally, sensitive species thrive in clean water, whereas tolerant species dominate polluted areas, reflecting variations in water quality. Moreover, diverse communities enhance nutrient recycling and oxygen balance, helping to maintain water quality. Finally, pollution, deforestation, and urbanization reduce biodiversity, alter species distribution, and degrade river health.

Over the years, a total of 2 studies have reported the presence of benthic macroinvertebrates in several areas or sub-watersheds in Krueng Aceh, including Gastropoda in 5 points representing the downstream area. However, there is no information on the structure of benthic macroinvertebrates community due to the lack of sampling points (Afwanuddin et al. 2019). Diversity of macrozoobenthos in the downstream area of Krueng Aceh is relatively low, and the location is moderately polluted (Fastawa et al. 2018). A comprehensive report on diversity and distribution of macroinvertebrates that can describe the overall conditions in Krueng Aceh watershed area has also never been conducted. This is important, considering that a study on benthic macroinvertebrates in this watershed can serve as an initial database for mapping sensitive and insensitive benthic fauna groups and their economic value. The results can also serve as an initial step in preparing a lotic water conservation plan in the future. The area is included in the Priority 1 watershed as stipulated in the 2010-2014 Medium-Term Development Plan (RPJM) based on the Decree of the Minister of Forestry of Indonesia Number: SK. 328/Menhut-II/2009. The management of Krueng Aceh watershed is regulated by Aceh Qanun Number 7 of 2018 concerning Integrated Watershed Management. Therefore, this study aims to describe and analyze diversity and distribution of benthic macroinvertebrates species in Krueng Aceh watershed. The specific objectives are to (i) analyze the composition and density of benthic macroinvertebrates species; (ii) measure the frequency of presence and distribution patterns; (iii) analyze ecological indices, such as diversity index and dominance index; (iv) assess the relationship between benthic macroinvertebrates ecological indices and water quality parameters.

MATERIALS AND METHODS

Study area

This study was conducted for 6 months, from March to August 2024, at Krueng Aceh watershed, Aceh Province, Indonesia. Geographically, it was located at 5003'41"-5038'10"N and 95011'41"-95049'46"E. The sampling sites were at 10 locations representing the 6 sub-watersheds of Kreung Aceh, namely Krueng Inong, Krueng Keumireu, Krueng Jrue, Krueng Seulimuem, Krueng Khea, and Krueng Aceh Hilir (Figure 1).

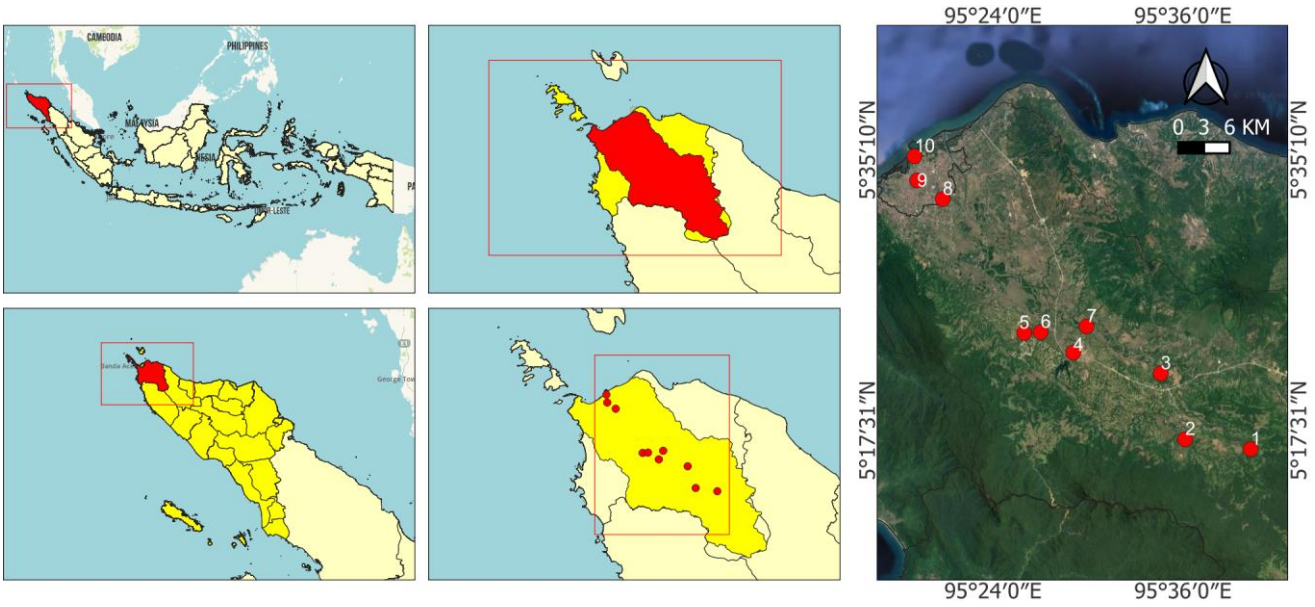

Figure 1. Research location in Krueng Aceh watershed, Aceh Besar, Aceh Province, Indonesia
Note: The site number information in the figure is in Table 1

Table 1. Benthic macroinvertebrate sampling site along the Krueng Aceh watershed, Aceh Province, Indonesia

Site	Coordinate	Substrate	Depth (m)	Width (m)	Velocity (m/s)	Other characteristics
1	5°16'22"N, 95°40'17"E	Sand (83%); silt (4%); clay (13%); loamy sand	3 ± 0.0	20 ± 0.1	3 ± 0.1	Near forests and away from urbanization
2	5°16'59"N, 95°36'09"E	sand (87%); silt (4%); clay (9%); loamy sand	2 ± 0.0	15 ± 0.1	2.5 ± 0.2	Near tourist attractions
3	5°21'07.2"N, 95°34'36.4"E	sand (86%); silt (4%); clay (13%); loamy sand	1.5 ± 0.0	21 ± 0.1	2.4 ± 0.1	Near forests and residential areas
4	5°22'26"N, 95°29'05" E	Sand (55%); silt (30%); clay (15%); sandy loam	2.9 ± 0.0	12 ± 0.1	1.8 ± 0.1	Near residential areas and sand mining
5	5°23'40"N, 95°25'59"E	Sand (87%); silt (9%); clay (4%); sandy loam	1.6 ± 0.0	30 ± 0.1	2.9 ± 0.2	Near farms and sand mining
6	5°23'43.3"N, 95°27'01.2"E	Sand (87%); silt (4%); clay (9%; loamy sand	1.2 ± 0.0	14 ± 0.1	2.7 ± 0.2	Near farms and sand mining
7	5°24'04.6"N, 95°29'55.3"E	Sand (67%); silt (28%); clay (5%); loamy sand	2.7 ± 0.0	12 ± 0.1	1.6 ± 0.1	Near farms, rice fields, and sand miners
8	5°32'04.8"N, 95°20'50.0"E	Sand (16%); silt (74%); clay (10%); loamy sand	4 ± 0.0	33 ± 0.1	0.68 ± 0.1	Near residential areas and farmland
9	5°33'15.5"N, 95°19'13.0"E	Sand (9%); silt (74%); clay (17%); loamy sand	3 ± 0.0	34 ± 0.1	0.42 ± 0.3	Estuary, Near residential areas and traditional markets
10	5°34'46"N, 95°19'03"E	Sand (2%); silt (81%); slay (17%); loamy sand	5 ± 0.0	35 ± 0.1	0.44 ± 0.1	Estuary, Urban area with dense settlements

Procedures

Determination of sampling location

Determination of sampling location was conducted purposively, however, it could represent the overall condition of watershed. Krueng Aceh watershed was divided into 3 areas or zones, namely the estuary area represented by 3 sub-watershed locations, downstream area, namely the rivers around Pango Village (5°32'04.8"N-95°20'50.0"E), Kampung Baru Village (5°33'15.5"N-95°19'13.0"E), Lampulo Village (5°34'46"N-95°19'03"E), middle area, represented by 4 sampling locations (sub-watershed), namely Krueng Keumireu sub-watershed represented by the river in Lamleupung Village (5°24'04.6"N-95°29'55.3"E), Krueng Jreu sub-watershed represented by the river in Reukih Dayah Village (5°23'40"N-95°25'59"E), Krueng Khea sub-watershed was represented by the river in Riting Indrapuri Village (5°23'43.3"N-95°27'01.2"E). Other areas included Krueng Jreu sub-watershed represented by the river in Keureuweung Village (5°22'26"N-95°29'05"E), and upstream area, represented by 3 locations (sub-watershed), namely Krueng Seulimuem sub-watershed represented by the river in Keunaloi Village (5°21'07.2"N-95°34'36.4" E), Krueng Inong sub-watershed represented by the river in Bukit Meusara Jantho Village (5°21'07.2"N-95°34'36.4"E), and the river in Jalin Village (5°16'22"N-95°40'17"E) (Figure 1). At each location, 3 sampling points were determined, and at each point, samples were taken 3 and 5 times. The determination of this was carried out by considering the safety and security of investigators because Krueng Aceh watershed had a strong water current in upstream area and different depths, specifically downstream area, which was very deep compared to upstream.

Benthic macroinvertebrates sampling

Benthic macroinvertebrates sampling was conducted using two tools, the Surber net and PVC pipe, due to the different river substrates, namely rocky and sandy textures. In upstream and middle areas of watershed with rock and sand textures, a surber net with dimensions of 300x300 mm and a pore size of 500 µm was used. In upstream and middle areas of the river, the surber net was placed against the current and did not sink. Then, disturbances were carried out at the front of the surber, such as shifting rocks, gravel, and sand, for 2-10 minutes to release and capture hiding macroinvertebrates samples (Muntalif et al. 2023). At each observation location, samples were taken from 3 areas representing the river's left, middle, and right banks with 3 repetitions each. In the estuary section with a dusty clay texture, PVC pipe with a length of 100 cm and a diameter of 86 cm was used. Conversely, downstream of the river could only be done on the right and left banks of the river because in the middle area, the current was fast, and water was deep. This was dangerous for investigators, and each was performed in 5 repetitions.

The captured benthic macroinvertebrates were then put into sample bottles, labeled, and preserved with 96% ethanol (Scott et al. 2019) and then taken to the Marine Biology Laboratory, Faculty of Marine and Fisheries, Universitas Syiah Kuala for further analysis. Benthic macroinvertebrates were identified under a microscope (Carl Zeiss Microscopy Gmbh Primo Star, Germany) using taxonomic key books and texts by McCafferty and Provonsha (1983), Hauer and Resh taxonomic keys (2017) and CT Dept. of Energy and Environmental Protection (2021), and Purnama et al. (2022).

Measurement of water quality parameters

Water quality parameter measurements were conducted in situ on the left, middle, and right banks of the river, with

three repetitions each, Measurement of water quality parameters in Krueng Aceh watershed was carried out in situ. Clarity was measured using a Secchi disk, current velocity was measured using a flow meter (Flowatch FL-03 JDC), Dissolved Oxygen (DO) was measured using a DO meter (Lutron DO-5510), depth was measured using a manual scale board, salinity was measured using a Refractometer (ATAGO manual), water temperature and Total Dissolved Oxygen were measured using a DO meter (TDS (Total Dissolved Solid) Ez-9909), and water pH was measured using a pH meter (Lutron pH-222) which was calculated directly at each station during sampling. However, for sediment parameter analysis, 2 kg of sediment samples were taken at each station and then placed in a plastic container. Sediment texture, C-organic, and N-total were analyzed at the Soil Laboratory, Faculty of Agriculture, Universitas Syiah Kuala, Aceh, Indonesia.

Ecological parameter measurement

Benthic macroinvertebrates density was the number of individuals in a certain unit area. The formula used refers to Brower and Zar (1977):

$$D = \frac{n_i}{A}$$

Where, D is density (ind/m^2), n_i is number of benthic macroinvertebrate species *i* and A is area (surber net and PVC pipe) (m^2).

Species diversity was referred to as species heterogeneity and a characteristic of community structure which could be determined using the Shannon-Wiener Index (H') by Shannon-Wiever (1964), which:

$$H = \sum_{i=1}^{s} P_i \, log_2 \, P_i$$

Where, H′ is diversity index, P_i is proportion of the number of individuals species (ni) to the total number of individuals (N)*I* (n_i/N), S is taxa, and log_2 is 3.32.

The criteria for diversity index (H') were H'<1, meaning that species diversity was very poor; H' value between 1-2 meant that species diversity was poor; H' value between 2-3 was moderate; H' value between 3-4 was good; and H'>4 was very good.

The dominance of a particular species could be observed using the dominance index (Brower and Zar 1977) which was inversely proportional to the evenness index value. This formula is:

$$\widehat{D} = \sum_{i=1}^{s} (P_i)^2 = \sum_{i=1}^{s} \left(\frac{n_i}{N}\right)^2$$

Where, $\widehat{D}$ is dominance index, n_i is is number of benthic macroinvertebrate species *i*, N is total number of individuals, and S is taxa.

The criteria for the dominance index ranged from 0-1, and when it approached 0, almost no individuals dominated and were usually followed by a large evenness index value. When the dominance index approached 1, there was a dominant group, and the uniformity index value was getting smaller. Furthermore, Legendre and Legendre (1998) divided the dominance index criteria into 3, namely when D<0.4, then it had low dominance, when 0.4<D <0.6, it was moderate, and when D>0.6, it was high.

Based on Krebs (2014), the presence frequency indicated how often a species was found in various stations or water samples. This formula was useful in aquatic ecology studies to assess distribution of benthic species in a certain area. This formula is:

Presence frequency (%) = (Number of samples with species presence)/(Total sample) × 100

The species distribution pattern was identified using the Morisita Index, and the formula used referred to Brower and Zar (1977), which:

$$I_\delta = n \, \frac{\sum X^2 - N}{N(N-1)}$$

Where, I_δ is Morisita index, n is number of sampling site, $\sum X^2$ is total of individuals each site, and N is total of individuals contained in n plots. In addition, the criteria for the Morisita index were I_δ<1, distribution pattern of individual species was uniform, I_δ=1 was random, and I_δ>1 was clustered.

Data analysis

All data obtained in this study were grouped into tables and figures, and then descriptive analysis was carried out by linking all results with existing citations. Water quality analysis was based on the Indonesian Government Regulation (Appendix 6, PP 22 of 2021), with class II water quality standards. Analysis of macroinvertebrates community composition to show the main differences and similarities between study sites was carried out using Hierarchical Cluster Analysis (HCA) with the Unweighted Pair Group Method with Arithmetic (UPGMA) mean based on the Bray-Curtis dissimilarity index (Roger et al. 2017). All statistical analyses were performed using PAST software version 4.03 (Hammer et al. 2001).

RESULTS AND DISCUSSION

Species composition and presence frequency

A total of 1240 benthic macroinvertebrates specimens were successfully collected during the study in Krueng Aceh watershed. The specimens consisted of 3 phyla, including Annelida, which comprised a single family (Nereididae) and 1 species (*Nereis pelagica*); Arthropoda, which was represented by 19 families and 35 species, and Mollusca, comprising 9 families and 13 species. Therefore, benthic macroinvertebrates identified were classified into 5 classes, 29 families, 42 genera, and 49 species (Tables 2 and 3). Photos of each macroinvertebrates species found during the study are presented in Figures 2 and 3. The results showed that the most dominant family was

Hydropsychidae (Figure 4.A), and *Hydropsyche* was the most dominant genus found during the study (Figure 4.B). The results also showed that *Hydropsyche angustipennis* was the most dominant species, but its presence frequency was only 60% (Figure 4.C). *Afrobrianax ferdyi* and *Tarebia granifera* had the highest presence frequency compared to other species (each presence frequency was 70%). Both species were found at 7 out of 10 stations, where *A. ferdyi* was found at Stations 1, 2, 3, 4, 5, 6, and 7, while *T. granifera* was found at Stations 2, 3, 4, 5, 6, 7, and 8. Furthermore, *A. ferdyi* belongs to the class of Insects, while *T. granifera* is under the class of Gastropoda (Tables 2 and 3).

Benthic macroinvertebrates' density and distribution patterns

Based on the characteristics of the sampling location's bottom sediment texture, it could be grouped into 2 types, namely hard substrates (rocks, gravel, and pebbles) and soft substrates (mud and clay). This adjustment was necessary because different sampling tools were used based on the substrate encountered. Stations with hard substrate, including Stations 1, 2, 3, 4, 5, 6, and 7, were sampled using a Surber net with a surface area of 0.09 m^2, while Stations 8, 9, and 10, characterized by soft substrate were sampled using PVC pipe with an area of 2.78 m^2**.**

Ecological index

In the hard substrate area, Hydropsychidae family, namely *H. angustipennis*, had the highest density compared to other species, with an average density of 77 ind/m^2. In the soft substrate area, the Thiaridae family, namely *T. granifera*, had the highest density of 42 ind/m^2 in this area. Based on the hard substrate area, namely rocky, gravel, and pebbles, Station 1 had the highest average density compared to other stations, namely 28 ind/m^2. The analysis of distribution patterns using the Morisita index showed that almost all benthic macroinvertebrates in Krueng Aceh watershed were clustered (I_δ>1). However, benthic macroinvertebrates were also found with unknown distribution patterns (I_δ=0) such as *Vittina turrita, Indoplanorbis exustus, Parreysia tavoyensis, Corbicula fluminea, Tropisternus quadristriatus, Parathelphusa pantherina, Litopenaeus vannamei, Caenis latipennis, Stenacron interpunctatum, Potamanthus luteus, Arctopsyche irrorata,* and *Psychomyia* sp. (Table 4 and 5).

The analysis showed that diversity index (H') values ranged from 0.99 to 3.46, the highest at Station 4 and the lowest at Station 9. Simpson's dominance index ranged from 0.10 to 0.62, with the highest at Station 9 (Table 6).

Hierarchical Cluster Analysis (HCA)

Based on the spatial HCA, the community at Station 10 differed significantly from those observed at other stations (Figure 5). The results of HCA analysis showed that out of 10, all stations were grouped into 2 similarity groups. The first group of stations was 10, while the second group of stations was 1, 2, 3, 4, 5, 6, 7, 8, 9, and each of these groups had similarities between its stations. However, among the existing stations, Stations 1 and 3 had higher similarities compared to the other stations.

Water quality

The results of water quality parameter measurements obtained temperature results ranging from 26.93-32.17^{0}C (average 29.29±1.77), conductivity ranging from 10.13-301 µmhos/cm (average 173.72±93.04). TDS had a range of 75-5053.33 mg/L (average 608.23±1507.63), pH had a range of 7.35-8.35 (average 7.94±0.34), DO had a range of 5-8.17 mg/L (average 6.63±0.96), and depth ranged from 21.67-220 cm (average 52.9±0.02). Furthermore, water brightness had a range of 11.70-74.17 cm (average 33.35±17.48), the current had a range of 0.15-0.86 m/s (average 0.422±0.27), and the salinity had a range of 0-10.67 ppm (average 1.16±3.23) (Table 7). The results of sediment type analysis showed that sand content had a range of 2-87%, dust had a range of 4-81%, clay had a range of 5-17%, organic C had a range of 0.10-2.05%, and total N had a range of 0.02-0.12% (Table 8).

Discussion

The study showed that Hydropsychidae was the most common family in Krueng Aceh watershed. This family belongs to the order of Trichoptera (caddisflies) group, often found in large numbers in an aquatic ecosystem (Tszydel et al. 2016; Ficsór and Csabai 2021; Miess et al. 2022). *Hydropsyche angustipennis* was one of the most common species in this study and had the highest density, specifically in locations with hard substrate areas (rocks, gravel, and pebbles). This could be because this species had quite good adaptation to moderate to fast-flowing river conditions such as Krueng Aceh watershed and had high tolerance to moderately polluted environments with low oxygen levels (Ficsór and Csabai 2021; Thamsenanupap et al. 2021). However, this group thrives in environments with high dissolved oxygen levels, namely fast-flowing rivers with high oxygen solubility (Higler and Tolkamp 1983; Luke 2017; Ficsór and Csabai 2021). Hydropsychidae group had an efficient feeding strategy as a filter feeder which built nets as traps to catch organic particles carried by river currents, such as algae and detritus, as food sources (Higler and Tolkamp 1983; Luke 2017). According Miess et al. (2022), *H. angustipenni* had a relatively short life cycle and the ability to reproduce rapidly when environmental conditions were suitable, however, its numbers tended to be abundant. Similarly, in arid streams (Benzina et al. 2021; Meradi et al. 2024), these organisms construct silk nets to capture suspended organic particles, detritus, and microorganisms from the water column, allowing them to efficiently utilize available resources in environments where food availability may be limited due to low productivity.

The results showed that *A. ferdyi* and *T. granifera* had the highest frequency of presence and were found at 7 out of 10 stations. According Lee et al. (2003), *A. ferdyi* was an aquatic insect from the Psephenidae family known as the "water penny" because it had a flat larval shape resembling a coin.

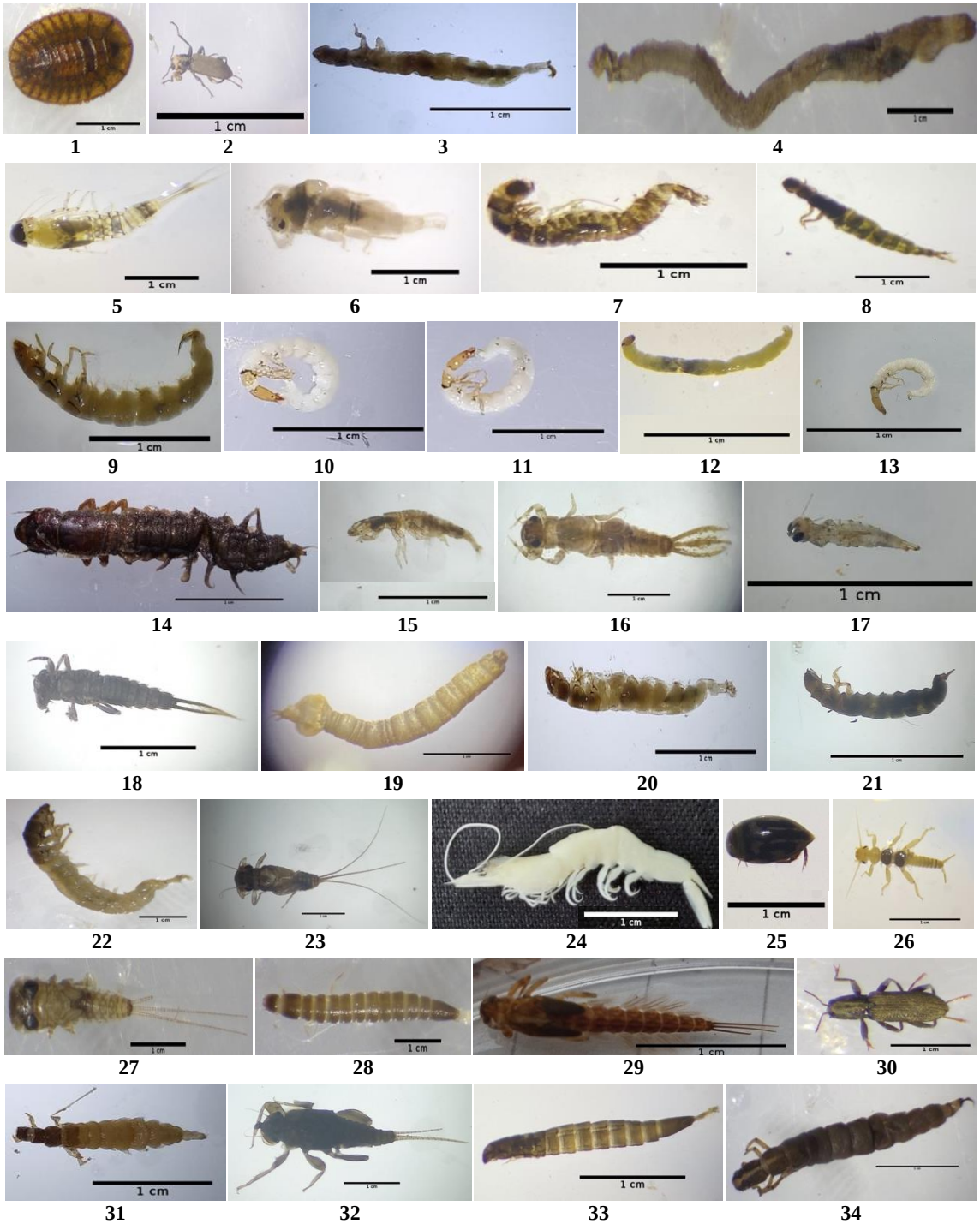

Figure 2. Arthropods species found in Krueng Aceh watershed, Aceh Province, Indonesia; (1) *Afrobrianax ferdyi* (Lee Philips &Yang, 2003); (2) *Ancyronyx variegatus* (Germar, 1824); (3) *Arctopsyche irrorata* (Banks, 1905; (4) *Anthoca* sp. (Osten Sacken, 1860); (5) *Baetis rhodani* (Pictet, 1843); (6) *Cheumatopsyche afra* (Mosely,1935)*;* (7) *Caenis latipennis* (Banks, 1907); (8) *Cheumatopsyche analis* (Banks, 1903); (9) *Cheumatopsyche lepida* (Pictet, 1834); (10) *Chimarra atterima* (Hagen, 1861); (11) *Chimarra marginata* (Linnaeus, 1767); (12) *Chironomus luridus* (Strenzke, 1959); (13) *Dolophilodes distinctus* (Walker, 1852); (14) *Corydalus cornutus* (Linnaeus, 1758); (15) *Diplectrona felix* (McLachlan, 1840); (16) *Ephemerella subvaria* (McDonnough, 1931); (17) *Habrophlebia fusca* (Curtis, 1834); (18) *Heterocloeon coriosum* (McDunnough, 1923); (19) *Hexatoma* sp. (Latreille 1809); (20) *Hydropsyche angustipenni* (Curtis, 1834); (21) *Hydropsyche rosii* (Flint, Voshell & Parker, 1979); (22) *Hydropsyche saxonica* (McLachlan, 1884); (23) *Leucrocuta petersi* (Allen, 1966); (24) *Litopenaeus vannamei* (Boone, 1931); (25) *Liodessus affinis* (Say, 1823)*;* (26) *Neoperla clymene* (Newman, 1839); (27) *Maccaffertium* sp. (Bednarik 1979); (28) *Microcylloepus pusillus* (Le Conte, 1852); (29) *Potamanthus luteus* (Linnaeus, 1767); (30) *Stenelmis consobrina* (Dufor, 1835); (31) *Psychomyia* sp. (Latreille 1829); (32) *Stenacron interpunctatum* (Say, 1839); (33) *Stenelmis canaliculata* (Gyllenhal, 1808); (34) *Tropistermus quadristriatus* (Horn, 1871).

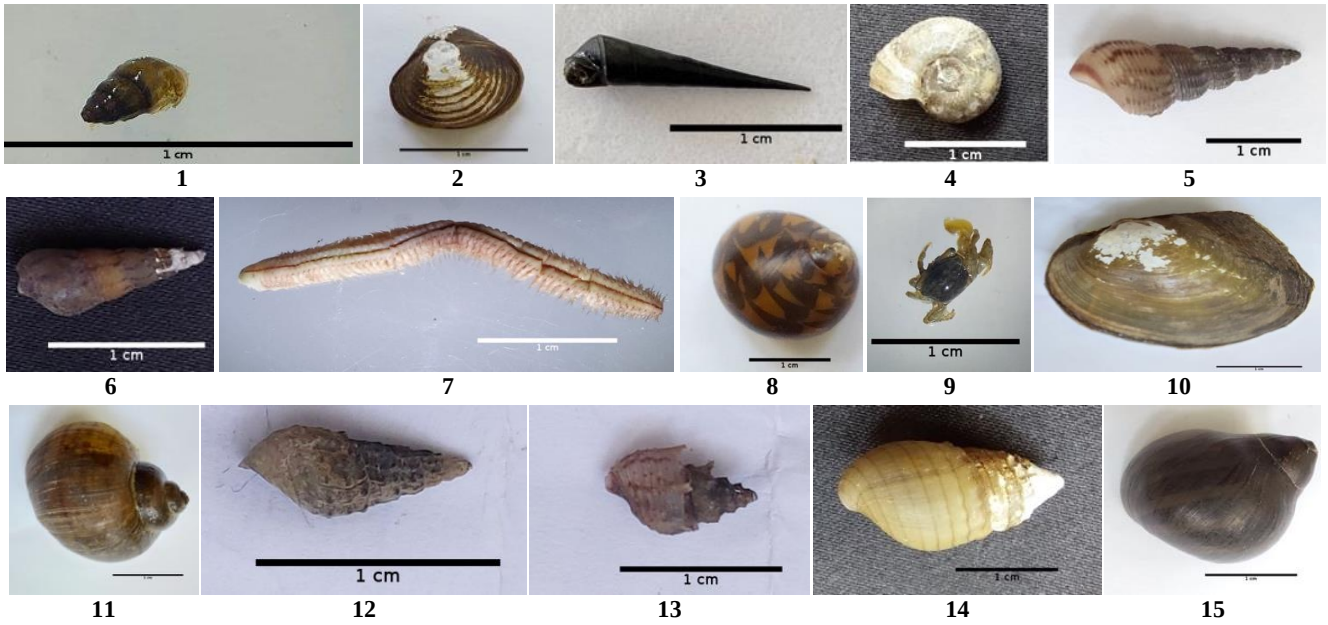

Figure 3. Mollucs and Annelids species found in Krueng Aceh watershed, Aceh Province, Indonesia; (1) *Bithynia spiralis* (Heude, 1890); (2) *Corbicula fluminea* (O.F. Muller, 1774); (3) *Faunus ater* (Linnaeus, 1758); (4) *Indoplanorbis exustus* (Deshayes, 1833); (5) *Melanoides tuberculata* (O.F.Muller, 1774); (6) *Melanoides fasciolata* (Olivier, 1804); (7) *Nereis pelagica* (Linnaeus, 1758); (8) *Neritodryas cornea* (Linneaeus, 1758); (9) *Parathelphusa pantherina* (Schenkel, 1902); (10) *Parreysia tavoyensis* (A.Gould, 1843); (11) *Pomacea canaliculata* (Lamarck, 1822); (12) *Tarebia granifera* (Lamarck, 1816); (13) *Thiara scabra* (O.F.Muller, 1774); (14) *Tiara lineata* (Broderip, 1836); (15) *Vittina turrita* (Gmellin, 1791)

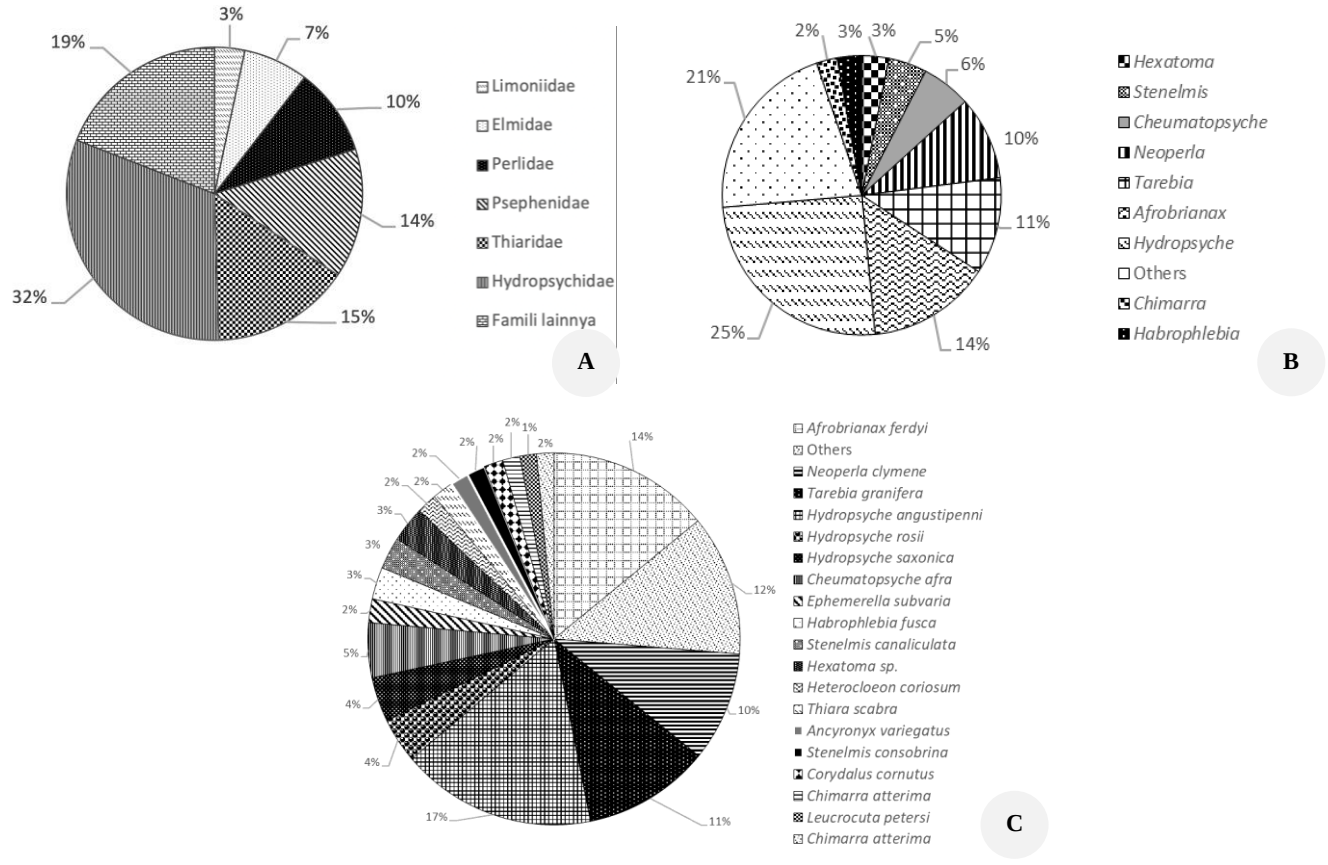

Figure 4. A. Benthic macroinvertebrate family composition by number of genus; B. Benthic macroinvertebrate genus composition by number of species; C. Benthic macroinvertebrate species composition by number of individuals in Krueng Aceh watershed, Aceh Province, Indonesia

Table 2. Number of individuals and presence frequency (%) of the Molluscs and Annelids in Krueng Aceh watershed, Aceh Province, Indonesia

Family	Species	Zonation*										Number of individuals (ind.)	Presence frequency (%)
		Upstream			Middlestream				Downstream				
		1	2	3	4	5	6	7	8	9	10		
Ampullariidae	*Pomacea canaliculata* (Lamarck, 1822)	0	0	0	0	0	0	4	0	0	0	4	10
Thiaridae	*Melanoides tuberculata* (O.F.Muller, 1774)	0	7	2	1	4	1	0	1	0	0	17	60
	Melanoides fasciolata (Olivier, 1804)	0	0	0	1	3	6	0	0	0	0	10	30
	Thiara scabra (O.F.Muller, 1774)	0	17	0	3	1	1	0	1	0	0	23	50
	Tarebia granifera (Lamarck, 1816)	0	10	29	6	35	35	2	22	0	0	139	70
Pachychilidae	*Faunus ater* (Linnaeus, 1758)	0	0	0	0	0	0	0	0	2	7	9	20
Neritidae	*Neritodryas cornea* (Linneaeus, 1758)	0	0	0	0	0	0	0	6	10	0	16	20
	Vittina turrita (Gmellin, 1791)	0	0	0	0	0	0	0	0	1	0	1	10
Bulinidae	*Indoplanorbis exustus* (Deshayes, 1833)	0	1	0	0	0	0	0	0	0	0	1	10
Bithyniidae	*Bithynia spiralis* (Heude, 1890)	0	0	0	3	0	0	0	0	0	0	3	10
Costellariidae	*Tiara lineata* (Broderip, 1836)	0	2	0	0	0	0	0	0	0	0	2	10
Unionidae	*Parreysia tavoyensis* (A.Gould, 1843)	0	0	0	1	0	0	0	0	0	0	1	10
Cyrenidae	*Corbicula fluminea* (O.F. Muller, 1774)	0	0	0	1	0	0	0	0	0	0	1	10
Nereididae	*Nereis pelagica* (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	2	2	10
Number of Individuals (individu)		0	37	31	16	43	43	6	30	13	9	228	

Note: *) zoning consists of 1 is river in Jalin Village; 2 is river in Bukit Meusara Jantho Village; 3 is river in Keunaloi Village; 4 is river in Keureuweung Village; 5 is river in Riting Indrapuri Village; 6 is river in Reukih Dayah Village; 7 is river in Lamleupeung Village; 8 is river in Pango Village; 9 is river in Kampung Baru Village; 10 is river in Lampulo Village

Table 3. Number of individuals and presence frequency (%) of the Arthropods in Krueng Aceh watershed, Aceh Province, Indonesia

Family	Species	Zonation*										Number of Individuals (individu)	Presence Frequency (%)
		Upstream			Middlestream				Downstream				
		1	2	3	4	5	6	7	8	9	10		
Psephenidae	*Afrobrianax ferdyi* (Lee Philips &Yang, 2003)	15	55	21	1	41	43	1	0	0	0	177	70
Elmidae	*Ancyronyx variegatus* (Germar, 1824)	1	1	6	9	0	0	3	0	0	0	20	50
	Microcylloepus pusillus (Le Conte, 1852)	0	13	0	0	0	0	0	0	0	0	13	10
	Stenelmis canaliculata (Gyllenhal, 1808)	1	16	0	2	7	8	1	0	0	0	35	60
	Stenelmis consobrina (Dufor, 1835)	0	0	0	0	5	15	0	0	0	0	20	20
Hydrophilidae	*Tropisternus quadristriatus* (Horn, 1871)	0	0	1	0	0	0	0	0	0	0	1	10
Dytiscidae	*Liodessus affinis* (Say, 1823)	0	0	0	9	0	0	0	0	0	0	9	10
Gecarcinucidae	*Parathelphusa pantherina* (Schenkel, 1902)	0	0	0	1	0	0	0	0	0	0	1	10
Penaeidae	*Litopenaeus vannamei* (Boone, 1931)	0	0	0	0	0	0	0	0	0	1	1	10
Chironomidae	*Chironomus luridus* (Strenzke, 1959)	0	0	3	0	3	4	3	0	0	0	13	40
Limoniidae	*Hexatoma* sp.	2	5	4	0	8	18	2	0	0	0	39	60
	Anthoca sp.	0	0	2	0	0	0	0	0	0	0	2	10
Baetidae	*Baetis rhodani* (Pictet, 1843)	1	0	0	0	9	0	0	0	0	0	10	20
	Heterocloeon coriosum (McDunnough, 1923)	0	0	1	2	0	19	0	0	0	0	22	30
Caenidae	*Caenis latipennis* (Banks, 1907)	1	0	0	0	0	0	0	0	0	0	1	10
Ephemerellidae	*Ephemerella subvaria* (McDonnough, 1931)	23	0	3	0	0	0	0	0	0	0	26	20
Heptageniidae	*Leucrocuta petersi* (Allen, 1966)	1	4	9	4	0	0	0	0	0	0	18	40
	Maccaffertium sp.	0	0	0	0	0	0	2	0	0	0	2	10
	Stenacron interpunctatum (Say, 1839)	1	0	0	0	0	0	0	0	0	0	1	10
Leptophlebiidae	*Habrophlebia fusca* (Curtis, 1834)	1	0	0	6	9	19	0	0	0	0	35	40
Potamanthidae	*Potamanthus luteus* (Linnaeus, 1767)	1	0	0	1	0	0	0	0	0	0	2	20
Corydalidae	*Corydalus cornutus* (Linnaeus, 1758)	2	0	1	0	4	14	0	0	0	0	21	40
Perlidae	*Neoperla clymene* (Newman, 1839)	34	37	0	0	18	28	3	0	0	0	120	50
Hydropsychidae	*Arctopsyche irrorata* (Banks, 1905)	0	0	0	1	0	0	0	0	0	0	1	10
	Cheumatopsyche afra (Mosely,1935)	0	13	29	2	3	4	9	0	0	0	60	60
	Cheumatopsyche analis (Banks, 1903)	0	2	0	0	0	0	0	0	0	0	2	10
	Cheumatopsyche lepida (Pictet, 1834)	6	0	0	0	0	0	3	0	0	0	9	20
	Diplectrona felix (McLachlan, 1840)	5	0	0	1	0	0	0	0	0	0	6	20
	Hydropsyche angustipennis (Curtis, 1834)	68	34	51	0	28	30	3	0	0	0	214	60
	Hydropsyche rosii (Flint, Voshell & Parker, 1979)	49	0	0	0	0	0	0	0	0	0	49	10
	Hydropsyche saxonica (McLachlan, 1884)	49	0	0	0	0	0	0	0	0	0	49	10
Philopotamidae	*Chimarra atterima* (Hagen, 1861)	0	0	0	0	9	10	0	0	0	0	19	20
	Chimarra marginata (Linnaeus, 1767)	11	0	0	0	0	0	0	0	0	0	11	10
	Dolophilodes distinctus (Walker, 1852)	0	0	0	2	0	0	0	0	0	0	2	10
Psychomyiidae	*Psychomyia* sp.	1	0	0	0	0	0	0	0	0	0	1	10
Number of Individuals (individu)		273	180	131	41	144	212	30	0	0	1	1022	

Note: *) zoning consists of 1 is river in Jalin Village; 2 is river in Bukit Meusara Jantho Village; 3 is river in Keunaloi Village; 4 is river in Keureuweung Village; 5 is river in Riting Indrapuri Village; 6 is river in Reukih Dayah Village; 7 is river in Lamleupeung Village; 8 is river in Pango Village; 9 is river in Kampung Baru Village; 10 is river in Lampulo Village

Table 4. Species Density (D) and Distribution Patterns (I_δ) of Molluscs and Annelids in Krueng Aceh Watershed, Aceh Province, Indonesia

Family	Species	D per-zonation (ind/m^2)*										D average (ind/m^2)	I_δ	Criteria
		Upstream			Middlestream				Downstream					
		1	2	3	4	5	6	7	8	9	10			
Ampullariidae	*Pomacea canaliculata* (Lamarck, 1822)	0	0	0	0	0	0	14	0	0	0	2	21	Clustered
Thiaridae	*Melanoides tuberculata* (O.F.Muller, 1774)	0	25	7	4	14	4	0	1	0	0	5	4,2	Clustered
	Melanoides fasciolata (Olivier, 1804)	0	0	0	4	11	22	0	0	0	0	4	4,2	Clustered
	Thiara scabra (O.F.Muller, 1774)	0	61	0	11	4	4	0	1	0	0	8	11,53	Clustered
	Tarebia granifera (Lamarck, 1816)	0	36	104	22	126	126	7	2	0	0	42	4,13	Clustered
Pachychilidae	*Faunus ater* (Linnaeus, 1758)	0	0	0	0	0	0	0	0	1	1	1	12,83	Clustered
Neritidae	*Neritodryas cornea* (Linneaeus, 1758)	0	0	0	0	0	0	0	1	1	0	1	10,5	Clustered
	Vittina turrita (Gmellin, 1791)	0	0	0	0	0	0	0	0	1	0	1	0	not found
Bulinidae	*Indoplanorbis exustus* (Deshayes, 1833)	0	4	0	0	0	0	0	0	0	0	1	0	not found
Bithyniidae	*Bithynia spiralis* (Heude, 1890)	0	0	0	11	0	0	0	0	0	0	1	21	Clustered
Costellariidae	*Tiara lineata* (Broderip, 1836)	0	7	0	0	0	0	0	0	0	0	1	21	Clustered
Unionidae	*Parreysia tavoyensis* (A.Gould, 1843)	0	0	0	4	0	0	0	0	0	0	1	0	not found
Cyrenidae	*Corbicula fluminea* (O.F. Muller, 1774)	0	0	0	4	0	0	0	0	0	0	1	0	not found
Nereididae	*Nereis pelagica* (Linnaeus, 1758)	0	0	0	0	0	0	0	0	0	1	1	21	Clustered
D average (ind/m^2)		0	10	8	4	11	11	2	1	1	1			

Note: *) zoning consists of 1 is river in Jalin Village; 2 is river in Bukit Meusara Jantho Village; 3 is river in Keunaloi Village; 4 is river in Keureuweung Village; 5 is river in Riting Indrapuri Village; 6 is river in Reukih Dayah Village; 7 is river in Lamleupeung Village; 8 is river in Pango Village; 9 is river in Kampung Baru Village; 10 is river in Lampulo Village

Table 5. Density and distribution pattern Arthropods in Krueng Aceh watershed, Aceh Province, Indonesia

Family	Species	Zonasi										D average (ind/m^2)	I_δ	Criteria
		Upstream			Middlestream						Downstream			
		1	2	3	4	5	6	7	8	9	10			
Psephenidae	*Afrobrianax ferdyi* (Lee Philips &Yang, 2003)	54	197	75	4	147	154	4	0	0	0	64	4,74	Clustered
Elmidae	*Ancyronyx variegatus* (Germar, 1824)	4	4	22	32	0	0	11	0	0	0	7	5,96	Clustered
	Microcylloepus pusillus (Le Conte, 1852)	0	47	0	0	0	0	0	0	0	0	5	21	Clustered
	Stenelmis canaliculata (Gyllenhal, 1808)	4	57	0	7	25	29	4	0	0	0	13	6,22	Clustered
	Stenelmis consobrina (Dufor, 1835)	0	0	0	0	18	54	0	0	0	0	7	6,22	Clustered
Hydrophilidae	*Tropisternus quadristriatus* (Horn, 1871)	0	0	4	0	0	0	0	0	0	0	1	0	Not found
Dytiscidae	*Liodessus affinis* (Say, 1823)	0	0	0	32	0	0	0	0	0	0	3	21	-
Gecarcinucidae	*Parathelphusa pantherina* (Schenkel, 1902)	0	0	0	4	0	0	0	0	0	0	1	0	Not found
Penaeidae	*Litopenaeus vannamei* (Boone, 1931)	0	0	0	0	0	0	0	0	0	1	1	0	Not found
Chironomidae	*Chironomus luridus* (Strenzke, 1959)	0	0	11	0	11	14	11	0	0	0	5	4,03	Clustered
Limoniidae	*Hexatoma* sp.	7	18	14	0	29	65	77	0	0	0	14	5,63	Clustered
	Anthoca sp.	0	0	7	0	0	0	0	0	0	0	1	21	Clustered
Baetidae	*Baetis rhodani* (Pictet, 1843)	4	0	0	0	32	0	0	0	0	0	4	16,8	Clustered
	Heterocloeon coriosum (McDunnough, 1923)	0	0	4	77	0	68	0	0	0	0	8	15,63	Clustered
Caenidae	*Caenis latipennis* (Banks, 1907)	4	0	0	0	0	0	0	0	0	0	1	0	Not found
Ephemerellidae	*Ephemerella subvaria* (McDonnough, 1931)	83	0	11	0	0	0	0	0	0	0	9	16,54	Clustered
Heptageniidae	*Leucrocuta petersi* (Allen, 1966)	4	14	32	14	0	0	0	0	0	0	6	9,69	Clustered
	Maccaffertium sp.	0	0	0	0	0	0	7	0	0	0	1	21	Clustered
	Stenacron interpunctatum (Say, 1839)	4	0	0	0	0	0	0	0	0	0	1	0	Not found
Leptophlebiidae	*Habrophlebia fusca* (Curtis, 1834)	4	0	0	22	32	68	0	0	0	0	13	7,83	Clustered
Potamanthidae	*Potamanthus luteus* (Linnaeus, 1767)	4	0	0	4	0	0	0	0	0	0	1	0	Not found
Corydalidae	*Corydalus cornutus* (Linnaeus, 1758)	7	0	4	0	14	50	0	0	0	0	8	9,8	Clustered
Perlidae	*Neoperla clymene* (Newman, 1839)	122	133	0	0	65	100	11	0	0	0	43	5,17	Clustered
Hydropsychidae	*Arctopsyche irrorata* (Banks, 1905)	0	0	0	4	0	0	0	0	0	0	1	0	Not found
	Cheumatopsyche afra (Mosely,1935)	0	47	104	7	11	14	32	0	0	0	22	5,08	Clustered
	Cheumatopsyche analis (Banks, 1903)	0	7	0	0	0	0	0	0	0	0	1	5,08	Clustered
	Cheumatopsyche lepida (Pictet, 1834)	22	0	0	0	0	0	11	0	0	0	3	5,08	Clustered
	Diplectrona felix (McLachlan, 1840)	18	0	0	4	0	0	0	0	0	0	2	14	Clustered
	Hydropsyche angustipennis (Curtis, 1834)	244	122	183	0	100	108	11	0	0	0	77	7,21	Clustered
	Hydropsyche rosii (Flint, Voshell & Parker, 1979)	176	0	0	0	0	0	0	0	0	0	18	7,21	Clustered
	Hydropsyche saxonica (McLachlan, 1884)	176	0	0	0	0	0	0	0	0	0	18	7,21	Clustered
Philopotamidae	*Chimarra atterima* (Hagen, 1861)	0	0	0	0	32	36	0	0	0	0	7	6,56	Clustered
	Chimarra marginata (Linnaeus, 1767)	40	0	0	0	0	0	0	0	0	0	4	6,56	Clustered
	Dolophilodes distinctus (Walker, 1852)	0	0	0	7	0	0	0	0	0	0	1	21	Clustered
Psychomyiidae	*Psychomyia* sp.	4	0	0	0	0	0	0	0	0	0	1	0	Not found
D average (ind/m^2)	28	18	13	4	15	22	3	0	0	0				

Note: *) zoning consists of 1 is river in Jalin Village; 2 is river in Bukit Meusara Jantho Village; 3 is river in Keunaloi Village; 4 is river in Keureuweung Village; 5 is river in Riting Indrapuri Village; 6 is river in Reukih Dayah Village; 7 is river in Lamleupeung Village; 8 is river in Pango Village; 9 is river in Kampung Baru Village; 10 is river in Lampulo Village

Table 6. Ecology index in Krueng Aceh watershed, Aceh Province, Indonesia

Biology index	Zonation*									
	Upstream			Middlestream				Downstream		
	1	2	3	4	5	6	7	8	9	10
Individual (N)	273	217	162	57	187	255	36	30	13	10
Taxa richness (S)	18	12	14	19	14	14	11	4	3	3
Diversity index Shannon-Wiener (H')	2.13	3.16	2.80	3.46	3.13	3.45	3.05	1.11	0.99	1.16
Criteria	Moderate	Good	Moderate	Good	Good	Good	Good	Bad	Bad	Bad
Dominance index Simpson (C)	0.38	0.14	0.18	0.20	0.15	0.10	0.16	0.58	0.62	0.54
Criteria	Low	Low	Low	Low	Low	Low	Low	Moderate	High	Moderate

Note: *) zoning consists of 1 is river in Jalin Village; 2 is river in Bukit Meusara Jantho Village; 3 is river in Keunaloi Village; 4 is river in Keureuweung Village; 5 is river in Riting Indrapuri Village; 6 is river in Reukih Dayah Village; 7 is river in Lamleupeung Village; 8 is river in Pango Village; 9 is river in Kampung Baru Village; 10 is river in Lampulo Village

Table 7. Measurement results of environmental parameters of Krueng Aceh watershed each station (mean ± standard deviation)

Parameters	Unit	Zonation*									
		Upstream			Middlestream				Downstream		
		1	2	3	4	5	6	7	8	9	10
Temperature	^{0}C	28.40±0.26	28.33±0.57	30.70±0	32.17±0.20	30.10±0.62	28±1	31.47±0.50	26.93±0.05	27.23±0.06	29.63±0.11
Conductivity	(µmhos/cm)	189.33±1.154	153.33±7.57	182.67±4.16	138.67±2.30	301.00±2	29.77±0.23	261.67±1.15	199.00±1.73	271.67±4.16	10.13±0.15
TDS	mg/L	94.33±0.57	75.00±1	92.67±0.57	70.33±0.57	182.33±38.99	148.33±3.21	130.33±0.57	99.00±1	136.67±1.53	5053.33±90.23
pH	-	8.35±0.05	8.31±0.005	7.78±0.08	7.60±0.18	7.99±0.02	8.10±0.06	7.91±0.035	7.87±0.005	8.22±0.05	7.35±0.11
DO	mg/L	8.17±0.61	7.07±0.20	7.03±0.05	7.03±0.05	5.00±0.2	6.80±0.26	7.03±0.05	5.87±0.47	5.33±0.80	7.03±0.05
Depth	cm	29.33±5.50	81.00±22.71	21.67±0.57	67.00±20.29	26.33±7.09	32.00±8.54	66.33±13.05	90±0	220.00±0.02	180±0
Clarity	cm	29.33±5.50	74.17±8.97	11.70±1.47	37.33±9.16	18.33±7.63	20.50±3.5	39.33±6.52	28.33±8.97	41.33±5.35	33.17±6.52
Current	m/s	0.86±0.10	0.15±0.07	0.66±0.13	0.27±0.005	0.42±0.03	0.68±0.46	0.16±0.02	0.44±0.07	0.41±0.06	0.16±0.05
Salinity	ppm	0.00±0	0.00±0	0.00±0	0.00±0	0.00±0	0.00±0	0.00±0	0.00±0	1.00±0	10.67±0.57

Note: *) zoning consists of 1 is river in Jalin Village; 2 is river in Bukit Meusara Jantho Village; 3 is river in Keunaloi Village; 4 is river in Keureuweung Village; 5 is river in Riting Indrapuri Village; 6 is river in Reukih Dayah Village; 7 is river in Lamleupeung Village; 8 is river in Pango Village; 9 is river in Kampung Baru Village; 10 is river in Lampulo Village

Table 8. Measurement results of substrate parameters in Krueng Aceh watershed, Aceh Province, Indonesia (mean±standard deviation)

Parameters	Unit	Zonation*									
		Upstream			Middlestream				Downstream		
		1	2	3	4	5	6	7	8	9	10
Sand	%	83.00±0	87.00±0	86.00±0	55.00±0	87.00±0	87.00±0	67.00±0	16.00±0	9.00±0	2.00±0
Silt	%	4.00±0	4.00±0	5.00±0	30.00±0	9.00±0	4.00±0	28.00±0	74.00±0	74.00±0	81.00±0
Clay	%	13.00±0	9.00±0	9.00±0	15.00±0	4.00±0	9.00±0	5.00±0	10.00±0	17.00±0	17.00±0
Organic carbon (C-organic)	%	0.22±0	0.10±0	0.19±0	0.40±0	0.20±0	0.26±0	0.50±0	1.02±0	1.22±0	2.05±0
N-total	%	0.06±0^j	0.04±0	0.02±0	0.04±0	0.04±0	0.03±0	0.04±0	0.08±0	0.10±0	0.12±0

Note: *) zoning consists of 1 is river in Jalin Village; 2 is river in Bukit Meusara Jantho Village; 3 is river in Keunaloi Village; 4 is river in Keureuweung Village; 5 is river in Riting Indrapuri Village; 6 is river in Reukih Dayah Village; 7 is river in Lamleupeung Village; 8 is river in Pango Village; 9 is river in Kampung Baru Village; 10 is river in Lampulo Village

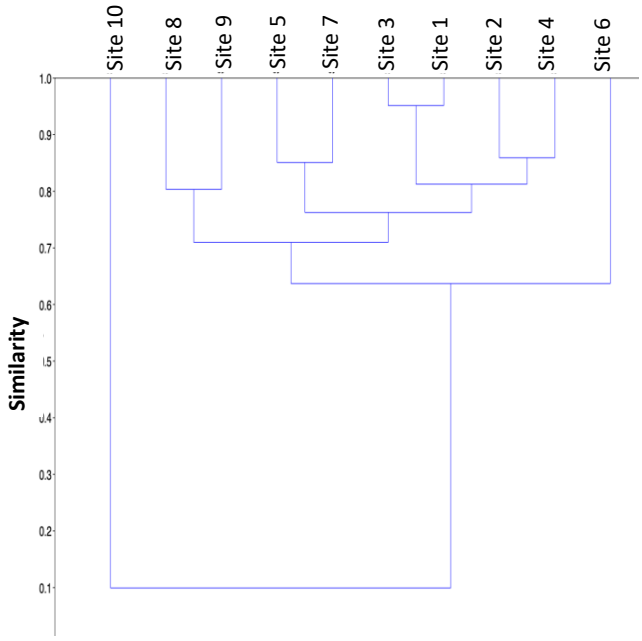

Figure 5. Classification of studied stations by macroinvertebrate community composition using spatially based hierarchical cluster analysis

However, the high presence of *A. ferdyi* larvae in the Krueng Aceh watershed was attributed to their ability to attach to rock surfaces or other hard substrates (Jung et al. 2020). This adaptation allowed it to survive in fast-flowing habitats that could be less favorable for other species. This had a good feeding strategy because, as an algae and detritus eater, the larvae utilized abundant food sources in their habitat, supporting effective growth and reproduction (Cai and Huang 2018). Field observations showed that the 7 stations were *A. ferdyi* was found in rivers with clean and clear waters and fast-flowing currents in upstream and middle areas of watershed, where the substrate was large rocks, gravel, and pebbles.

In water areas with soft substrate (mud and clay), the species with the highest density was *T. granifera*. This species was found at 7 stations, where the substrate of these stations tended to be soft, while at locations with hard substrates such as large rocks, its presence was low or even not found, for example, Stations 1, 9, and 10. This was because this species preferred muddy water bottom habitats (Sirza et al. 2020; Nguyen et al. 2021). The presence of vegetation around the river flow was also thought to be the reason for the presence of *T. granifera* at the 7 locations. Based on field observations, *T. granifera* tended to stick to leaves around the river flow, such as grass. This could be related to the adaptation of *T. granifera*, which sought shelter and spawning habitats (Jones et al. 2017; Sirza et al. 2020).

Tarebia granifera (Thiaridae) is a freshwater snail in lotic and lentic habitats. This species is a benthic fauna and lives attached to various substrates or on the edges of aquatic habitats (Isnaningsih et al. 2018). According to Jones et al. (2017), the native habitat of *T. granifera* was in waters of Southeast Asia, including Indonesia. However, this had become invasive on at least 3 continents, North and South America and Africa. This also occurred in several southern states of the United States, Hawaii, and many Caribbean Islands, as well as Mexico, Venezuela, South Africa, and Israel (Appleton et al. 2009; Malatji et al. 2021).

The study results showed that almost all benthic macroinvertebrates found in Krueng Aceh watershed had a clustered distribution pattern, where 1 species tended to gather in a location that was most suitable and supported their lives (Mohebi and Mirzaei 2021; Tanner and Jackson 2012; Yuditaningtyas et al. 2022). Therefore, the clustering pattern reflected the environmental conditions that supported the population of certain organisms and the location. Krueng Aceh watershed had diverse habitat characteristics, and this diversity was distinguished by physical characteristics, water flow, and basic substrate. Upstream area tended to be a rapid current habitat (riffle) with characteristics of fast-flowing water, shallow water, and lots of rocks and gravel on the riverbed. Middle area tended to be a combination habitat between rapid current (riffle) and calm water habitat (pool). This pool habitat had characteristics of slow-flowing water, deeper than riffle with muddy or fine sand substrate. In upstream and middle areas, vegetation such as grass, shrubs, and trees existed. In downstream area, there was a combination of habitat between the pool and estuary, and vegetation was also found on the banks of the river.

This diversity caused some benthic macroinvertebrates to gather in suitable areas, for example, habitats with large rocks or aquatic vegetation that protect from predators and strong water currents (Bergey and Cooper 2015). In addition to having been influenced by habitat characteristics, distribution patterns were also influenced by the social behavior of species that lived in groups, such as Chironomidae (mosquito larvae) (Nicacio and Juen 2015; Antczak-Orlewska et al. 2021). These often lived together in groups to protect themselves from predators. Large groups created a dilution effect where the chances of individuals becoming prey were reduced because predators could be confused or only attack a small part of the group (Kranzfelder and Ferrington 2018; Molineri et al. 2020; Ocon et al. 2023). Reproductive behavior also played a role in distribution patterns, and some benthic macro-invertebrates species laid eggs in certain areas that were optimal for larval development, causing the next generation to group (Nicacio and Juen 2015; Serra et al. 2017).

The Shannon-Wiener diversity index (H') in Krueng Aceh watershed showed diverse conditions, where, in general, upstream and middle areas of watershed were in good to moderate condition. In contrast, the downstream area showed poor conditions, and Station 4 was one of the stations with a high diversity index value, indicating good water conditions. The high value of species diversity suggested that environmental conditions were improving, and the community was relatively stable (Reshetnikova et al. 2017; Retnaningdyah et al. 2023). Based on environmental parameter values such as temperature, conductivity, total dissolved solids, dissolved oxygen, and salinity, Station 4 was still in the established water

environment quality standards. Based on observations in the field, Station 4 was a river utilized by the surrounding community, namely the discovery of sand mining activities and the community taking river water to their livestock.

Benthic macroinvertebrate diversity is also influenced by the characteristics of each section of the river (upstream, midstream and downstream) (Huong et al. 2017). In Upstream sections are fast-flowing so they have rocky substrates and low temperatures that are rich in dissolved oxygen. This leads to the dominance of organisms that are tolerant of strong currents, such as certain aquatic insects (e.g. Ephemeroptera and Plecoptera) (Șandru 2015; Desrosiers et al. 2020). In the river middle, the current is more moderate and the temperature increases and the substrate varies (sand, gravel, mud). This causes higher benthic macroinvertebrate diversity due to more stable environmental conditions (Huong et al. 2017; Octavina et al. 2019). In downstream, currents are slower, and temperatures are higher, leading to mud-dominated substrates and high sedimentation rates. This environment is characterized by the dominance of organisms tolerant of lower oxygen levels, such as worms and certain mollusks (Reenamole 2016; Luque et al. 2020).

Station 9 had a low diversity index value compared to other stations, specifically in downstream area of Krueng Aceh watershed. However, water quality parameters were still in the quality standards for benthic macroinvertebrates life. Based on field observations, Station 9 was a river close to residential areas, plantations, and general hospitals. The low diversity of benthic macroinvertebrates at the station was thought to be caused by excessive sedimentation. Visually, the downstream area of Krueng Aceh watershed, including Station 9, was very turbid due to fine particles such as mud and clay mixed and floating in water. This condition was caused by soil erosion and excavation for road repairs on the riverbank.

HCA analysis result showed that out of 10, these stations were grouped into 2 groups, namely the first group consisting of stations was 10 and the second group consisting of Stations 1, 2, 3, 4, 5, 6, 7, 8 and 9. Each of these groups had similarities in community structure between stations. Nevertheless, among the existing stations, Stations 1 and 3 had higher community structure similarities compared to other stations. This could be because the flow of rivers 1 and 3 was still close, therefore, the location's typology was similar, with rocky and gravelly substrate conditions and vegetation, and it tended to have high currents.

The community at station 10 differed greatly from those observed at other stations in HCA diagram. This was thought to be due to the very different sedimentation conditions and flow velocities between station 10 and other stations, where station 10 had a high TDS value exceeding the established quality standard, indicating that the station was experiencing sedimentation downstream. This was a phenomenon of accumulation of sediment particles such as sand, mud, and gravel at the bottom or edge of the river, which often occurred due to the deposition of material carried by water flow from upstream (Nasir et al. 2020). In addition, it was considered that the high TDS value was due to seawater runoff containing minerals, considering that this area was the downstream area of the river. Waste pollution, specifically those containing ions such as sodium, calcium, chloride, sulfate, and organic matter, which were discharged directly into the river, could also increase the TDS value (Merriam et al. 2020).

In conclusion, a total of 1240 benthic macroinvertebrates were identified across 3 phyla, 5 classes, 29 families, 42 genera, and 49 species. *Hydropsyche angustipennis* dominated hard substrates, while *Tarebia granifera* dominated soft substrates. Most macroinvertebrates exhibited a clustered distribution, with some showing no clear pattern. The diversity index (H') ranged from 0.99 to 3.46 (moderate to high), and the Simpson dominance index from 0.10 to 0.62 (low dominance). Hierarchical Cluster Analysis (HCA) grouped the 10 stations into two similarity clusters. Overall, macroinvertebrate diversity in Krueng Aceh was relatively high, and water quality remained within acceptable standards.

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