BIODIVERSITAS ISSN: 1412-033X
Volume 24, Number 3, March 2023 E-ISSN: 2085-4722
Pages: 1773-1784 DOI: 10.13057/biodiv/d240352

Benthic macroinvertebrates functional feeding group community distribution in rivers connected to reservoirs in the midstream of Citarum River, West Java, Indonesia

FIKRI ILMI♥, BARTI S. MUNTALIF♥♥, NURUL CHAZANAH, NAVISYA E. SARI, SATRIA W. BAGASKARA
Department of Environmental Engineering, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung. Jl. Ganesha No. 10, Bandung 40132, West Java, Indonesia. Tel.: +62-22-2504952, Fax.: +62-22-2516586, email: ♥fikriilhi@gmail.com, ♥♥barti@ftsl.itb.ac.id

Manuscript received: 4 December 2022. Revision accepted: 25 March 2023.

Abstract. *Ilmi F, Muntalif BS, Chazanah N, Sari NE, Bagaskara SW. 2023. Benthic macroinvertebrates functional feeding group community distribution in rivers connected to reservoirs in the Midstream of Citarum River, West Java, Indonesia. Biodiversitas 24: 1773-1784.* An imbalance in the composition of the feeding groups can indicate a disturbed environment; therefore, in recent years, feeding group composition analysis has been widely used by academics to assess the health of river ecosystems. This research aims to describe the general distribution of functional feeding groups related to their habitat condition. The research was conducted in the midstream of the Citarum River, around the Saguling, Cirata, and Jatiluhur Dams of West Java Province, Indonesia. The midstream Citarum region starts from the Margaasih Sub-district, Bandung District (before Saguling Dam) to the Jatiluhur Sub-district, Purwakarta District (after Jatiluhur Dam). The research was conducted from July to September 2022. Environmental data, including water and sediment samples, were taken monthly, whereas benthic macroinvertebrates samples were taken every two weeks using a Surber net. Benthic macroinvertebrates samples were then classified based on their species and feeding group. In addition, water pollution levels were classified based on Nemerow Pollution Index. Pollution levels and sediment characteristics were then tested for correlation with the benthic macroinvertebrate feeding group distribution. In general, in midstream Citarum, gathering collectors are the group with the highest relative abundance (82.64%), followed by scrapers (35.6%), predators (11.66%), and filtering collectors (2.14%). Based on Pearson's correlation, environmental conditions such as pollution and types of substrates have several negative correlations with the distribution of functional feeding groups. A dam in the midstream Citarum region has proven to affect environmental conditions. Differences in flow velocity, substrate characteristics, physicochemical quality of water, and pollution levels characterize this.

Keywords: Benthic macroinvertebrates, Citarum River, functional feeding group, reservoirs

INTRODUCTION

Benthic macroinvertebrates are one of the most vital components of the river ecosystem that help in nutrient recycling and the completion of the food chain and hence energy flow (Kripa et al. 2013; Windsor et al. 2019). Benthic macroinvertebrates have various ways to obtain food. Benthic macroinvertebrates can be classified into five Functional Feeding Groups (FFG) according to their way of obtaining food. Furthermore, the different food sources used by benthic macroinvertebrates comprise: the coarse detritus, composed chiefly of leaves falling from riparian vegetation (consumed by shredders); the epilithic layer that grows on the surface of substrates (consumed by scrapers); the Fine Particulate Organic Matters (FPOM), either deposited on the substrate (consumed by gatherers) or suspended in the water column (consumed by filterers); and finally live animals (consumed by predators) (Cummins 2018).

The classification of functional feeding groups on benthic macroinvertebrates differs from the traditional morphological classifications. It is mainly based on the type of food resources of benthic animals and the morphological adaptation mechanism in obtaining food. The functional feeding group on benthic macroinvertebrates could reflect habitat change's impact. It also reveals the community structure and habitat adaptation characteristics (Bohan et al. 2017). Many biological water quality assessments have been researched using benthic macroinvertebrates (Ojija et al. 2017; Chazanah et al. 2020). In addition, according to Gholizadeh and Heydarzadeh (2020), there have been very few attempts at how the functional composition of macroinvertebrate assemblages changes concerning habitat conditions. Measures of feeding or trophic dynamics encompassing functional feeding groups provide information on the balance of feeding strategies (food acquisition) in the benthic macroinvertebrate community.

Freshwater ecosystems are among the most threatened ecosystems in the world (Hasan et al. 2020; Hasan et al. 2022). They are affected by water pollution, habitat degradation, climate change, overexploitation, species invasion, and flow modification (Kaaya et al. 2015; Hasan et al. 2021). The river's environmental changes can affect relative abundance among aquatic macroinvertebrate assemblages' Functional Feeding Groups (FFGs). Generally, that also changes the structure of the benthic macroinvertebrates community that inhabits the site (Mesa 2014). Research conducted by Dulic et al. (2014) reveals that benthic macroinvertebrates responded to environmental changes relatively quickly. As the environment changes negatively, the abundance, species richness, and biomass are substantially reduced in less than a year. The benthic macroinvertebrate's functional feeding group can better reflect the impact of human activities on the river ecosystem and the damage thereon. Therefore, in recent years, FFG has been widely used by researchers to evaluate river ecosystem quality (Bohan et al. 2017; Zhu et al. 2020). Citarum River is the longest and largest river in West Java Province, Indonesia, with a length of about 297 km (BAPPENAS 2014). Midstream Citarum Region in West Java Province is the location of the cascade dam system (Saguling, Cirata, and Jatiluhur) (Cordova et al. 2022). The Saguling, Cirata, and Jatiluhur dams contain ± 982 million m^3, ± 2,165 million m^3, and ± 3,000 million m^3 of water, respectively (Imansyah 2012). The dammed water is used for various purposes such as irrigation, raw water sources for big cities, and Java-Bali electricity generation (Iwan et al. 2004). The reservoirs in this region are also widely used for aquaculture using floating net cages. This technique could lead to a major environmental problem. According to Astuti et al. (2022), the Jatiluhur Reservoir had a trophic status at the level of eutrophic-hypertrophic. It was characterized by high chlorophyll-a and total phosphate. The source of phosphate is mainly aquaculture activities. In 2017, the loading of phosphate pollution to Jatiluhur Reservoir reached 13,474.4 tonnes/yr, which came from internal and external sources (Astuti et al. 2020). Overall, dam operation has several negative impacts on the environment, such as the excessive release of sediment, river flow disturbance, and water pollution (Alla and liu 2021; Liro 2022). Activities in the reservoirs and the surrounding area can affect the composition of FFG in the benthic macroinvertebrate community. Furthermore, to the best of our knowledge, research on the distribution of FFG in the Midstream Citarum Region has not been reported to date. The aim of this research is to describe the general distribution of FFGs related to their habitat condition. This also evaluation of the river ecosystem using ecological parameters based on functional feeding taxa could provide a basis for the ecological environment protection of the Citarum River.

METHODS AND MATERIALS

Study area

This study is located in the Midstream of the Citarum River (Figure 1). The midstream Citarum region starts from the Margaasih Sub-district, Bandung District (before Saguling Dam) to the Jatiluhur Sub-district, Purwakarta District (after Jatiluhur Dam) of West Java Province, Indonesia. The sampling points were placed near the inlet and the outlet of the Saguling Dam, the outlet of the Cirata Dam, and the Jatiluhur Dam. The coordinates of each sampling point are presented in Table 1. Water samples were taken once a month, while benthic macroinvertebrates samples were taken every two weeks every month to ensure data validity. The research was conducted from July to September 2022.

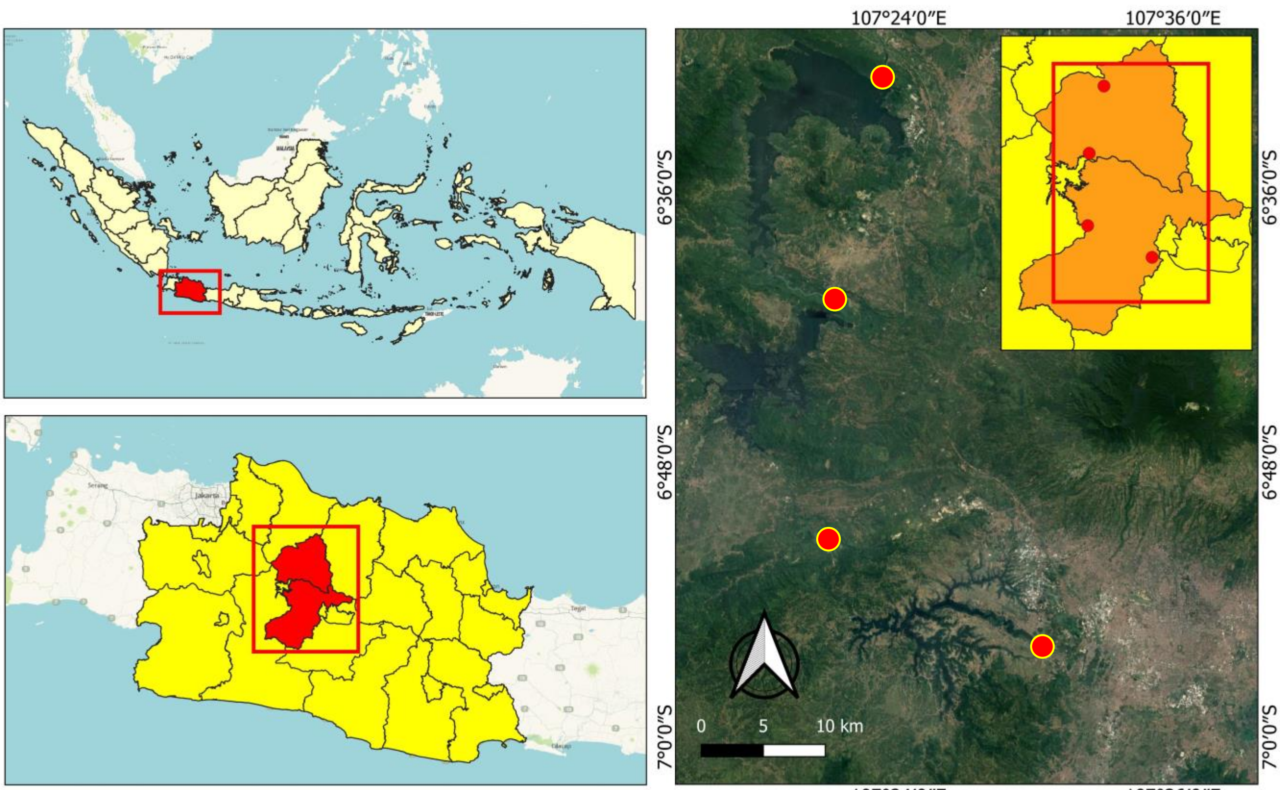

Figure 1. Map of Midstream Citarum Region (research stations marked with a red dot, grey represent settlements) (drawn using Arc GIS version 10.41)

Table 1. Research stations coordinate

Stations	Location	Coordinates	Width	Other characteristics
Station 1	Saguling Dam Inlet	6°56'0.14"S 107°30'20.47"E	126.67±1.5	Urban area with dense settlements Inlet of Saguling Dam ±3 km from industrial parks (mostly textiles) river surface covered with hydrophytes ±30-60 m wide strips of vegetation on banks agricultural land on riverbanks receiving direct domestic waste discharge
Station 2	Saguling Dam Outlet	6°51'24.04"S 107°20'57.86"E	36.37±0.57	Rural settings ±1 km from the Saguling Dam outlet agricultural land on riverbanks ±10-15 m wide, strips of vegetation on banks receiving direct domestic waste discharge
Station 3	Cirata Dam Outlet	6°40'54.19"S 107°21'11.10"E	65±2.64	Rural settings ±750 m from Cirata Dam outlet agricultural land on riverbanks, Vegetation on riverbanks is sparse and not dense
Station 4	Jatiluhur Dam Outlet	6°31'8.21"S 107°23'19.98"E	52.66±4.1	Rural settings ±300 m from Jatiluhur Dam Outlet ±20-40 m wide strips of vegetation on banks Very little human activity on the riverbanks

Method

The sampling of benthic macroinvertebrates was carried out using a mesh Surber with dimensions of 25 x 40 cm^2 with a pore of 0.5 mm. In each sampling location, within a stretch approximately 20 m in length, ten subsamples were collected approximately 1 m apart (Wakhid et al. 2021). Benthic macroinvertebrates were then put into vials, labeled, and preserved with 70% alcohol preservative. The sample was identified using the McCafferty (1983) and Purnama et al. (2022) references. After identification, each species was grouped into several groups based on their FFG types, according to Cummins (2018). Water samples were taken as much as 2 liters for each location using a glass container, while sediment samples were taken on the sides and middle of the river (1 kg for each sampling location). Sediment samples were collected using shovels and then placed in a metal container. Water quality analyses were conducted in the Water Quality Laboratory, Bandung Institute of Technology, and West Java Province Public Health Laboratory. The water parameters selected in this study are presented in Table 2. Water parameters are selected based on human activities around the watershed and the possible pollutants each activity releases. The main anthropogenic activities in the study area are domestic, agricultural, and aquaculture. Parameters such as dissolved oxygen (DO) (DO meter, Lutron PDO-519), river current velocity (flow meter, Flowatch FL-03 JDC), turbidity (turbidimeter, Lovibond TB 211 IR), pH and temperature (pH meter, Kedida CT-6020) were tested on-site. In contrast, other parameters were tested in the laboratory (Table 2). Sediment samples were analyzed in the Department of Energy and Mineral Resources Laboratory, West Java Province. In addition, the distribution of sediments particle was analyzed from gravel to clay.

Data analysis

Determination of the water quality status is based on the Nemerow pollution index method according to the Ministry of Environment of Indonesia (KepMenLH 115/2003). The Pollution Index (PI) method determines the pollution level relative to the permissible water quality parameters. The water quality analysis refers to the river water quality standards according to Indonesia's Government Regulation No. 22, the year 2021, where the water quality standards used are class II. The equations used to calculate the pollution index are as follows (Nemerow 1974):

$$PI = \sqrt{\frac{{(Ci/L_{ij})_{max}}^2 + {(Ci/L_{ij})_{avg}}^2}{2}}$$

Where:
IP : pollution index,
C_i : concentration of water quality parameters *i*,
L_{ij} : concentration of water quality parameters *i* listed in the water designation standard *j*,
M : maximum,
R : average.
The *IP* index class consists of 4 scores:
$0 \leq IP \leq 1.0$: meet quality standards,
$1.0 < IP \leq 5.0$: lightly polluted,
$5.0 < IP \leq 10$: moderately polluted,
$IP > 10.0$: heavily polluted.

The diversity and Evenness of benthic macroinvertebrates were determined using the Shannon-Wiener and Pielou index. We also calculate FFG surrogate ratio for ecosystem attributes to determine the TDP index (Top Down Predator), FC index (Filtering-Collectors), HS index (Habitat Stability), and AH index (Autotrophy-Heterotrophy) based on Cummins (2018). Before data analysis, all data is tested for normality using the Shapiro-

Wilk Test. After the normality test, all data was declared normal. The differences in environmental parameters and distribution of FFG between stations were estimated by One-way Analysis Of Variance (ANOVA) (α=0.05). Tukey's HSD post hoc test was used when significant differences occurred. Before conducting the ANOVA, we used Levene's test to analyze the homogeneity of variance. The correlation between the distribution of FFG with environmental parameters were tested using Pearson's Correlation Coefficient. The Breusch-Pagan test was performed first to test the heteroscedasticity of the data. All of these tests were processed using R version 4.2.1. Tests for the significant differences in FFG distributions and FFG correlation tests with environmental parameters were only carried out for scrapers and gathering collectors because only these two types were found in all four research stations.

We also applied Principal Component Analysis (PCA) to identify significant variables which explain a high level of variability in the data set (Ochieng et al. 2020). Species richness was estimated from the abundance data using Chao 1 estimator. Sampling completeness for each station was assessed by calculating the number of observed species as a percentage of this estimation (Wakhid et al. 2021). We also estimate the total species richness using Chao 2, Jackknife 1, Jackknife 2, and Bootstrap analysis. Individual-based rarefaction curves were used to generate the species accumulation curve of species richness for each site. Hierarchical Cluster Analysis (HCA) using Unweighted Pair Group Method with Arithmetic Mean (UPGMA) based on the Bray-Curtis similarity index was performed on macroinvertebrate species and FFG compositions to show major differences and similarities among the study sites. PCA, individual-based rarefaction curves and HCA were performed in PAST software version 4.03.

RESULTS AND DISCUSSION

Environmental parameters

A summary of environmental variables in midstream Citarum is presented in Table 2. Based on the pollution index calculation, it can be concluded that station 4 (Jatiluhur Reservoir outlet) is the most polluted station with a moderately polluted category (Table 3). Another station with a moderately polluted category is station 1 (Saguling Dam Inlet), while stations 2 and 3 are categorized as lightly polluted. Station 1 experiences moderate pollution because it is the closest station to a big city (Bandung City), where there are still many industrial activities and high population density (Liyanage and Yamada 2017) (Figure 1). Station 1 has the most parameters that do not comply with the standard (Indonesia's Government Regulation No. 22, the year 2021) (Table 2).

After station 1, anthropogenic activities are dominated by the agricultural and fisheries sectors. Station 4 (Jatiluhur outlet) can be polluted due to intense aquacultures in the reservoir (Astuti et al. 2020; Astuti et al. 2022). Jatiluhur is the largest reservoir compared to Saguling and Cirata (Imansyah 2012). The distribution of sediment particles in all stations was dominated by fine sand with an average value above 30%. Silt and clay can be found in large percentages at stations 3 and 4 (Table 2). The distribution of sediment particles is important to study because, according to Aisyah et al. (2019), the bottom substrate is one of the main environmental factors that influence the structure of the aquatic organism.

PCA results show the separation of each research station, which means every station has different characteristics from the others (Figure 2; Table 2). Axis 1 shows 59.5% of the variability of environmental variables, while Axis 2 shows 29.14%. Station 1 is associated with nitrite, nitrate, Total Suspended Solids (TSS), total nitrogen, medium sand, dissolved oxygen, and fine sand. Station 2 is characterized by high current velocity and low turbidity. Conversely, Station 3 is associated with high turbidity and low current velocity. Station 4 has high surfactants, clay, oil and grease, and silt characteristics. The PCA analysis showed differences in the characteristics of the water and sediment physicochemical parameters at each station. This results in different environmental characteristics, which might affect the distribution of benthic macroinvertebrates (Scotti et al. 2019). PCA results are in line with the pollution index calculation. Stations with high pollution index (stations 1 and 4) were associated with more pollution parameters than less polluted stations (Table 2; Table 3; Figure 2).

Benthic macroinvertebrate FFG distribution

A total of 2.251 specimens were collected during the study (Table 4). Based on Figure 3, overall in the midstream Citarum, Gathering Collectors (GC) are the group with the highest relative abundance (82.64%), followed by Scrapers (Sc) (35.6%), Predators (Pr) (11.66%) and FilteringCollectors (FC) (2.14%). On the other hand, Shredders (SH) are found in very small amounts (<1%), so they are not displayed on the pie chart. The five feeding groups consist of 11 Orders, 16 Families, and 18 Species. Research conducted by Gholizadeh and Heydarzadeh (2020) in Zarin-Gol River, Iran, with similar research station characteristics (agriculture sites and fish culture sites) shows a similarity in FFG composition where GC dominates, and SH is the least. But the difference is in the Zarin-Gol River, FC occupies the second position in terms of relative abundance, followed by scrapers and predators.

Table 3. The pollution index in midstream Citarum

Parameters	Station			
	1	2	3	4
Pollution Index	5.37	4.80	4.90	5.65
Interpretation	Moderately polluted	Lightly polluted	Lightly polluted	Moderately polluted

In contrast, research by Wakhid et al. (2021) in the headwater of the Ciliwung river showed that filtering collectors were the FFG with the highest relative abundance (61.34%), followed by shredders (16.29%), gathering collectors (15.32%), and predators (6.94%). The low number of shredders in this research can be caused by a lack of supply of Coarse Particulate Organic Matter (CPOM) and river characteristics. More shredders can usually be found in forested areas, probably due to the accumulation of CPOM in forested areas (Encalada et al. 2010; Wakhid et al. 2021). The riverside in this study is mostly covered with agricultural and built-up land. Shredders were also reported to be a little more abundant in upper streams, such as research in Malaysia by Shafie et al. (2017), while this research was conducted in midstream.

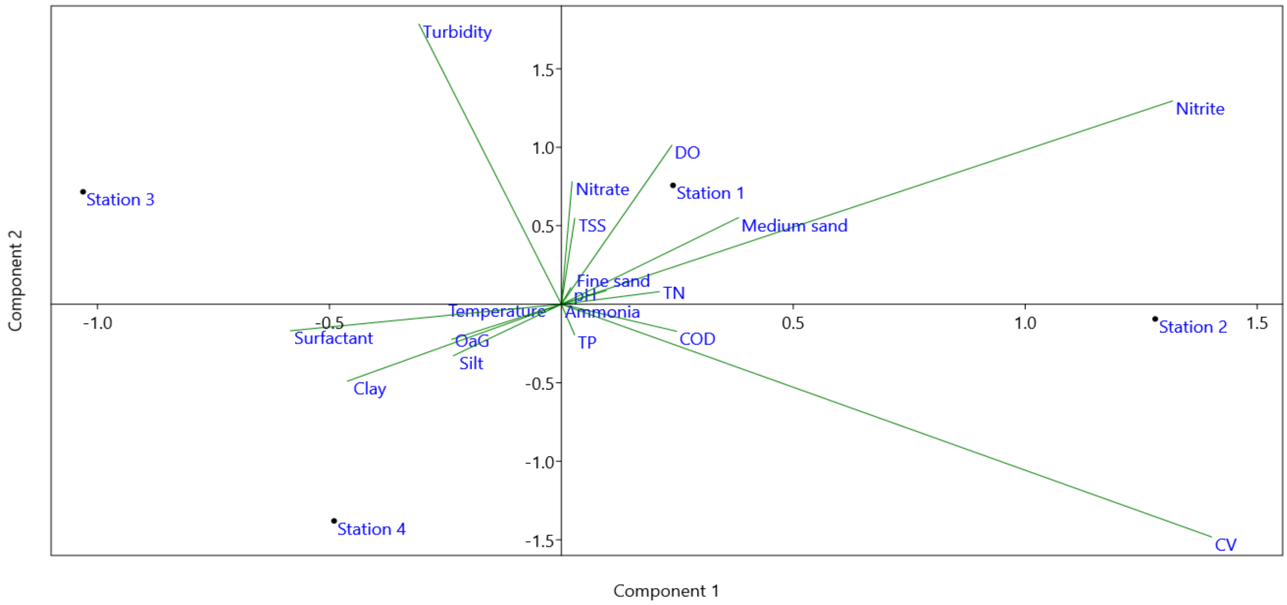

Figure 2. PCA correlation biplot for environmental variables in midstream Citarum

Table 2. The average value of environmental parameters and their PCA values

*Parameters	unit	Stations				PCA Values		
		1	2	3	4	PC 1	PC 2	PC 3
Temperature	°C	25.40 ±1.23	26.97±1.45	27.94±0.85	27.28±0.5	-0.011943	-0.010873	-0.050539
Turbidity	NTU	59.83±21	25.20±20.38	69.67±23.41	17.58±5.61	-0.14043	0.56966	0.073753
TSS	mg/L	21.33±15.77	20.17±7.52	22.50±14	14.50±12.17	0.013205	0.17456	-0.062577
pH	mg/L	7.26±0.31	7.97±0.85	7.96±0.46	6.98±0.28	0.0092664	0.033774	-0.079964
DO*	mg/L	4.57±0.93[d]	7.62±0.43[d]	6.93±1.33[d]	**2.53±0.58**[abc]	0.10891	0.32308	-0.46292
COD	mg/L	**29.54±6.54**	20.78±11.84	12.92±7.96	22.46±10.97	0.11348	-0.054919	0.42923
TP	mg/L	**2.87±0.47**	**1.86±1.04**	**1.66±1.29**	**2.58±1.15**	0.012985	-0.061972	0.37381
TN	mg/L	0.35±0.13	0.28±0.1	0.20±0.1	0.25±0.15	0.096476	0.02557	0.26031
Nitrite	mg/L	**0.18±0.18**	**0.25±0.27**	0.04±0.05	0.03±0.05	0.60259	0.41344	0.19792
Nitrate	mg/L	0.13±0.16	0.10±0.08	0.12±0.01	0.07±0.02	0.010555	0.24891	0.03396
Ammonia	mg/L	0.01±0.01	0.01±0.02	0.01±0.01	0..01±0.01	0	0	0
OG	mg/L	**3.20±2.04**	**2.48±1.66**	**3.44±2.08**	**4.01±3.12**	-0.10817	-0.071419	0.10532
Surfactant	mg/L	**0.35±0.41**	0.16±0.08	**0.40±0.36**	**0.45±0.37**	-0.2671	-0.053895	0.28826
CV	m/s	0.27±0.03	0.9±0.17	0.10±0	0..47±0.06	0.64119	-0.47308	-0.11776
MS*	%	32.5±0.70[bc]	30±1.41[c]	18.5±0.70[bcd]	16±1.41	0.17466	0.17614	0.14677
FS*	%	36.5±0.70[bcd]	39.5±0.70[acd]	34.5±0.70[abd]	33±0[abc]	0.04408	0.02765	-0.023805
Silt *	%	12±1.41[bcd]	19.5±0.70[acd]	26.5±0.70[abd]	23±0.70[abc]	-0.10647	-0.10464	-0.40947
Clay *	%	17.5±0.70[bcd]	11.33±0.57[acd]	20.5±0.70[abd]	28.5±0.70[abc]	-0.21092	-0.15628	0.19368

Note: Parameters marked with * show significant differences between stations ($P < 0.05$); Significant Tukey HSD results ($P < 0.05$) are marked with letters after the mean value of each parameter. Stations 1-4 are assigned as a-d. If Station 1 is marked with b, this indicates significant differences between station 1 and 2; Parameters that do not comply with the standard (Indonesia's Government Regulation No. 22, the year 2021) are marked in bold TSS: Total Suspended Solids; DO: Dissolved Oxygen; COD: Chemical Oxygen Demands; TP: Total Phosphate; TN: Total Nitrogen; OG: Oil and Grease; CV: Current Velocity; MS: Medium Sand; FS: Fine Sand

Table 4. The abundance of benthic macroinvertebrates species and FFG in midstream Citarum

Taxon	FFG*	Site 1	2	3	4	Total
Diptera						
Chironomidae						
Chironomus sp1.	GC	22	40	75	172	309
Chironomus sp2.	GC	-	8		-	8
Cricotopus sp.	GC	-	2		-	2
Tipulidae						
Tipula sp.	SH	-	4	-	-	4
Ceratopogonidae						
Bezzia sp	Pr	-	-	-	34	34
Trichoptera						
Hydropsychidae						
Hydropsyche sp.	FC	-	44	-	-	44
Hemiptera						
Belostomatidae						
Belostoma sp.	Pr	-	-	4	-	4
Ephemeroptera						
Baetidae						
Baetis sp.	GC	-	576	-	-	576
Odonata						
Libellulidae						
Libellula sp.	Pr	-	-	20	-	20
Coenagrionidae						
Enallagma sp.	Pr	-	-	20	-	20
Amphipoda						
Gammaridae						
Gammarus sp.	GC	8	18	-	-	*26*
Tubificida						
Naididae						
Tubifex sp.	GC	688	-	4	240	932
Hirudinida						
Hirudinidae						
Hirudinea sp.	Pr	-	-	2	-	2
Architaenioglossa						
Ampullariidae						
Pomacea canaliculata	Sc	120	8	10	-	138
Viviparidae						
Filopaludina javanica	Sc	8	16	4	-	28
Neotaenioglossa						
Thiaridae						
Melanoides tuberculata	Sc	2	24	18	12	56
Bassomatophora						
Planorbidae						
Gyraulus convexiusculus	Sc	-	-	4	-	4
Lymnaeidae						
Lymneae rubiginosa	Sc	20	-	16	-	36
Number of individuals (N)		864	724	173	458	2219

Species richness, diversity, and evenness

The estimation of species richness at all stations by Chao 1 showed that the expected species richness was the same as their observed values (Table 5), or the sampling completeness at all stations reached 100%. Conversely, the total observed species richness was underestimated compared to the mean of Chao 2, Jackknife 2, and Bootstrap analysis (Table 5). Only jackknife 1 has a mean value close to the total observed richness. Sastranegra et al. (2020) also found that Jackknife 1 values were close to the observed richness. Based on Individual-based rarefaction curves (Figure 5), station 3 accumulated the most species (11 species) even though it had the fewest specimens (173). While Stations 1, 2, and 4 accumulated seven, ten, and four species, respectively. Besides having the highest number of species, station 3 also has the highest diversity (Table 5).

However, compared to the diversity in the headwater streams/upstream areas, the diversity in the midstream area (this research location) can be lower. The diversity of benthic macroinvertebrates in the upstream Citarum has the highest H' value of 1.98 (Figure 8) (Bagaskara 2022, unpublished data). Research on the distribution of aquatic insects by Wakhid et al. (2021) on the headwater streams of the Ciliwung Rivers also shows high diversity (H'= 2.27-2.68). According to Melo et al. (2020), different land uses alter habitat conditions, water quality, and the benthic invertebrate assemblies.

Apart from land use, diversity differences in each station can be caused by the depth and speed of the water flow, which fluctuates depending on the dam's operation. (Ryder et al. 2015; Liro et al. 2022). The three dams at the study site have different sizes, so the effect on river flow and depth can differ. According to Liro et al. (2022), a river's water depth and flow velocity may be temporarily disturbed by the water level fluctuations connected to the operation of an artificial dam.

FFG spatial distribution

Overall, the distribution of benthic macroinvertebrates FFG and species at each station has a different composition (Figure 6). Based on HCA, the FFG composition between stations 2 and 1 shows high similarity because of the very high amount of GC and less amount of other FFG (Figure 4). Station 4 are slightly different from station 1 and 2, it is because predators were present, and scrapers show very low abundance. More even distribution of FFG is found in the less polluted station (Station 3) (Figure 4), making station 3 separated into different HCA branches (Figure 6). Various human activities on the riverbanks can cause the uneven distribution of FFGs. Agriculture, fish culture, and land-use changes often lead to decreases in diversity and shifts in relative abundance among the Functional Feeding Groups (FFGs) of aquatic macroinvertebrate assemblages (Mesa 2014; Bohan et al. 2017).

On the other hand, from the species distribution perspective, stations 1 and 4 are more similar than station 3, whereas station 2 is on a different HCA branch. Station 2 has a very different community composition from the other stations because it is the only rocky rapid with high current velocity (Table 2). The Species such as *Baetis* sp. and *Hydropsyche* sp. were only found at station 2. That may contribute to the dissimilarity of benthic macroinvertebrate distribution with other stations (Table 4). In addition, high current velocity may reduce other taxa, such as mollusk and oligochaetes, which are usually found in rivers with low current velocities (Ryder et al. 2015).

The one-way ANOVA results showed no significant difference in abundance for scrapers at all research stations (p-value = 0.46>0.05). Indicating that the midstream Citarum can still provide the needs of scrapers, despite most of the scrapers being classified as an invasive species (*Melanoides tuberculata* (O.F.Müller, 1774) and *Pomacea canaliculata* (Lamarck, 1822)) (Chaichana and Sumpan

2015; Quirós-Rodríguez et al. 2018) (Figure 7b). Scrapers require surfaces that remain in a stable facing-up position since scraper grazes the macrophyte attached to the bedrock, stones, and vegetation (Oliveira et al. 2010; Cummins et al. 2018). In contrast, there is a significant abundance difference for gathering collectors (*p*-value = 0.03<0.05). Post hoc tests by Tukey's HSD show significant differences at stations 4 and 3. Furthermore, Figure 4 shows that station 4 has the highest relative abundance of gathering collectors compared to other stations, while station 3 has the lowest relative abundance of gathering collectors. Different GC distributions can be influenced by the pollution level and sediment type (explained further in the environmental effect section). Gathering collector distribution is also influenced by the supply of fine particulate organic matter on or in the bottom sediments (Benthic Fine Particulate Organic Matter or BFPOM) (Cummins et al. 2022).

Table 5. Species richness, diversity, and evenness index

Parameters	**Site**				
	Total	**1**	**2**	**3**	**4**
Number of individuals		864	724	173	458
Shannon-Wiener Diversity Index (H')		0.71	0.86	1.79	0.99
Pielou Evenness Index (J)		0.29	0.26	0.60	0.67
Observed species richness (S)		7	10	11	4
Estimated species richness (Chao 1)		7	10	11	4
Total observed species richness	18				
Total estimated species richness					
Chao 2	19.82				
Jackknife 1	18.15				
Jackknife 2	9.51				
Bootstrap	0.60				

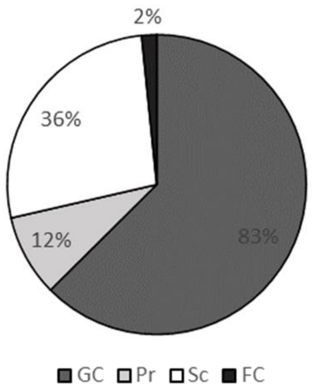

Figure 3. FFG distribution in Midstream Citarum

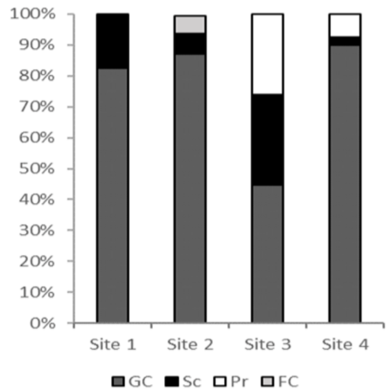

Figure 4. FFG relative abundance in each station

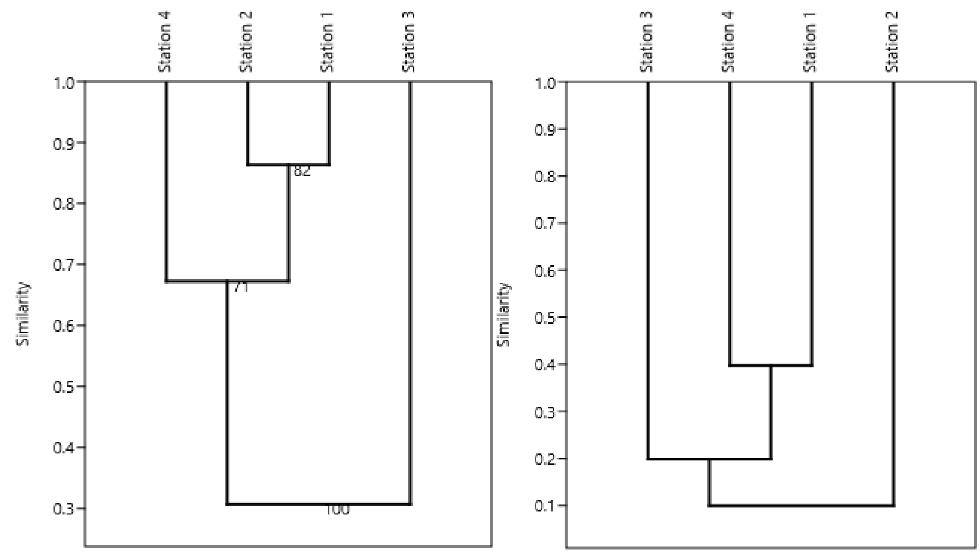

Figure 6. Hierarchical Cluster Analysis using UPGMA on benthic macroinvertebrates assemblages based on FFG distribution (left) and species distribution (right) in midstream of Citarum River

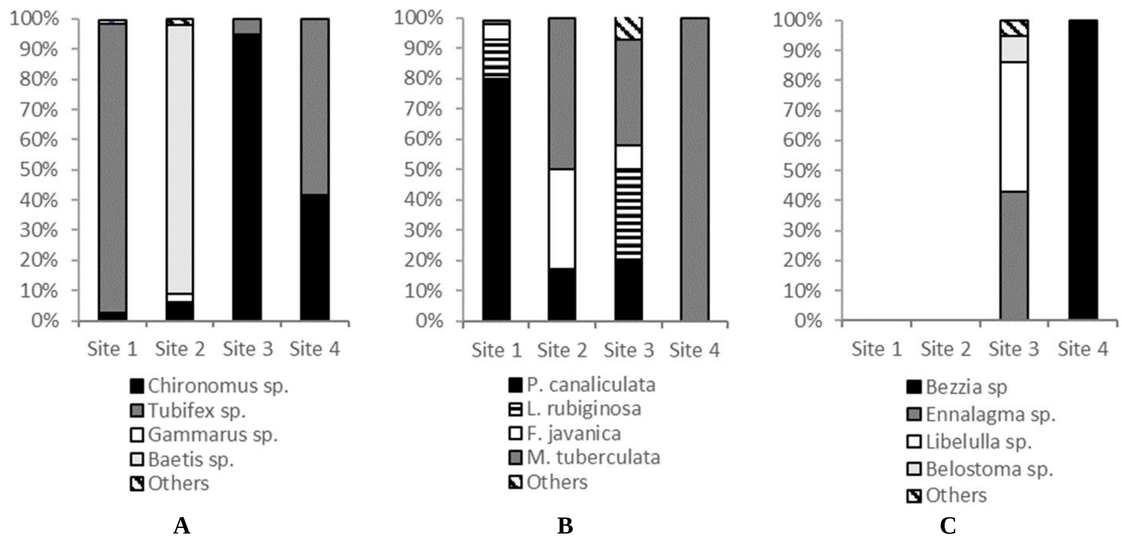

Figure 7. A. Gathering collectors; B. Scrapers; C. Predators relative abundance

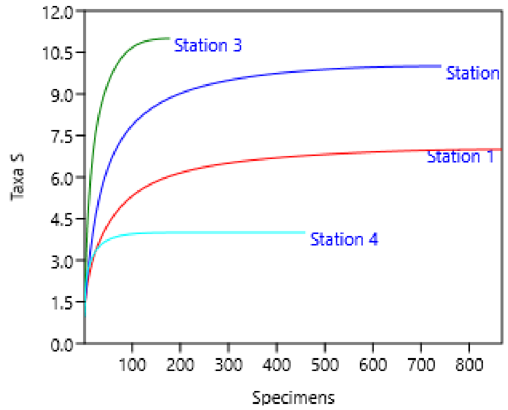

Figure 5. Individual-based rarefaction curves for benthic macroinvertebrates based on sampling sites

Sediment particle distribution and FFG distribution

Fine sand, which is the dominant type of sediment texture, has a positive correlation with the abundance of all FFGs (r=0.64) (Figure 9). This is supported by Jabłońska (2014) findings that *Tubifex* sp. (in this study, the species with the highest number of individuals) has a habitat preference with fine-grained sediment characteristics. A positive correlation is also shown by the relationship between medium sand and the abundance of all species (r=0.87), the abundance of gathering collectors (r=0.81), and the abundance of scrapers (0.88). This study found a moderate negative correlation between the abundance of benthic macroinvertebrates and clay percentage (r= -0.51). That follows the findings of Basyuni et al. (2018), where the lower the clay content, the more abundant macrozoobenthos tends to increase. Clay percentage also negatively correlates with the gathering collector (r= -0.46). On the other hand, clay has a significant negative correlation with the abundance of scrapers (r= -0.98). According to Kanaya (2014), macrozoobenthos (especially mollusks) were in small amounts in clay type substrate. The clay substrate can suppress the development and life of macrozoobenthos. The clay particles are also difficult to be penetrated by macrozoobenthos to carry out their life activities. However, in this study, the silt percentage has a stronger negative correlation with the abundance of gathering collectors (r= -0.89) and the total abundance of all species (r= -0.92). Meanwhile, the correlation between silt percentage and the abundance of scrapers only had a moderate negative correlation (r= -0.51). Overall, fine sediment accumulation can cause a loss of abundance and diversity in macroinvertebrate communities (e.g., taxa from the EPT orders). Increases in fine sediment can change the suitability of the substrate for some taxa, increase macroinvertebrate drift and affect respiration and feeding activities (Harrison and Wilkinson 2007).

Water pollution and FFG composition

Water pollution shows several negative correlations with the FFGs. The correlation test between the Pollution Index (PI) and the abundance of scrapers in the Midstream Citarum shows a negative correlation (Figure 9). On the other hand, PI did not correlate with gathering collector and overall benthic macroinvertebrate abundance. This finding shows that the abundance of the gathering collector is not too affected by pollution. The presence of high numbers of certain species that are tolerant to pollution, such as *Chironomus* sp. and *Tubifex* sp., explains why there is no relationship between PI and the FFGs (Jabłońska 2014; Chazanah et al. 2020) (Table 4; Figure 7a). Although stations 1 and 4 have a high abundance, it turns out that stations 1 and 4 have the fewest number of species compared to other stations (Figure 5). This is confirmed by the fact that PI and the number of species have a significant negative correlation (r= -0.95) (Figure 9). Diversity also decreases with increasing pollution (correlation of PI and H', r= -0.51), but PI is not correlated with Evenness. High diversity and abundance of macroinvertebrates, especially the intolerant taxa, were usually observed in the least polluted river (Al-Shami et al. 2011). Furthermore, if we compare the midstream versus upstream H' data, H' has the highest and lowest values in the Upstream Citarum stations (H'ST1 = 1.98 and H'ST4= 0.28) (Figure 8). Station 1 in upstream Citarum is close to the spring that became the source of Citarum River water. In contrast, the research station after station 1 in upstream Citarum is an urban area with many industrial activities, especially textiles. There was a sharp decrease in diversity from stations 1 to 4 in upstream Citarum. This decrease in H' can be caused by river pollution (Al-Shami et al. 2011). The PI index also has the lowest and highest values in the upstream Citarum stations (PI ST1= 1.81 and PI ST2= 12.92) (Bagaskara 2022, unpublished data). H' and PI in the midstream Citarum do not show extreme changes like those in the upstream Citarum stations. The standard deviations of H' and PI in midstream were 0.37 and 0.34, respectively, while the upstream has a standard deviation of 4.8 (PI) and 0.7 (H').

Although the pollution level in the midstream is not as severe as that of the upstream, more attention should be paid to the midstream area. The problem that becomes particularly concerning is the high relative abundance of *Tubifex* sp. at the most polluted stations. GC has a relative abundance of 82% at station 1 (PI = 5.37), and 95% of the GC is *Tubifex* sp. In station 4 (PI = 5.65), almost 90% of the FFG is GC, where 58.3% of the GC is *Tubifex* sp. The average concentration of DO at each station was 4.5 mg/L (station 1) and 2.5 mg/L (station 4) (Table 2; Figure 7a). The low DO and high pollution resulted in only a few species that could live at the two stations, especially *Tubifex* sp., which was tolerant of low DO levels. *Chironomus* sp. was also found at station 4, with a relatively large abundance (41.7%) (Figure 7a). The two gathering collector species have a high environmental stress tolerance (Chazanah et al. 2020). Rodrigues and Reynoldson (2011) also stated that the abundance of oligochaetes usually increases with growing waste concentration, while other, less resistant organisms disappear. This is consistent with the finding that PI has a negative correlation with the abundance of scrapers (r= -0.71). Scrapers are still found in the most polluted stations but are dominated by invasive species. *P. canaliculata* dominates station 1, while *M. tuberculata* is the only scraper at station 4. In addition, Chaichana and Sumpan (2015) state that *P. canaliculata* is very adaptive and can live in various environmental conditions even with low DO, making them a successful invasive species. *M. tuberculata* was found at all stations but was dominant at station 4 without the presence of other scrapers. *M. tuberculata* is also an invasive species, it shows high resistance to pollution and other harsh conditions (Pointier et al. 1993; Santos et al. 2012; Quirós-Rodríguez et al. 2018).

On the other hand, even though there is a high dominance of one gathering collector at station 2 (Figure 7a), the dominant gathering collector is a type of Ephemeroptera, Plecoptera, Trichoptera group (EPT), namely *Baetis* sp. There is also the only type of filtering collector, *Hydropsyche* sp. The total EPT percentage at station 2 reaches 83%; this indicates that even though some species are dominant, station 2 has good water quality because it can support EPT life. Furthermore, EPT indicated a preserved habitat integrity since these invertebrates are sensitive to human disturbance. However, those species (*Hydrposyche* sp. and *Baetis* sp.) are considered tolerant EPT (Bae and Park 2017; Masese and Raburu 2017; Andrade et al. 2020). Indeed, the presence of EPT which was only found at station 2, is influenced by pollution level and the characteristics of the river, which is the preference of the EPT (as explained in the spatial distribution section).

FFG surrogate ratios for stream ecosystem attributes

This study calculated the Habitat Stability (HS) index at all stations. The Filtering Collector (FC) index was only calculated at station 2 because FC was only found at station 2. The Top-Down Predator (TDP) index was only calculated at stations 3 and 4 because predators are not found at other stations. The FFG surrogate ratio values are presented in Table 6. Only station 3 has a value above 0.50 for the HS index because station 3 has a more even distribution of FFG compared to other stations. The high number of gathering collectors compared to other FFGs causes the HS value to be lower than 0.50. HS index higher than 0.50 indicates that stable locations for scraping and attachment are in greater abundance than shifting unstable substrate (Cummins 2018). Based on the top-down predator index calculation, station 3 has a value of 0.35, while station 4 has a value of 0.08. Cummins (2018) states that the best predator-to-prey ratio is 0.10-0.20 for the total macroinvertebrate population. This predator population density (or biomass) level allows sufficient prey to support them. If TPD index >20 probably indicate populations of rapid turnover (polyvoltine prey populations present). Most stream macroinvertebrate predators are larger than their prey and have longer generation durations, resulting in a slower turnover time. Some prey has univoltine generation times (one generation per year), but most are polyvoltine (two or more generations per year). Most predators have univoltine or have longer generation times (Huryn et al. 2008).

Based on the Filtering-Collector (FC) index calculation, station 2 has an FC index value of 0.06. Cummins (2018) stated that the FFG ratio above 0.50 indicates suspended Fine Particulate Organic Matter (FPOM) load > storage (entrained) FPOM (Table 6). The FC ratio in station 2 is lower than 0.50, meaning that FPOM food for collectors at lower density and/or have lower quality than FPOM storage. This can also cause the low FFG from FC in this study because filtering collectors depend on the availability of FPOM transported in the current (FC) (Cummins et al. 2022). Apart from the effects of pollution, the presence of FC only at station 2 could be affected by the river's current speed, where the current speed reaches 0.9 m/s (the highest compared to all stations) (Table 2). This condition follows the research by Morse et al. (2019), filtering collectors commonly inhabit fast-flowing water that allows them to obtain organic matter efficiently. Other stations have relatively calm currents, where the speed ranges from 0.1 m/s (station 3) to 0.5 m/s (station 4).

The autotrophy-heterotrophy index at all stations shows a value below 0.50. That means all stations have conditions where stream plant (algae and vascular) production is lower than riparian plant litter inputs (or total respiration of microbes, plants, and animals) (Cummins 2018). The predominance of heterotrophy over autotrophic production could be attributed to the extensive pollution by organic waste. That could promote a high abundance of collectors over scrapers (Masese et al. 2014). Therefore, an inappropriate ratio of FFG surrogate ratios could indicate a disturbed ecosystem. In this study, most of the FFG surrogate ratios did not reach the threshold, so it can be said that the FFGs in the midstream Citarum have an unbalanced ratio between types of FFGs. Only station 3 shows FFG surrogate ratios close to/reach the threshold.

Dam activity and implication for biodiversity

This study result provides the first comprehensive investigation of benthic macroinvertebrates' FFG distribution in the midstream Citarum. Research on the effects of dam activity on the environment and biodiversity is still rarely carried out in the Citarum River, even in Indonesia. The dam's role is vital, but its environmental impact needs more attention. According to Alla and Liu (2021), the most important impacts of dams are the effects on water quality. A decrease in water quality could be caused due to excessive sediment release, pollution from hazardous materials, household wastewater, and solid waste. Moreover, dams also have fragmented rivers and threaten aquatic biodiversity globally. Macroinvertebrate richness reductions were primarily attributed to changes in downstream substrate composition (Wang et al. 2020). Another important issue is the number of floating net cages in the three dams in the midstream Citarum. Based on the Decree of the Governor of West Java Number: 660.31/Kep.923-DKP/2019 concerning the number of floating net cages in the Cirata, Saguling, and Jatiluhur Reservoirs that meet the environmental carrying capacity, the number of Floating Net Cages (FNC) is determined as follows: Cirata, a maximum of 7,204 FNC; Saguling, a maximum of 3,282 FNC; and Jatiluhur Reservoirs, a maximum of 11,306 FNC.

In fact, according to the Indonesian Ministry of Maritime Affairs and Fisheries, in 2019, there were 32,000 FNC in the Saguling Reservoir, 93,641 in the Cirata Reservoir, and 33,888 in the Jatiluhur Reservoir. These FNCs greatly exceed the recommended amount (Citarum Harum Taskforce 2020, unpublished data). As mentioned in the introduction, one of the reservoirs (Jatiluhur) had a trophic status at the level of eutrophic-hypertrophic. The average DO concentration in all Saguling Reservoir and Cirata Reservoir sampling locations are below 2 mg/L and 0.8 mg/L, respectively. In the inlet and outlet of Jatiluhur, the average DO concentration is only 1 and 4.5 mg/L, respectively (Prihadi et al. 2017; Marselina et al. 2021; Astuti et al. 2022). Therefore, pollution in this reservoir can greatly affect living species and the rivers connected to it.

Table 6. FFG surrogate ratios for stream ecosystem attributes

Index	Stations				
	1	2	3	4	Threshold*
HS index	0.21	0.14	0.66	0.03	>0.50
FC index	-	0.06	-	-	>0.50
TDP index	-	-	0.35	0.08	0.10-0.20
AH index	0.21	0.07	0.66	0.03	>0.75

Note: *The threshold value is obtained from Cummins (2018)

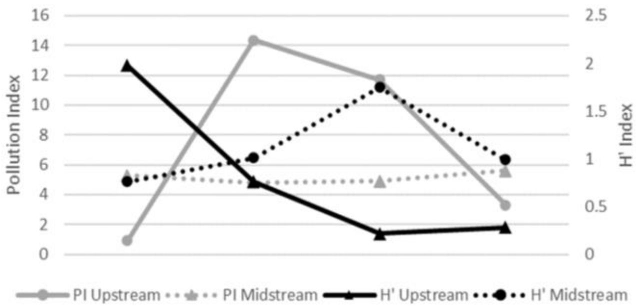

Figure 8. Comparison of H' and PI index in the upstream and midstream Citarum

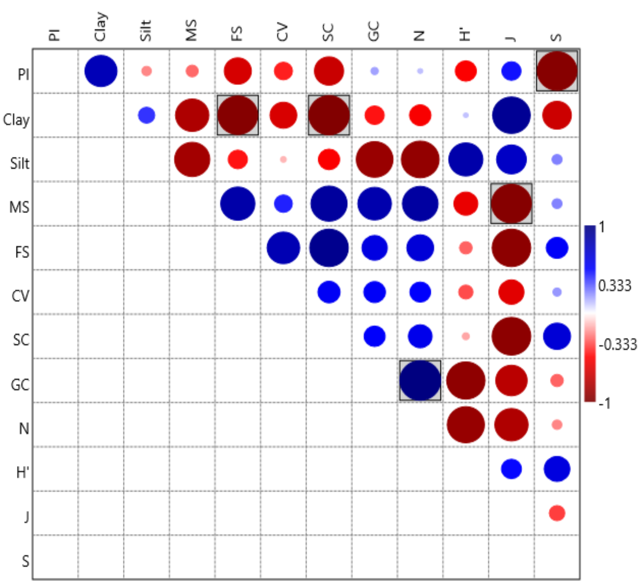

Figure 9. Pearson's correlation plot for environmental variables and benthic macroinvertebrates FFG distribution in Midstream Citarum. Blue color indicates positive correlation (r close to 1); Red color indicate negative correlation (r close to -1). >0.33/>-0.33 indicating moderate correlation; No color indicates no correlation; Significant correlations (P < 0.05) are marked with a box

If not treated immediately, environmental damage due to FNC activities can worsen the environmental conditions in the midstream Citarum, especially for benthic macroinvertebrates. In conclusion, environmental conditions such as pollution and types of substrates have several negative correlations with FFG composition and could damage ecosystem stability due to inappropriate ratios between FFG types. Cascading dam system in the midstream Citarum has proven to affect environmental conditions; this is characterized by differences in flow velocity characteristics, substrate, water physico-chemicals quality, pollution levels, and all of which may have an impact, namely the dissimilarity of the FFG composition between stations. Therefore, hopefully, the results of this research can become the basis for environmental management and raise awareness among all researchers worldwide, especially in Indonesia, to conduct more holistic research on dam activities and their effects on the environment.

ACKNOWLEDGEMENTS

We would like to express gratitude to the Bandung Institute of Technology, Indonesia which has supported the funding of this research through P2MI funding.

REFERENCES

Aisyah S, Soedarso J, Satya A, Syawal M. 2020. Relationship between the surface sediment substrate characteristic with the abundance of macrozoobenthos in River Ranggeh, West of Sumatra. IOP Conf Ser: Earth Environ Sci 535 (1): 012010. DOI: 10.1088/1755-1315/535/1/012010.

Alla YMK, Liu L. 2021. Impacts of dams on the environment: A review. Intl J Environ Agric Biotechnol 6 (1): 64-74. DOI: 10.22161/ijeab.61.9.

Andrade ICP, Krolow TK, Boldrini R, Pelicice FM. 2020. Diversity of EPT (Ephemeroptera, Plecoptera, Trichoptera) along streams fragmented by waterfalls in the Brazilian Savanna. Neotrop Entomol 49 (2): 203-212. DOI: 10.1007/s13744-019-00751-z.

Astuti LP, Sugianti Y, Warsa A, Sentosa AA. 2022. Water quality and eutrophication in Jatiluhur Reservoir, West Java, Indonesia. Pol J Environ Stud 31 (2): 1493-1503. DOI: 10.15244/pjoes/142475.

Astuti LP, Wahju DD, Tjahjo H. 2020. Potential of phosphorus loads in Ir. H. Djuanda Reservoir at Purwakarta Regency, West Java. Bawal 12 (1): 41-50. DOI: 10.15578/bawal.12.1.2020.41-50. [Indonesian]

Bae MJ, Park YS. 2017. Diversity and distribution of endemic stream insects in a nationwide scale, South Korea: Conservation perspectives. Water 9 (11): 833. DOI: 10.3390/w9110833.

BAPPENAS. 2014. Citarum Facts. http://citarum.bappenas.go.id/en/about-us/citarum-facts.html.

Basyuni M, Gultom K, Fitri A, Susetya IE, Wati R, Slamet B, Sulistiyono N, Yusriani E, Balke T, Bunting P. 2018. Diversity and habitat characteristics of macrozoobenthos in the mangrove forest of Lubuk Kertang Village, North Sumatra, Indonesia. Biodiversitas 19 (1): 311-317. DOI: 10.13057/biodiv/d190142.

Bohan W, Thant U, Zhang JY, Xuwang. 2017. Diversity and spatiotemporal dynamics of macrobenthos feeding functional groups in Jinan Rivers. J Ecol 37 (21): 7128- 7139. [Chinese]

Chaichana R, Sumpan T. 2015. Environmental tolerance of invasive golden apple snails (*Pomacea canaliculata* (Lamarck, 1822)) and Thai native apple snails (*Pila scutata*, (Mousson, 1848)). Trop Ecol 56: 347-355.

Chazanah N, Muntalif BS, Rahmayani RA, Sudjono P. 2020. Macrozoobentos distribution as a bioindicator of water quality in the upstream of the Citarum River. J Ecol Eng 21 (3): 10-17. DOI: 10.12911/22998993/116335.

Cordova MR, Nurhati IS, Shiomoto A, Hatanaka K, Saville R, Riani E. 2022. Spatiotemporal macro debris and microplastic variations linked to domestic waste and textile industry in the supercritical Citarum River, Indonesia. Mar Poll Bull 175: 113338. DOI: 10.1016/J.MARPOLBUL.2022.113338.

Cummins KW, Wilzbach M, Kolouch B, Merritt R. 2022. Estimating macroinvertebrate biomass for stream ecosystem assessments. Intl J Environ Res Public Health 19 (6): 3240. DOI: 10.3390/ijerph19063240.

Cummins KW. 2018. Functional Analysis of Stream Macroinvertebrates. Limnology: Some New Aspects of Inland Water Ecology. IntechOpen, London. DOI: 10.5772/intechopen.79913.

Dulić Z, Marković Z, Zivić M, Ćirić M, Stanković M, Subakov-Simić G, Živić I. 2014. The response of phytoplankton, zooplankton and macrozoobenthos communities to change in the water supply from surface to groundwater in aquaculture ponds. Ann Limnol - Intl J Lim 50 (2): 131-141. DOI: 10.1051/limn/2014005.

Encalada AC, Calles J, Ferreira V, Canhoto CM, Graça MAS. 2010. Riparian land use and the relationship between the benthos and litter decomposition in tropical montane streams. Freshw Biol 55 (8): 1719-1733. DOI: 10.1111/j.1365-2427.2010.02406x.

Gholizadeh M, Heydarzadeh M. 2020. Functional feeding groups of macroinvertebrates and their relationship with environmental parameters (case study: In Zarin-Gol River). Iran J Fish Sci 19 (5): 2532-2543. DOI: 10.22092/ijfs.2019.118132.

Harrison ET, Norris RH, Wilkinson SN. 2007. The impact of fine sediment accumulation on benthic macroinvertebrates: Implications for river management. Proceeding of the 5th Australian Stream Management Conference, Thurgoona, New South Wales.

Hasan V, Mamat NB, South J, Ottoni FP, Widodo MS, Arisandi P, Isroni W, Jerikho R, Samitra D, Faqih AR, Simanjuntak CPH, Mukti AT. 2022. A checklist of native freshwater fish from Brantas River, East Java, Indonesia. Biodiversitas 23 (11): 6031-6039. DOI: 10.13057/biodiv/d231158.

Hasan V, Widodo MS. 2020. Short communication: The presence of Bull Shark *Carcharhinus leucas* (Elasmobranchii: Carcharhinidae) in the fresh waters of Sumatra, Indonesia. Biodiversitas 21 (9): 4433-4439. DOI: 10.13057/biodiv/d210962.

Hasan V, Valen FS, Islamy RA, Widodo MS, Saptadjaja AM, Islam I. 2021. Short Communication: Presence of the vulnerable freshwater goby *Sicyopus auxilimentus* (Gobiidae, Sicydiinae) on Sangihe Island, Indonesia. Biodiversitas 22 (2): 571-579. DOI: 10.13057/biodiv/d220208.

Huryn AD, Wallace JB, Anderson NH. 2008. Habitat, Life History, Secondary Production, and Behavioral Adaptations of Aquatic Insects. In An Introduction to the Aquatic Insects of North America, 4th ed.; Kendall/Hunt Publishing Company, Dubuque.

Imansyah MF. 2012. Studi umum permasalahan dan solusi DAS Citarum serta analisis kebijakan pemerintah. Jurnal Sosioteknologi 11 (25): 18-33. [Indonesian]

Jabłońska A. 2014. Oligochaete communities of highly degraded urban streams in Poland, Central Europe. North-West J Zool 10 (1): 74-82.

Kaaya LT, Day JA, Dallas HF 2015. Tanzania River Scoring System (TARISS): A macroinvertebrate based biotic index for rapid bioassessment of rivers. Afr J Aquat Sci 40 (2): 109-117. DOI: 10.2989/16085914.2015.1051941.

Kanaya G. 2013. Recolonization of macrozoobenthos on defaunated sediments in a hypertrophic brackish lagoon: Effects of sulfide removal and sediment grain size. Mar Environ Res 95: 81-88. DOI: 10.1016/j.marenvres.2013.12.014.

Kripa PK, Prasanth KM, Sreejesh KK, Thomas TP. 2013. Aquatic macroinvertebrates as bioindicators of stream water quality-A case study in Koratty, Kerala, India. Res J Recent Sci 2: 217-222.

Liro M, Nones M, Mikuś P, Plesiński K. 2022. Modelling the effects of dam reservoir backwater fluctuations on the hydrodynamics of a small mountain stream. Water 14 (19): 3166. DOI: 10.3390/w14193166.

Liyanage CP, Yamada K. 2017. Impact of population growth on the water quality of natural water bodies. Sustainability 9 (8): 1405. DOI: 10.3390/su9081405.

Marselina M, Sabar A, Fahimah N. 2021. Spatial and temporal assessment of surface water quality using water quality index the Saguling Reservoir, Indonesia. J Water Land Dev 49 (IV - VI): 111-120. DOI: 10.24425/jwld.2021.137103.

Masese FO, Kitaka N, Kipkemboi J, Gettel GM, Irvine K, McClain ME. 2014. Macroinvertebrate functional feeding groups in Kenyan highland streams: Evidence for a diverse shredder guild. Freshw Sci 33 (2): 435-450. DOI: 10.1086/675681.

Melo ALU, Ono ER, Uieda VS. 2020. Benthic invertebrate communities structure in headwater streams with different states of the riparian

vegetation conservation. Community Ecol 21 (1): 43-53. DOI: 10.1007/s42974-020-00011-w.
Mesa LM. 2014. Influence of riparian quality on macroinvertebrate assemblages in subtropical mountain streams. J Nat Hist 48 (19-20): 1153-1167. DOI: 10.1080/00222933.2013.861937.
Morse JC, Frandsen PB, Graf W, Thomas JA. 2019. Diversity and ecosystem services of Trichoptera. Insects 10 (5): 125. DOI: 10.3390/insects10050125.
Nemerow NL. 1974. Scientific Stream Pollution Analysis. Scripta Book Co, Washington.
Ochieng H, Odong R, Okot-Okumu J. 2020. Comparison of temperate and tropical versions of Biological Monitoring Working Party (BMWP) index for assessing water quality of River Aturukuku in Eastern Uganda. Glob Ecol Conserv 23 (8): e01183. DOI: 10.1016/j.gecco.2020.e01183.
Ojija F, Gebrehiwot M, Kilimba N. 2017. Assessing ecosystem integrity and macroinvertebrates community structure: Towards conservation of small streams in Tanzania. Intl J Sci Technol Res 6 (2): 148-155.
De Oliveira ALH, Nessimian JL. 2010. Spatial distribution and functional feeding groups of aquatic insect communities in Serra da Bocaina streams, southeastern Brazil. Acta Limnol Bras 22 (4): 424-441. DOI: 10.4322/actalb.2011.007.
Pointier JP, Theron A, Borel G. 1993. Ecology of the introduced snail *Melanoides tuberculata* (Gastropoda: Thiaridae) in relation to *Biomphalaria glabrata* in the marshy forest zone of Guadeloupe, French West Indies. J Molluscan Stud 59 (4): 421-428. DOI: 10.1093/mollus/59.4.421.
Prihadi TH, Saputra A, Taufik I, Ardi I. 2017. The application of life cycle assessment to evaluate water quality condition around fish cages in Cirata Reservoir, Indonesia. Indones Aquac J 12 (2): 83-91. DOI: 10.15578/iaj.12.2.2017.83-91.
Quirós-Rodríguez JA, Yepes-Escobar J, Santafé-Patiño G. 2018. The invasive snail *Melanoides tuberculata* (Müller, 1774) (Gastropoda, Thiaridae) in the lower basin of the Sinú River, Córdoba, Colombian Caribbean. Check List 14 (6): 1089-1094. DOI: 10.15560/14.6.1089.
Ryder D, Vernes K, Dorji L, Armstrong S, Brem C, Donato RD, Frost L, Simpson I. 2015. Experimental effects of reduced flow velocity on water quality and macroinvertebrate communities: Implications for hydropower development in Bhutan. Proceedings of the Bhutan Ecological Society, Bhutan: 1-21.
Santos SB, Thiengo SC, Fernandez MA, Miyahira IC, Gonçalves ICB, Ximenes RF, Mansur MCD, Pereira D. 2012. Espécies de moluscos límnicos invasores no Brasil. In: Mansur MCD, Santos CP, Pereira D, Paz ICP, Zurita MLL, Rodriguez MTR, Nehrke MV, Bergonci PEA (eds.). Moluscos límnicos invasores no Brasil: Bio-logia, prevenção e controle. Redes Editora, Porto Alegre. [Portuguese]
Shafie MSI, Wong ABH, Harun S, Fikri AH. 2017. Land use influence on the aquatic insect communities on tropical forest streams of Liwagu River, Sabah, Malaysia. Aquac Aquar Conserv Legis Bioflux 10 (2): 341-352.
Wakhid, Rauf A, Krisanti M, Sumertajaya IM, Maryana N. 2021. Aquatic insect communities in headwater streams of Ciliwung River watershed, West Java, Indonesia. Biodiversitas 22 (1): 30-41. DOI: 10.13057/biodiv/d220105.
Wang J, Ding C, Heino J, Jiang X, Tao J, Ding L, Su W, Huang M, He D. 2020. What explains the variation in dam impacts on riverine macroinvertebrates? A global quantitative synthesis. Environ Res Lett 15 (12): 124028. DOI: 10.1088/1748-9326/abc4fc.
Windsor FM, Tilley RM, Tyler CR, Ormerod SJ. 2019. Microplastic ingestion by riverine macroinvertebrates. Sci Total Environ 646: 68-74. DOI: 10.1016/j.scitotenv.2018.07.271.
Zhu C, Mo K, Tang L, Wu Y, Li T, Lin Y, Chen Q. 2020. Spatial-temporal distribution and ecological effects of macroinvertebrate functional feeding groups in the Lijiang River. Sheng Tai Xue Bao 40 (1): 60-69. DOI: 10.5846/stxb201811262574. [Chinese]