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Impacts of long-term freshwater benthic insect community shifts on downstream coastal ecosystems

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ABSTRACT
Background: Sungai Ijuk is a vital freshwater ecosystem, where benthic macroinvertebrates serve as key indicators of water quality and ecosystem stability. This study evaluates long-term changes in the benthic insect community structure over a 20-year period, comparing data from 2001 and 2022, to assess the ecological impacts on this aquatic system. **Methods:** A descriptive method was applied through direct observation at three sampling stations along the Ijuk River. Analyses included species composition, density, diversity index, evenness index, dominance index, and similarity index. Samples were collected from rocky, sandy, and litter substrates, and statistical analyses were conducted to compare changes over the two decades. **Findings:** The results show a significant decline in community composition, from 9 orders, 30 families, and 62 genera in 2001 to 7 orders, 22 families, and 36 genera in 2022. Insect density also decreased, with the highest recorded density dropping from 1696 ind/m^2 in 2001 to 1448 ind/m^2 in 2022. While the diversity index peaked in 2022 on leaf-litter substrates at Station I, the dominance index remained low across both years, and the similarity index among stations increased in 2022, indicating greater community uniformity. **Conclusion:** This article highlight a significant ecological shift likely driven by anthropogenic pressures such as pollution and substrate modification. Despite reduced species richness and density, the low dominance and increased similarity suggest a relatively stable, though simplified, ecosystem. **Novelty/Originality of This Study:** This research lies in its longitudinal analysis of benthic insect community structure and its demonstration of anthropogenic impacts over time. It also reinforces the utility of benthic insects as bioindicators of freshwater quality in Indonesia and underscores the urgency of conservation efforts to sustain freshwater ecosystems.

KEYWORDS: anthropogenic impact; bottom-water insects; diversity index; Ijuk River; insect community.

1. Introduction

Freshwater ecosystems are environments found in habitats with freshwater, rich in minerals and typically maintaining a pH of around 6. Surface water conditions in these ecosystems can vary due to unpredictable weather patterns and, in extreme cases, may even dry out. Freshwater ecosystems are generally categorized into two main types: lotic ecosystems, which include flowing waters such as springs, rivers, and streams, and lentic ecosystems, consisting of standing waters such as lakes, ponds, swamps, reservoirs, and dams (Odum, 1993).

Isau-Isau Wildlife Sanctuary is a conservation area that maintains a relatively natural ecosystem, although some surrounding regions have been affected by human activities such as the expansion of coffee plantations and mixed farms, including rubber, durian, and other fruit crops. The sanctuary contains several small streams, with the Ijuk River being a major

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watercourse approximately 3 km in length. This river plays a critical role as a water catchment area, hydrological balancer, microclimate regulator, and soil fertility maintainer. These functions are vital for sustaining aquatic organisms such as benthic macroinvertebrates that dwell on the riverbed (Salmin, 2005).

Benthic aquatic insects, invertebrates from the class Insecta, are highly sensitive to pollution, although some taxa can survive in contaminated environments. Their presence is closely tied to the availability of organic material, which supports their life cycles. These insects play a crucial role in nutrient cycling and are key components of aquatic food webs. Although only about 3% of all insect species globally inhabit aquatic environments, nearly 95% of them are freshwater benthic macroinvertebrates. Major aquatic insect orders include Diptera, Ephemeroptera, Hemiptera, Megaloptera, Odonata, Plecoptera, and Trichoptera (Ward, 1992).

Aquatic insects are organisms that spend part or all of their life cycles in aquatic habitats, living as benthic, periphytic, or free-swimming organisms. These insects contribute significantly to nutrient cycling and form essential components of aquatic food webs (Jana, 2009). Their habitats are classified based on physical and chemical environmental factors into three major categories: natural or permanent habitats, temporary habitats, and artificial habitats. These can be found in various freshwater environments, including streams with microhabitats consisting of leaf litter, rocks, gravel, sand, and silt, as well as lakes, ponds, and wetlands (Merritt & Cummins, 1996).

The microhabitats of benthic macroinvertebrates in the Ijuk River are essential for their survival. Any disturbances, whether natural or anthropogenic, can degrade water quality and negatively affect insect populations. A primary threat to these habitats is land-use change, a growing issue in the Ijuk River area. For example, the expansion of coffee fields close to the riverbanks in the Isau-Isau Wildlife Sanctuary threatens the ecological balance of this aquatic system. This situation calls for a reassessment of the surrounding environment, particularly concerning the sustainability of benthic insect habitats.

In addition to land-use changes, population growth and low community awareness regarding river conservation further contribute to river degradation. Increased human activity along the forest margins—converted into coffee plantations and mixed gardens—affects water quality. The construction of a dam near the area, which diverts water to nearby villages through large concrete pipes, also impacts river conditions. These factors collectively threaten the Ijuk River ecosystem and demand greater attention to maintain water quality and ensure the sustainability of benthic insect habitats in the region.

This study focuses on benthic macroinvertebrates because of their critical role as indicators of riverine environmental change. These organisms are highly vulnerable and sensitive to pollution, especially during their extended larval stages, which occur on the riverbed. The study specifically evaluates the impact of plantation activities, excluding domestic factors (Popoola & Otalekor, 2011). Previous research on benthic insects in the Isau-Isau Wildlife Sanctuary was conducted by Elsa and Agustina in 2001. Elsa (2001) recorded 10 orders, 26 families, and 45 species of insects, while Agustina (2001) identified 9 orders, 30 families, and 62 species. Over two decades have passed without updated scientific data on benthic insects in the Ijuk River, highlighting the urgent need for a recent study to assess ecological changes in this freshwater ecosystem.

2. Methods

This study was conducted from January 2022 to July 2022 in the Isau-Isau Wildlife Sanctuary, located in Lawang Agung Village, Mulak Ulu Subdistrict, Lahat Regency. Sampling sites were selected based on the existing environmental features of the area. The determination of research stations employed a purposive sampling method, chosen with the specific objective of obtaining samples that accurately represent the environmental conditions at each site.

Each station was selected by considering distinct environmental characteristics, such as proximity to human activities and the presence of natural ecosystems. Furthermore, site selection also took into account the diversity of habitats, which could influence the composition of benthic macroinvertebrate communities. The main objective of this study was to provide a comprehensive understanding of the environmental conditions and the factors affecting benthic macroinvertebrate populations.

By applying this approach, it was expected that accurate data could be obtained on the presence and diversity of benthic macroinvertebrates in the Ijuk River, as well as their implications for the quality of the aquatic ecosystem in the area. The locations of the research stations within the Isau-Isau Wildlife Sanctuary in Lahat Regency are shown in Figure 1.

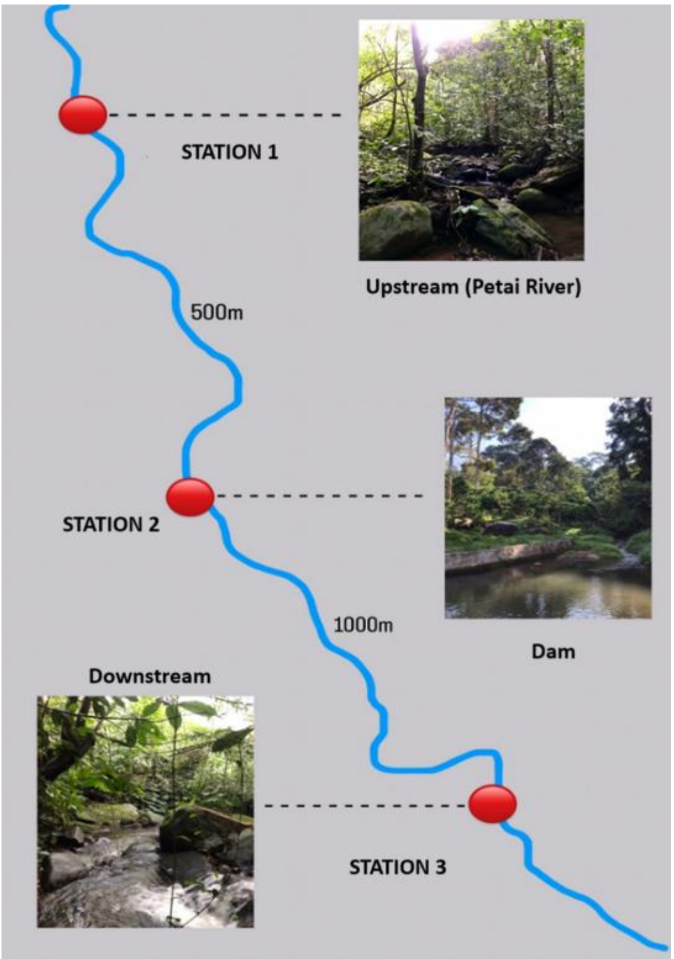

Fig. 1. Location of the research station in SM.Isau-Isau, Lahat Regency.

Sampling was conducted using a Surber net at three different stations or sampling points, each representing four distinct types of microhabitats or substrates: rocky, sandy, gravelly, and leaf litter. Each microhabitat was sampled twice to ensure the accuracy and reliability of the data. In total, 24 samples were collected and subsequently analyzed through taxonomic identification methods.

In addition to biological sampling, several physicochemical parameters of the Ijuk River were measured at each research station. These included temperature, current velocity, water depth, pH, and dissolved oxygen (DO). Water samples of 1 liter were also collected at each station for phosphate and nitrate analysis, which were then tested at the UPTD Laboratory of the Environmental Agency of Palembang City.

Taxonomic identification of field samples was carried out at the Ecology Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Sriwijaya University. For data analysis, a quantitative descriptive approach was employed using the Shannon-Wiener, Simpson, and Sorensen indices to assess species diversity and similarity.

3. Results and Discussion

3.1 Dominance and similarity index of marine bottom insect communities

Based on the dominance index values shown in the graph, all stations exhibited values ranging from 0.12 to 0.50. The highest dominance index was recorded at Station I, with a value of 0.50, while the lowest values were observed at Stations I and II, each with a dominance index of 0.12. According to Fachrul (2007), a high dominance index at a given station indicates an unstable aquatic environment, where a single species dominates over others. Conversely, a low dominance index reflects a relatively stable environment, characterized by a more even distribution of species.

This suggests that stations with lower dominance index values are better able to support biodiversity. In the context of this study, the results provide insight into the ecological stability of the aquatic ecosystem in the Ijuk River. The observed variation in dominance index values highlights differences in the level of ecosystem stability across the sampled stations.

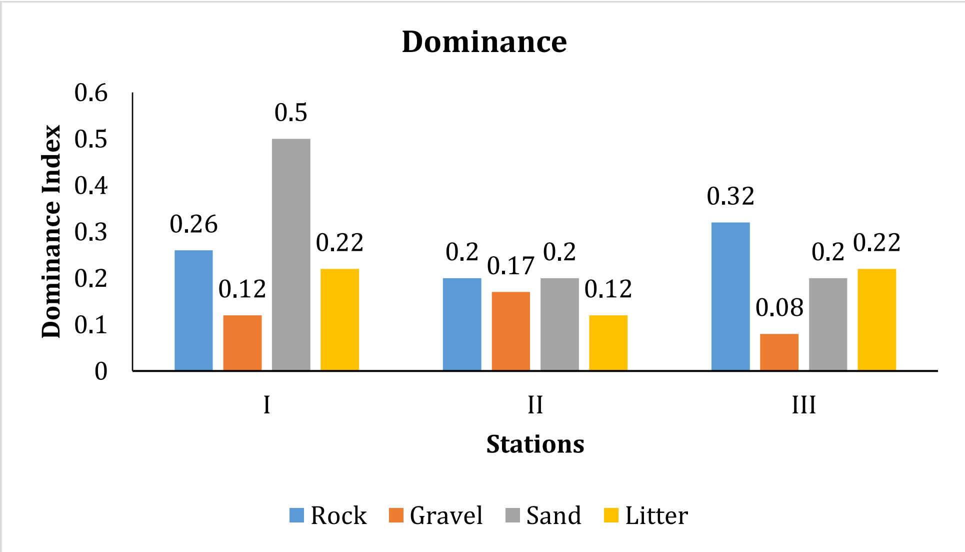

Fig. 1. Bar Chart of Aquatic Insect Dominance Index Based on Water Base Substrate at 3 Stations in Ijuk River, Isau-Isau Wildlife Sanctuary, Lahat Regency

The highest dominance index in this study was recorded at Station I, with a value of 0.5, indicating low dominance among benthic macroinvertebrates, as no single species dominated the population. Benthic insects found in sandy substrates did not show clear species dominance. At Station II, dominance was slightly higher on rocky and sandy substrates, with a dominance index value of 0.20. Meanwhile, at Station III, the population of Prionochaeta sp. dominated the rocky substrate, whereas at Station I on gravel substrate, the dominant species was Polypedilum sp. According to Soegianto (1994), a dominance index (C) value approaching 0 (<0.5) indicates low dominance, meaning no single species dominates, while a value approaching 1 (>0.5) reflects high dominance by one species over others. These findings reflect the species diversity at each station, which is influenced by the variation in substrate types.

Furthermore, the lowest dominance index values were recorded at Station I on gravel substrate and Station II on leaf-litter substrate, both with a value of 0.12, indicating no dominant species in these habitats. According to Rahmawaty (2011), a low dominance index suggests that macrozoobenthic taxa do not exhibit uniform adaptability and survival capacity across all observation sites. This also indicates that macrozoobenthos utilize resources optimally within each type of substrate at the sampling locations. Therefore, the dominance index serves as a crucial indicator for understanding the population balance of aquatic insects. Through the use of community similarity indices, as shown in Table 1, it is possible to assess how species interact and adapt to their respective habitat conditions.

The results of the study show that the community similarity index values of benthic aquatic insects in the Ijuk River ranged from 50% to 64.80% across all stations. This index is used to describe the degree of similarity among species that form the insect community at each sampling location. A similarity index value above 50% indicates a high level of species similarity, while a value below 50% indicates low similarity. Stations I and II recorded a similarity index of 50%, indicating a relatively high degree of species overlap, although these values were the lowest among all station comparisons.

Table 1. Similarity index value of aquatic insect community based on basic water substrate at each station in Ijuk River, Isau-Isau Wildlife Sanctuary, Lahat Regency

Station	I	II	III
I		50%	54.50%
II			68.40%
III			

According to Resh and Rosenberg (1984), substrate characteristics significantly influence the types of aquatic insect larvae or nymphs present, as different insect groups possess varying abilities to adapt to their environmental conditions. The community similarity between Stations I and III was recorded at 54.50%, also indicating high species similarity. This suggests that the environmental conditions surrounding these two stations are relatively similar, characterized by dense tree cover in the surrounding areas. However, Station III is more accessible to the public due to its proximity to coffee plantations, resulting in a shorter distance from the river's upstream source.

Suin (2002) stated that relatively homogeneous microhabitats often result in higher community similarity, as individuals of the same species tend to dominate habitats they are well-adapted to. These species have naturally developed mechanisms of adaptation and tolerance, allowing them to thrive in such environments. This reflects the importance of microhabitat suitability in influencing the community structure of benthic aquatic insects in river ecosystems.

The highest community similarity index was observed between Stations II and III, reaching 68.40%. Although Station II faces potential water pollution due to the construction of a dam and the installation of water pipelines for community use, these disturbances did not significantly alter the similarity of benthic insect communities in the river. This suggests a level of community stability despite environmental changes.

According to Odum (1993), community similarity among benthic insects can be influenced by a combination of internal and external factors. External factors such as sunlight, food availability, and humidity play a significant role in shaping community structure. Meanwhile, internal factors such as water quality and the availability of suitable substrates influence species adaptation and distribution within the ecosystem. Thus, even in the face of physical environmental changes, these factors can contribute to maintaining the stability of benthic insect communities in the Ijuk River.

3.2 Physical and chemical factors of the environment

Table 2 presents the results of physical and chemical parameter measurements conducted in the Ijuk River, located within the Isau-Isau Pasemah Wildlife Reserve, Lahat Regency. These measurements include several key parameters: current velocity, water temperature, and water depth, recorded at three observation stations (St. I, St. II, and St. III). The data are presented in standardized units: current velocity in centimeters per second (cm/s), temperature in degrees Celsius (°C), and water depth in centimeters (cm). Measurements were carried out by comparing environmental conditions across each station, taking into account different substrate types, namely rocky, sandy, gravelly, and leaf-litter substrates. This data is critical for understanding the spatial variation in physical and chemical conditions along the river and assessing how these environmental factors may influence the benthic aquatic insect communities inhabiting the area.

Table 2. Results of Measurement of Physical and Chemical Factors in the Ijuk River, Isau-Isau Pasemah Wildlife Sanctuary, Lahat Regency

Parameter	St.I				St.II				St.II			
	B	K	P	S	B	K	P	S	B	K	P	S
Current Velocity (cm/s)	24.3	15.3	4.97	4.62	18.8	58.8	11.2	83.3	43.4	29.4	14.2	9.02
Temperature (°C)	21	21	21	21	22	21.6	21.8	21.5	21.6	22	21.9	22
Depth (cm)	15	18	37	20	10	10	35	15	17	19	27	18

The results of current velocity measurements using a Current Velocity Meter indicate significant variation across different benthic substrates in the Ijuk River. The highest current velocity was recorded at Station II on leaf-litter substrate, reaching 83.8 cm/s, whereas the lowest was observed at Station I, also on leaf-litter substrate, at 4.63 cm/s. According to the classification by Mason (1981), the current velocity at Station II falls under the category of "very fast" (>100 cm/s), while Station I is classified as "very slow" (<10 cm/s). These current variations are influenced by the underlying substrate and can significantly affect the distribution of aquatic organisms. The differences in flow dynamics across substrates reflect diverse hydrological conditions at each sampling site. Faster currents allow greater mobility for organisms, whereas slower currents tend to create more stable microhabitats that support the persistence of specific species. Hence, measuring current velocity is crucial for understanding the aquatic ecosystem dynamics of the Ijuk River.

Water temperature in the Ijuk River also varied across stations. Station I showed relatively stable temperatures at 21°C across all substrate types. In contrast, Station II exhibited temperatures ranging from 21.5°C to 22°C, while Station III recorded 21.6°C to 22°C. These variations may be attributed to topographical differences, where Station I is located upstream with dense canopy cover providing shade, Station II lies in a more open area, and Station III experiences greater anthropogenic access due to its proximity to agricultural lands. According to Nybakken (1992), water temperature plays a key role in regulating physical, chemical, and biological processes within aquatic ecosystems, thereby influencing the distribution of aquatic biota.

River depth measurements ranged from 10 to 35 cm, with the greatest depth of 35 cm observed at Station II, likely due to the construction of dams and water pipelines for local use. Water transparency was generally low at all stations, attributed to high water discharge leading to increased turbidity from suspended particulate matter (Siahaan, 2011).

Table 3. Results of chemical factor measurements in the Ijuk River, Isau-Isau Pasemah Wildlife Sanctuary, Lahat Regency

Parameter	St.I	St.II	St.III
DO (mg/L)	8.8	6.6	7.5
pH	6.7	6.5	6.6
Nitrat (mg/L)	0.2	0.3	0.4
Fosfat (mg/L)	0.015	0.007	0.011

Table 3 presents the results of chemical parameter measurements in the Ijuk River, located within the Isau-Isau Pasemah Wildlife Reserve, Lahat Regency. The measured parameters include Dissolved Oxygen (DO), pH, nitrate, and phosphate across three sampling stations: Station I, Station II, and Station III. These measurements provide insight into water quality conditions, which directly impact the presence and survival of aquatic organisms. DO is a crucial parameter that supports the metabolic activity of aquatic fauna, while pH indicates the acidity or alkalinity of the water, both of which are vital to biodiversity maintenance. Additionally, nitrate and phosphate concentrations serve as indicators of organic pollution and may contribute to eutrophication if present in excessive amounts. The information presented in this table is essential for understanding the chemical environment of the Ijuk River, the focal area of this study.

The results of the study indicate that dissolved oxygen (DO) concentrations in the Ijuk River vary across the three sampling stations. Station I recorded the highest DO level at 8.8 mg/L, while Station II showed the lowest at 6.6 mg/L, and Station III measured 7.5 mg/L. Despite these differences, all DO values fall within acceptable ranges, suggesting that the Ijuk River is not classified as polluted. Dissolved oxygen plays a crucial role in aquatic ecosystems, as it is required by aquatic organisms for respiration (Anzani et al., 2013).

Measurements of pH levels in the Ijuk River also indicated relatively stable values across all stations: 6.7 at Station I, 6.5 at Station II, and 6.6 at Station III. These values fall within the normal range of pH 6–9, indicating that the river water at all stations does not exhibit sensitivity to pH fluctuations that could adversely affect aquatic life. Accordingly, the three stations may be classified as unpolluted aquatic environments based on pH.

In addition to DO and pH, phosphate and nitrate concentrations were measured to further assess water quality in the Ijuk River. The results showed phosphate levels of 0.015 mg/L at Station I, 0.007 mg/L at Station II, and 0.011 mg/L at Station III. According to Government Regulation No. 22 of 2021 (Indonesia), phosphate concentrations exceeding 0.02 mg/L are indicative of eutrophic conditions. Therefore, the phosphate levels recorded at all stations suggest that the Ijuk River falls within the category of moderately productive or fertile waters.

Similarly, nitrate concentrations ranged from 0.2 mg/L to 0.4 mg/L across the three stations. Elevated nitrate levels can influence the composition and abundance of benthic macroinvertebrates, potentially enhancing aquatic biodiversity. Referring to the same regulation, the maximum allowable nitrate concentration for freshwater bodies is 10 mg/L, indicating that the nitrate levels in the Ijuk River are well below the regulatory limit, thus confirming that the water quality remains good and unpolluted.

3.3 Evaluation and trends of the aquatic bottom insect community in the ijuk river over a 20-year period

The structural components of aquatic insect communities in the Ijuk River between a study conducted in 2001 by Agustina (2001) and a more recent study carried out in 2022. The earlier study recorded the presence of 9 orders, 30 families, and 62 genera of aquatic insects. In contrast, the 2022 study reported a decline in diversity, with only 7 orders, 22 families, and 36 genera identified. This reduction in taxonomic richness indicates a notable change in community structure over the 21-year period. In 2001, density was measured in a general and randomized manner, while in 2022, density was calculated specifically for each substrate type at each station. This methodological refinement in the recent study allows for a more detailed understanding of habitat-specific insect distributions.

In addition, significant variations were observed in the values of community indices, including those measuring evenness, diversity, dominance, and community similarity. These variations reflect broader ecological changes in the aquatic environment of the Ijuk River over the two decades. Meanwhile, the structural components of aquatic insect communities in the Ijuk River have undergone significant changes between 2001 and 2022. This evaluation encompasses key ecological parameters, including overall taxonomic composition, benthic insect density, diversity index, dominance index, evenness index, and community similarity index. The most apparent change is observed in the overall taxonomic composition, which showed a substantial decline. In 2001, a total of 9 orders, 30 families, and 62 genera were recorded, whereas in 2022, these numbers declined to 7 orders, 22 families, and 36 genera. This nearly 50% reduction may be attributed to environmental changes, particularly those driven by anthropogenic activities. According to Setiawan (2009), shifts in taxonomic composition can result from substrate alterations caused by human activities such as pollution or the discharge of industrial or mining waste, which exert pressure on certain aquatic insect taxa.

The density of benthic insects in 2022 also declined when compared to data from two decades prior. The highest recorded density in 2001 was 1,696 individuals/m^2, while in 2022, the maximum density was only 1,448 individuals/m^2, observed at Station I on leaf litter substrate. This decline suggests a reduction in individual abundance, potentially influenced by factors such as water quality degradation and food availability for aquatic insects. Insect density, categorized by order, is closely related to supporting environmental factors, including substrate condition and the presence of pollutants in the water. This trend indicates that the aquatic ecosystem of the Ijuk River may be experiencing stress or disturbance affecting benthic organism abundance.

The diversity index, used to assess aquatic environmental conditions, also showed notable differences between 2001 and 2022. In 2001, the highest diversity index was observed on rocky substrates, whereas in 2022, the highest index was recorded on leaf litter substrate at Station I. This shift may indicate changes in habitat preferences among aquatic insects, potentially driven by alterations in environmental conditions. According to Fikriyati (2009), a healthy or stable aquatic environment is typically characterized by high diversity and evenness indices and a low dominance index. The observed changes in the diversity index reflect a decline in the stability and ecological health of the Ijuk River ecosystem over time. This condition underscores the need for enhanced conservation and management strategies to maintain the ecological balance and integrity of aquatic habitats.

The evenness index calculated in 2022 ranged from 0.246 to 0.787, indicating uneven distribution of aquatic insect communities in the Ijuk River. This unevenness is reflected in the varying number of species recorded at each sampling station. A low evenness value suggests that one or a few species dominate the community at a particular station, indicating an imbalance in the aquatic insect community where certain species monopolize the available ecological niche. Conversely, high evenness values imply a more equitable distribution among species.

Despite these fluctuations, the dominance index recorded in 2001 indicated no dominant species, with all values remaining below 0.5. Similarly, in 2022, the dominance value remained low at 0.50, suggesting that no single species exhibited ecological dominance, and species distribution remained relatively balanced.

Furthermore, the community similarity index showed a notable shift over time. In 2001, similarity values were less than 50%, while in 2022, they exceeded 50%. According to Odum (1993), community similarity between stations can be categorized using two criteria: if the similarity index is ≥50%, the stations are considered ecologically similar, whereas a value <50% suggests that species compositions differ significantly among stations. Therefore, the lower similarity in 2001 reflects a greater heterogeneity in aquatic insect communities across sampling stations, while the higher similarity in 2022 suggests a more uniform composition of species among stations.

This shift may reflect changes in ecosystem structure and water quality over time. According to Hart et al., as cited in Hanafiah (1998), unpolluted waters are typically characterized by the absence of dominant species, with a balanced distribution of organisms across trophic levels. Consequently, the observed increase in the similarity index between 2001 and 2022 may indicate a transformation in the ecological condition of the Ijuk River, potentially influenced by natural succession or anthropogenic factors affecting environmental homogeneity.

4. Conclusions

Research on benthic macroinvertebrate communities in the Ijuk River reveals significant changes in community structure over the past two decades. In 2001, a total of 9 orders, 30 families, and 62 genera were recorded, which declined to 7 orders, 22 families, and 36 genera in 2022. This nearly 50% reduction in taxonomic composition indicates substantial ecological pressure on the aquatic insect communities. Anthropogenic factors, such as pollution and changes in substrate composition, are suspected to be the primary drivers of this transformation. A decline in the density of aquatic insects was also observed, with the highest density recorded at 1696 individuals/m^2 in 2001, decreasing to 1448 individuals/m^2 in 2022.

Despite the reduced species richness, the community still exhibited relative stability, as indicated by low dominance values and moderate evenness indices. This suggests that, although species diversity has decreased, the benthic insect community in the Ijuk River has managed to maintain a functional ecological balance.

Changes in diversity indices between 2001 and 2022 further reflect alterations in habitat quality. The highest diversity index in 2001 was associated with rocky substrates, whereas in 2022, leaf litter substrates at Station I exhibited the highest diversity. The evenness index in 2022 indicated uneven species distribution, reflecting localized imbalances in community composition at certain stations. Nevertheless, the dominance index remained low, suggesting that no single species dominated the ecosystem.

The community similarity index between stations increased to above 50% in 2022, indicating a greater resemblance in benthic macroinvertebrate composition among stations compared to 2001. This increase in similarity may reflect a more homogeneous ecosystem structure, despite the overall decline in species richness and density.

Overall, these findings underscore the importance of maintaining water quality to prevent further degradation of benthic macroinvertebrate communities in the Ijuk River ecosystem.

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