



Integration of microrobots study into environmental education poster material as an innovation in climate change learning

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Abstract

This study examines the community structure of macrozoobenthos as bioindicators of water quality in the mangrove ecosystem of Mengkapan Village and creates a high school biology learning poster focused on environmental change teaching. Fieldwork was performed in the mangrove habitat of Mengkapan Village, Siak Regency, whereas laboratory studies were executed at the Biology Education Laboratory in University of Riau. A descriptive quantitative methodology was implemented, employing purposive sampling and applying survey and belt transect techniques along a 120 m transect extending from the shoreline inland. There were three transects at each station. Primary parameters were species composition, density, diversity index, evenness, and dominance index. The supporting parameters were temperature, pH, salinity, dissolved oxygen, substrate type, and organic matter content. Fourteen species from the Gastropoda, Bivalvia, and Crustacea were discovered, suggesting that the water quality ranged from slightly to moderately contaminated. The poster created from this research is anticipated to serve as a novel educational tool that improves students' comprehension of environmental and climate change topics while promoting ecological consciousness among high school students.

Keywords: Mengkapan Village; Macrozoobenthos; Water Quality; Poster

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Introduction

A mangrove ecosystem is an ecosystem consisting of organisms (plants and animals) that interact with environmental factors and with each other within a mangrove habitat ([Djamaluddin, 2018](#)). Mangrove habitats are often found at the meeting point between river mouths and seawater, where they serve as protectors of the land from large ocean waves. Mangroves are one of the important ecosystems in coastal areas, growing in locations still influenced by the tidal movements of seawater. According to data from [source], Riau Province is the province with the largest mangrove area and ranks third in terms of the largest mangrove coverage in Indonesia ([Ministry of Maritime Affairs and Fisheries, 2021](#)). The mangrove forest area in Riau Province covers approximately 224,895 hectares. One of the areas with a mangrove ecosystem in Riau Province is located in Mengkapan Village, Sungai Apit District, Siak Regency.

The mangrove land cover value in Mengkapan Village, based on Landsat imagery analysis from 2010 to 2020, has shown a decrease in area from 4,740.05 hectares to 249.81 hectares ([Armanda et al., 2021](#)). Mengkapan Village is generally an area where the development of the Tanjung Buton port, oil industry activities, and residential housing are being actively carried out, leading to waste disposal and the use of mangrove land as settlement areas. Tourism activities in the mangrove ecotourism area also affect the condition of the mangrove forest in Mengkapan Village. The presence of oil drilling activities, the operations of the Tanjung Buton port, household waste disposal into the water, and the large amount of garbage discarded carelessly by tourists and local residents have resulted in polluted water conditions, which will impact the biota living in the mangrove ecosystem.

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One of the biota groups associated with the mangrove ecosystem is macrozoobenthos. Macrozoobenthos plays a crucial role in the nutrient cycle at the bottom of the water. They serve as an important link in the energy flow and cycle, from planktonic algae to higher-level consumers ([Santoso & Sutanto, 2021](#)). Macrozoobenthos plays several important roles in the mangrove ecosystem, such as in the decomposition and mineralization of organic material entering the water, as well as occupying trophic levels in the food chain ([Afif et al., 2014](#)). Macrozoobenthos transfers energy from primary producers to the next trophic level. In addition, macrozoobenthos plays a role in neutralizing the aquatic environment by converting organic waste back into its food source.

Macrozoobenthos is one of the biological indicators that can be used as a reference in assessing environmental quality in various aquatic ecosystems. The reason macrozoobenthos can serve as a bioindicator of water quality is based on its life characteristics and sensitivity to environmental changes. Macrozoobenthos can be used as bioindicators because its movement is very limited, its body size is relatively large, making it easy to identify, it lives on the bottom of the water and is relatively stationary, so it is continuously exposed to the surrounding water conditions, and changes in environmental factors will affect the diversity of macrozoobenthos communities ([Roziaty et al., 2017](#)). Microrobots are increasingly popular for environmental restoration, such as water filtration, acting as navigators of aquatic environments and minimizing contaminants ([Dabbagh, et al., 2022](#)). In mangrove forest ecosystems, this technology can be used for biological monitoring using macrozoobenthos that can reduce pollution.

The issues of environmental change and water pollution can be linked to one of the learning objectives in the biology subject with the Merdeka curriculum in Phase E, Class X, regarding environmental change. Understanding biology in Phase E requires students to have the ability to create solutions to local, national, and global issues. The environmental issue concerning water pollution in the mangrove ecosystem of Mengkapan Village, linked with the community structure of macrozoobenthos as a bioindicator of water quality, will create more contextual learning based on local issues, which is expected to achieve the intended learning outcomes.

Learning about environmental change in schools is generally still abstract and does not relate to real-life situations around students, causing them to merely memorize without truly understanding ([Diana dan Winarsih, 2023](#)). This statement is supported by the results of a pre-survey conducted through interviews with high school biology teachers in Pekanbaru, who stated that during the learning process, teachers predominantly use textbooks or worksheets provided by the government, which are general in nature. The media used are not varied, and there is a lack of real-life illustrations or up-to-date information related to the topics being studied. This causes the learning process to become ineffective, less engaging, and there is insufficient feedback between students and teachers. Students' knowledge and understanding of the environmental changes around them is very limited, which is unfortunate because Riau Province has great potential for developing mangrove ecosystems for learning. Such learning conditions do not align with the expectations of the Merdeka curriculum.

Learning with the Merdeka curriculum can be developed contextually into local content according to the region's potential ([Ministry of Education and Culture, 2023](#)). Teachers are expected to be able to explore materials related to local issues in the students' environment so that the learning becomes more contextual. This needs to be done to make learning more engaging, which can enhance students' understanding of the concepts presented and motivate them to learn. However, to achieve this, it is not enough to only consider the content of the material; varied, effective, and innovative learning media are also needed so that students can receive and understand the material well during the learning process.

The use of posters in learning, linked to local issues based on research findings, can be used to introduce and convey information that illustrates the water quality conditions of the mangrove ecosystem in Mengkapan Village, based on the community structure of macrozoobenthos as a

bioindicator. The purpose of using the poster is to provide an illustration through images that closely resemble the reality of an object or situation, so that it can influence and motivate behavior and seem to provide a direct experience to those who view it ([Munsofia et al., 2021](#)). A poster, as a message delivery medium from the sender to the receiver, attracts attention, clarifies the presentation of ideas, and illustrates facts that are easily forgotten, making them easier to remember when depicted graphically or through the visualization process, thus making learning more memorable.

In learning, posters serve as enrichment material to help students understand the concept of environmental change and its impacts. The use of posters as a learning medium is beneficial for students to enhance their understanding of the content because it is supported by data, images, graphs, and materials presented in the form of summaries or key points, making it easier for students to engage their reasoning in discussing the topic to be studied. Moreover, the attractive and concise presentation of posters can motivate students to learn and make the learning experience more memorable.

Method

This research is an exploratory study with two stages: the field research stage and the poster design stage. The field research stage was conducted using a direct survey method in the mangrove forest of Mengkapan Village, and the poster design stage was carried out at the Biology Education Department, FKIP, University of Riau. The parameters in this study are divided into main and supporting parameters. The main parameters include biological parameters such as species composition, density, diversity index, evenness index, and dominance index. Additionally, supporting parameters were observed, which include physical and chemical parameters of the water obtained both in situ and ex situ, such as temperature (measured with a thermometer in situ), pH (measured with a digital water tester in situ), dissolved oxygen (measured with a DO meter in situ), salinity (measured with a digital water tester in situ), substrate type, and organic content (analyzed in the Laboratory of University of Riau).

The determination of research stations used purposive sampling technique, considering the environmental features and ecological characteristics of the mangrove ecosystem, such as community activities around the area. There are three sampling stations for macrozoobenthos: Station I is in the mangrove ecosystem area of the Tanjung Buton port, Station II is in the natural mangrove area of Dusun I Mengkapan, which is far from community activities, and Station III is in the mangrove ecotourism area of Mengkapan Village. The macrozoobenthos sampling technique used was belt transect. Samples were taken at each station by drawing a line from the shoreline to 120 meters, with three transects. Each transect had six plots measuring 20 x 20 m². Within each plot, three sub-plots measuring 2 x 2 m² were created as sampling points for macrozoobenthos.

Macrozoobenthos samples were collected by taking all types of macrozoobenthos within the 2 x 2 m² sub-plot area. Infauna macrozoobenthos samples were taken by digging the substrate to a depth of 10-15 cm using a shovel, and then sieved using a tiered strainer. Meanwhile, macrozoobenthos found on the substrate surface (epifauna) and those associated with the roots and stems of mangroves (tree fauna) were collected directly by hand (hand collecting). The collected macrozoobenthos were then preserved by being treated with 10% formalin. The benthos samples were identified at the Laboratory of the Faculty of Teacher Training and Education (FKIP), University of Riau, using taxonomic references from [Abbott \(1974\)](#) and [Gosner \(1971\)](#).

After obtaining the results of data analysis from the field research, the next phase of the study is the design of the learning poster. The poster design consists of two stages: the analysis stage and the design stage. The analysis conducted is a Merdeka curriculum analysis to determine the learning objectives that can be integrated with the research findings. The design stage consists of two designs: the design of learning tools, including the Learning Objective Flow and teaching modules, as well as the design of the poster, which is developed from the research results conducted in the field.

Results and Discussion

Composition of Macrozoobenthos Species

The species of macrozoobenthos found at each station varied. The macrozoobenthos found in the waters of the mangrove ecosystem in Mengkapan Village, Siak Regency, consisted of 14 species from three classes: Gastropoda, Bivalvia, and Crustacea, with a total of 565 individuals. The species composition of macrozoobenthos at each research station is presented in Table 1.

Table 1. Species Composition and Number of Macrozoobenthos in the Mangrove Ecosystem of Mengkapan Village

Class	Family	Species	Station			Number (ind)	Proportion (%)
			I	II	III		
Gastropoda	Ellobidae	<i>Cassidula aurisfelis</i>	16	24	19	59	10,44
		<i>Ellobium aurisjudae</i>	19	9	19	47	8,32
	Littorinidae	<i>Littoraria melanostoma</i>	0	10	22	32	5,66
		<i>Littoraria scabra</i>	0	0	24	24	4,25
	Muricidae	<i>Chicoreus capucinus</i>	0	0	15	15	2,65
		<i>Indothais gradata</i>	0	15	7	22	3,89
	Neritidae	<i>Nerita articulata</i>	45	27	0	72	12,74
	Potamididae	<i>Cerithidea quadrata</i>	29	0	0	29	5,13
		<i>Telescopium telescopium</i>	51	31	34	116	20,53
		<i>Cerithidea obtusa</i>	14	39	37	90	15,93
Bivalvia	Corbiculidae	<i>Polymesoda erosa</i>	0	12	0	12	2,12
	Glaucnomyidae	<i>Glaucnomya virens</i>	0	21	0	21	3,72
Crustacea	Sesamidae	<i>Aratus pisonii</i>	0	14	8	22	3,89
	Penaeidae	<i>Metapenaeus monoceros</i>	4	0	0	4	0,70
Total			178	202	185	565	100

Based on the observations in Table 1, the highest species composition in the waters of the mangrove ecosystem of Mengkapan Village was found in *Telescopium telescopium* at 20.53% and *Cerithidea obtusa* at 15.93%. Both of these species belong to the Potamididae family, which is one of the gastropods native to mangroves. According to [Ernawati et al \(2019\)](#), the Gastropod group native to mangroves refers to gastropod species that spend all or most of their lives in mangrove ecosystems, resulting in relatively high density. The presence of *Telescopium telescopium* and *Cerithidea obtusa*, which is higher compared to other species, is due to their grouping behavior in the water. *Telescopium telescopium* forms groups because individuals within the population respond similarly to their habitat ([Hasibuan, 2018](#)). Additionally, this is also due to the condition of the substrate, which is muddy and sandy, providing favourable conditions for the life of this organism.

The species composition of macrozoobenthos in the mangrove ecosystem of Mengkapan Village overall consists of the classes Gastropoda, Bivalvia, and Crustacea, which, based on their tolerance levels, are considered facultative macrozoobenthos. The presence of these organisms indicates water conditions that are lightly to moderately polluted. This is in line with [Wilhm \(1975\)](#) statement in [Russo \(2020\)](#) stated that ordo Odonata, filum Mollusca (Gastropod and Bivalvia class), and Crustaceans are a type of facultative organism that can survive in environments that are more harsh than those tolerated by intolerant organisms, but cannot tolerate heavily polluted environments.

Macrozoobenthos Density

Macrozoobenthos density reflects the number of macrozoobenthos individuals per unit area. The species of macrozoobenthos found in the mangrove area of Mengkapan Village are species that are resistant to high organic pollution. This is because the mangrove area receives waste from residential activities, mangrove ecotourism sites, and port areas. The differences in macrozoobenthos abundance values at each research station are also closely related to anthropogenic activities in each

area, which are the sources of organic material entering the water. The results of the macrozoobenthos density calculations at each station can be seen in Figure 2.

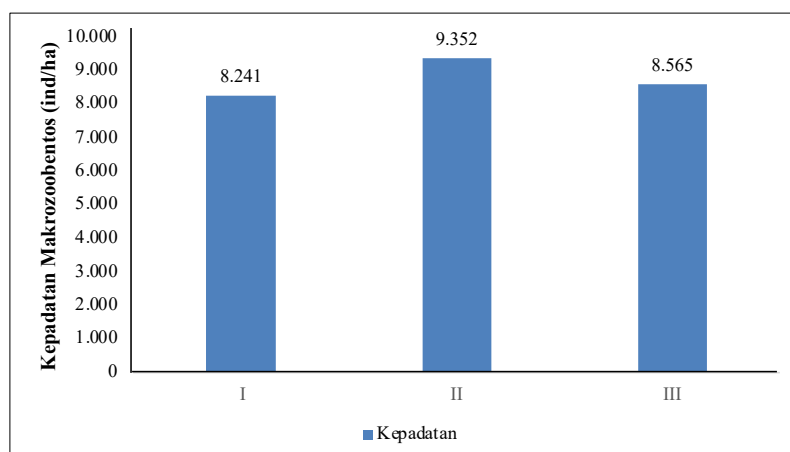


Figure 2. Macrozoobenthos Density in the Mangrove Area of Mengkapan Village, Siak Regency

The results of the macrozoobenthos density calculations in the mangrove ecosystem of Mengkapan Village show that the highest density value is found at Station II, which is 9,352 (ind/ha). This is due to the fact that the physicochemical conditions of the water at Station II are better compared to Stations I and III. Additionally, the good condition of the natural mangrove ecosystem at Station II is also one of the reasons why the density value at Station II is higher than at Stations I and III. The organic content comes from the vegetation in a particular location. The organic content will affect the density of macrozoobenthos ([Bai'un et al., 2021](#)). The decomposition of mangrove litter will be utilized by macrozoobenthos as a food source. According to [Kasmira \(2022\)](#), water quality influences macrozoobenthos density; the better the water quality, the higher the macrozoobenthos density in that water.

The macrozoobenthos density at Stations I and III shows low density values, with a density of 8,241 (ind/ha) at Station I and 8,565 (ind/ha) at Station III. The low density at Station I may be caused by the poor physicochemical environmental conditions due to high human activity around the port area. This is indicated by the measured physicochemical factors such as temperature (32.2°C), pH (6.9), and dissolved oxygen content (4.7 mg/L), which do not meet the water quality standards based on PPRI No. 22 of 2021. Station III is a mangrove ecotourism area near residential settlements, which receives waste from tourists and household waste from the surrounding community. According to [Manalu \(2023\)](#), The high level of human activity in tourist areas will cause a decrease in the density of macrozoobenthos.

Macrozoobenthos Diversity Index (H')

The diversity index values obtained in the mangrove ecosystem of Mengkapan Village at the three stations range from 1.74 to 2.20. The diversity index values at each station are shown in Table 2.

Tabel 2. Indeks keanekaragaman makrozoobentos di ekosistem mangrove Desa Mengkapan

Station	Diversity Index (H')	Category
I	1,74	Moderate
II	2,20	Moderate
III	2,08	Moderate

The diversity index values in Table 2 indicate that the macrozoobenthos diversity level in the mangrove ecosystem of Mengkapan Village is moderate. This is because the number of species found is relatively high, and the number of individuals of each species is evenly distributed, so no species dominates. The diversity index is influenced by factors such as the number of species and the distribution of individuals within each species ([Barus, 2020](#)). A moderate diversity index value indicates that the macrozoobenthos diversity is moderate, the productivity is sufficient, the ecological pressure is moderate, and the stability is moderate. The moderate stability of the macrozoobenthos community represents a condition where the community is unstable and can easily change when environmental changes occur.

A moderate diversity index indicates that the water quality in the mangrove ecosystem of Mengkapan Village has declined. The decline in water quality in the mangrove ecosystem of Mengkapan Village is caused by the input of waste from household and tourist activities, port activities, and offshore oil drilling. The various inputs of waste from anthropogenic activities have led to a decrease in the presence of species that are intolerant to high environmental pressures, which can affect the macrozoobenthos diversity index in the area. The better the water environmental conditions, the higher the biodiversity index value of the biota species, and vice versa ([Bai'un et al., 2021](#)).

Based on the species diversity index and referring to the water quality assessment by Shannon-Wiener in ([Rahmat et al., 2017](#)) the water quality assessment of the Mangrove Ecosystem of Mengkapan Village can be seen in Table 3.

Table 3. Water Quality of the Mangrove Ecosystem of Mengkapan Village, Siak Regency, Based on the Shannon-Wiener Diversity Index

Station	Water Pollution in the Mangrove Ecosystem of Mengkapan Village, Siak Regency, Based on Parameters		
	Diversity Index (H')	Criteria	Pollution Level
I	1,74	Moderate	Half Polluted
II	2,20	Moderate	Lightly Polluted
III	2,08	Moderate	Lightly Polluted

Based on the interpretation of the research results presented in Table 3, it shows that the water quality of the mangrove ecosystem in Mengkapan Village, Siak Regency, is moderately polluted to lightly polluted. Station I has the lowest diversity index with a pollution level of half polluted. This is due to the greater environmental pressure at this station compared to Stations II and III. The poor condition of the mangrove ecosystem, coupled with the activities around the port, shipping activities, and offshore oil drilling industries, results in more pollutants, which affects the macrozoobenthos. The diversity at Stations II and III tends to be higher due to the relatively good mangrove vegetation and the nutrient-rich mangrove sediments. The mangrove litter will deposit on the waterbed and continuously accumulate, becoming nutrient-rich sediment, which is an ideal habitat for the survival of macrozoobenthos ([Sabar, 2016](#)).

Evenness Index (E)

The Evenness Index (E) represents the characteristic of organisms in showing the balance of individual distribution among species within a community in a specific area. The evenness index of macrozoobenthos in the mangrove ecosystem of Mengkapan Village can be seen in Table 3.

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Table 3. Macrozoobenthos Evenness Index

Station	Evenness Index (E)	Category
I	1,74	High
II	2,20	High
III	2,08	High

The evenness index (E) values based on Table 3 at each station are close to 1. This indicates a stable community with high evenness, where the number of individuals per genus can be considered equal or not significantly different. If the value of E approaches zero, it means that the distribution of individuals per species is not equal. The macrozoobenthos evenness index is categorized as high, reflecting that no species dominate, and the distribution of individuals across species is very uniform or equal.

Dominance Index (C)

The dominance index (C) is an index that shows a condition where many individuals from the same species are present in a particular area. The macrozoobenthos dominance index in the mangrove ecosystem of Mengkapan Village can be seen in Table 4.

Table 4. Macrozoobenthos Dominance Index

Stasiun	Evenness Index (E)	Category
I	0,20	Low
II	0,12	Low
III	0,14	Low

The macrozoobenthos dominance index (C) in Mengkapan Village, Siak Regency, at each station is close to zero, meaning that no macrozoobenthos species dominate in the mangrove area of Mengkapan Village, with values ranging from 0.12 to 0.20. This value indicates that at the three research stations, no particular species dominates, and all species are evenly distributed. The result of the low dominance index analysis is consistent with the high evenness index. The evenness index approaching 1 and the dominance index approaching 0 indicate that the habitat conditions at the observation sites are relatively stable. According [Destiana et al. \(2022\)](#), the low dominance of a species in a habitat reflects that the environment is ideal for the stability and balance of the macrozoobenthos community.

Physicochemical Factors of the Water

The results of the physicochemical parameter measurements in the waters of the Mangrove Ecosystem of Mengkapan Village, Siak Regency, can be seen in Table 5.

Table 5. Physicochemical Factors of the Water

Parameters	Station			Normal Quality Standards
	I	II	III	
Temperature (°C)	32,2	29	30	28-32
pH	6,9	7,1	7,2	7-8,5
Salinity (‰)	29	24.2	26.5	s/d 34
Dissolved Oxygen (mg/L)	4,7	6,1	5,9	>5
Substrate Type	Muddy Sand	Muddy Sand	Muddy Sand	-
Organic Content (%)	6,03	8,75	7,18	-

**PPRI No. 22 of 2021 on Water Quality Standards for Marine Biota (Mangrove)*

Temperature is one of the physical parameters that plays an important role in the metabolism of aquatic organisms. Based on temperature measurements taken during the research, the lowest temperature was recorded at Station II, which was 29°C. This is because Station II is a natural mangrove area with relatively high density, resulting in lower light intensity penetrating the water. In contrast, the highest temperature was found at Station I, at 32.2°C. Station I is located near a port, and the mangrove density in this area is relatively low, allowing higher light intensity to enter the water. This condition aligns with the findings of Agustini *et al.* (2021), who stated that water temperatures in mangrove ecosystems near port areas tend to be lower, allowing higher light intensity to penetrate the water. Biological and physiological activities in aquatic ecosystems are highly influenced by temperature. The optimum temperature for macrozoobenthos is between 25–35°C, while temperatures between 36.5°C and 41°C are considered lethal for macrozoobenthos ([Bai'un et al., 2021](#)).

pH reflects the amount or activity of hydrogen ions in water, indicating the acidity or alkalinity of a water body ([Riza et al., 2015](#)). The pH measurements of the water in the mangrove area of Mengkapan Village ranged from 6.9 to 7.2. This condition can still support the life of macrozoobenthic organisms. According to the Decree of the Minister of Environment Number 22 of 2021, the standard pH quality for marine aquatic biota to support life in mangrove areas is 7–8.5. Extremely alkaline or acidic water conditions can endanger the survival of organisms because they disrupt metabolic and respiratory processes ([Hamuna et al., 2018](#)).

The salinity levels at the research site ranged between 24.2–29‰. The lowest salinity was recorded at Station II, which is located near a river and thus influenced by freshwater input. This range of salinity is still within the tolerance limits for macrozoobenthos to survive in these waters. The salinity conditions at each research station indicate ideal values for growth, in accordance with Government Regulation of the Republic of Indonesia (PPRI) No. 22 of 2021 on the implementation of environmental protection and management, which states that the standard salinity level for marine biota in seawater is up to 34‰.

Dissolved oxygen (DO) is essential for all living organisms for respiration, metabolic processes, or the exchange of substances that generate energy for growth and reproduction. According to Government Regulation of the Republic of Indonesia (PPRI) No. 22 of 2021, the standard threshold for dissolved oxygen in aquatic environments is above 5 mg/L. The DO values at Stations II and III meet this quality standard, whereas the value at Station I is still below the threshold. Dissolved oxygen content influences water quality — the higher the DO level, the greater the abundance and diversity of macrozoobenthos ([Bai'un et al., 2021](#)). The low DO level at Station I may be due to its location near a port area with intense shipping activity and proximity to offshore oil drilling industries, which release oil waste into the water. Dissolved oxygen levels in aquatic environments can decrease when oil waste discharged into the water forms a layer on the surface. This oil layer hinders the diffusion of oxygen from the air into the water, thereby reducing the amount of oxygen dissolved in the water ([Riza et al., 2015](#)).

The substrate analysis results at each research station generally showed a sandy mud substrate type. The similarity in substrate type across the three stations is due to their location along the open coastline, where tidal currents and waves carry sand particles from the sea and deposit them on the shore, in accordance with the area's coastal characteristics. Sandy mud substrates are capable of supporting the life of macrozoobenthos. According to [Saputri et al. \(2021\)](#), Mud substrates usually have a high organic matter content because they more easily accumulate organic materials present in the water.

The soil organic matter content in the mangrove ecosystem of Mengkapan Village, Siak Regency, averages 7.31%. The highest organic matter content was found at Station II, at 8.75%, followed by Station I at 7.18%, and the lowest was recorded at Station III, at 6.03%. According to Reynold (1971) as cited in [Valentino et al. \(2022\)](#), the organic matter category at Station I falls into the

low category, while Stations II and III fall into the moderate category. The higher organic content observed at Stations II and III compared to Station I is likely due to the denser mangrove vegetation at those stations. This aligns with the findings of [Isman et al. \(2018\)](#), who stated that mangroves are a major source of organic matter due to the shedding of leaves and branches, which significantly contribute to organic input in mangrove ecosystems. Additionally, the unique root structures of mangroves help trap organic material in the sediment, preventing it from easily escaping the mangrove ecosystem.

Poster Layout of Research Findings

The research findings on the structure of macrozoobenthos communities as bioindicators of water quality in the mangrove ecosystem of Mengkapan Village can be utilized in the development of an educational poster as a learning medium for the topic Environmental Changes in Grade 10 Senior High School Biology. The process of designing this learning media is divided into several stages, as follows:

1. Analysis Result

Based on the analysis of the Merdeka Curriculum, a relevant learning objective was identified that aligns with the research findings—namely, environmental change in Phase E (Grade 10 of Senior High School). One of the topics under environmental change is environmental change and water pollution. This material requires students to identify cases of water pollution, analyze the contributing factors, and understand its impacts.

The issue of water pollution found in the mangrove ecosystem of Mengkapan Village, Siak Regency, serves as an example of a local environmental problem. Data on the structure of the macrozoobenthos community, obtained through the research, are used as bioindicators of water quality, which has been affected by environmental changes due to pollutants originating from anthropogenic activities around the mangrove ecosystem. Therefore, the most suitable instructional media to be developed based on the research findings is a poster focused on the topic of water pollution.

2. Design Result

Tahap perancangan poster berdasarkan hasil penelitian adalah sebagai berikut :

a. Results of the design of the learning objectives flow (ATP) and teaching modules

Based on the learning objectives flow that has been created, the material on environmental changes and water pollution related to the research is covered in the first meeting. The research data includes the structure of the macrozoobenthos community and the results of the measurement of physical-chemical water factors, which indicate the presence of water pollution cases in the mangrove ecosystem of Desa Mengkapan, Siak Regency, caused by various human activities. The learning model integrated based on this research is the Problem Based Learning (PBL) model. The PBL model consists of five phases, which include: (1) orientation of students to the problem, (2) organizing students for learning, (3) assisting independent or group investigations, (4) developing and presenting the work results, (5) analyzing and evaluating the problem-solving process. Process skills in learning are also considered and designed according to the learning outcomes of the Merdeka curriculum, which include scientific skills such as observing, questioning and predicting, planning and conducting investigations, processing and analyzing data and information, evaluating and reflecting, and communicating the results.

b. Poster Design Results

The poster design was carried out by integrating the research data with the material on water pollution. The poster design is adapted to the format from the modification of [Atiko \(2019\)](#), as follows in Table 6:

Table 6. The structure of poster design and the description of the content

No	Poster Structure	Content
1	Poster Title	The title of this poster design is "Structure of Macrozoobentos Community as a Bioindicator of Water Quality in the Mangrove Ecosystem of Desa Mengkapan, Siak Regency." The title section also includes the author's identity, the supervising lecturer, the University of Riau logo, and the Tutwuri Handayani SMA logo.
2	Learning Objectives	The learning objectives on the poster are adjusted to the learning outcomes that can be achieved through the use of the poster as a learning medium. The learning objective on the poster is for students to be able to analyze the factors and impacts of water pollution.
3	Introduction	The introduction contains a description of the research location, which faces high environmental pressures due to various community activities, leading to environmental changes and water pollution that will affect macrozoobentos. This section also explains why macrozoobentos can be used as bioindicators.
4	Content	The content of the poster includes brief material on the factors causing water pollution, illustrated with habitat conditions, research methods, biological parameters results such as the structure of the macrozoobentos community, and the results of the physical-chemical water parameters. Based on the research results, there are differences in the number of individuals, species count, diversity index, evenness, and dominance at each research station. Research stations with natural habitat conditions and far from human activities producing waste have higher diversity and evenness indexes compared to other stations. Meanwhile, research stations with more human activity show a decrease in the number of individuals, species count, diversity index, and evenness index. The moderate diversity index indicates that the water quality is in a state of light to moderate pollution.
5	Conclusion	The conclusion on the poster summarizes the overall results of the research regarding water quality, which is categorized as lightly to moderately polluted.

The table above presents the structured components of the poster, encompassing the title, learning objectives, introduction, content, and conclusion. Each element is designed to systematically present the research findings on the role of macrozoobenthos as bioindicators of water quality in the mangrove ecosystem. This structure not only facilitates clear communication of scientific data but also enhances audience engagement in understanding environmental challenges and the significance of biodiversity conservation within the study area.

The visual representation in Figure 2 integrates the structured components outlined in Table 6 into a cohesive and informative format. It illustrates the research findings in a manner that is both scientifically accurate and visually engaging, enabling viewers to easily grasp the role of macrozoobenthos as bioindicators and the implications for water quality management in the mangrove ecosystem. The poster design based on the research results can be seen in Figure 2.



Figure 2. The developed poster based on research result

Conclusion

The macrozoobentos found in the mangrove ecosystem of Desa Mengkapan, Siak Regency, consists of 14 species from 3 classes: Gastropod, Bivalvia, and Crustacea. The diversity index ranges from 1.74 to 2.20, indicating that the water quality is lightly to moderately polluted. Based on the physical-chemical environmental parameters, the water quality still meets the normal standard values, except for temperature, pH, and DO at station I. However, overall, the condition is still capable of supporting microrobots life. The research data was developed to design a biology poster for high school grade X, focusing on the learning outcome of environmental changes, specifically water pollution.

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