Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

[biodiv] Submission Acknowledgement

1 pesan

Ahmad Dwi Setyawan via SMUJO <support@smujo.com> 30 September 2024 pukul 11.13
Balas Ke: Ahmad Dwi Setyawan <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

Rozirwan Rozirwan:

Thank you for submitting the manuscript, "Implication of Microplastics Presence in Sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia" to Biodiversitas Journal of Biological Diversity. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Submission URL: https://smujo.id/biodiv/authorDashboard/submission/19666
Username: rozirwanb

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Ahmad Dwi Setyawan

Biodiversitas Journal of Biological Diversity

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

3 pesan

Smujo Editors via SMUJO <support@smujo.com> 2 Oktober 2024 pukul 05.56
Balas Ke: Smujo Editors <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

Rozirwan Rozirwan:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Implication of Microplastics Presence in Sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia". **Complete your revision with a Table of Responses containing your answers to reviewer comments (for multiple comments) and/or enable Track Changes**.

Our decision is: Revisions Required

Reviewer A:

Dear Author(s),

Thank you very much for your submission. Here is my review.

-Abstract is too brief. An abstract is required (about 200-300 words).

-Keywords are about five words, covering scientific and local names (if any), research themes, and special methods used; and sorted from A to Z.

- Running title is about 5-7 words.

-The introduction is too brief. An introduction is required (about 600-700 words).

-Materials and Methods should emphasize the procedures and data analysis.

- Figures and tables must be mentioned in the body text

- For non mother tongue, a Certificate of Proofreading from USA, UK, Canada or Australia is needed.

- All manuscripts must be written in clear and grammatically correct English (U.S.).

-Please write all the citations and references based on the author's guidelines (https://smujo.id/biodiv/guidance-for-author), include DOI. Kindly see the example below:
e.g.,
Mukkun L, Kleden YL, Simamora AV. 2021. Detection of Spodoptera frugiperda (J.E. Smith) (Lepidoptera: Noctuidae) in maize field in East Flores District, East Nusa Tenggara Province, Indonesia. Intl J Trop Drylands 5: 20-26. DOI: 10.13057/tropdrylands/t050104.

- The usage of "et al." in long author lists will also be accepted. For example, if the number of authors is more than 20, then it is permissible to use "et al."; if there are less than 20, writing all the authors' names is recommended.

Kindly check and correct accordingly
Thank you

Recommendation: Revisions Required

Biodiversitas Journal of Biological Diversity

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id> 8 Oktober 2024 pukul 10.12
Kepada: Smujo Editors <editors@smujo.id>

Dear Editor,

We hereby submit the revised manuscript titled "Implications of Microplastic Presence in Sediments and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia". The manuscript has been revised following the Reviewer's suggestions, and we have attached the updated version for your consideration.

Thank you,
Regards
[Kutipan teks disembunyikan]
--
Dr. Rozirwan
Head of Marine Bioecology Laboratory
Department of Marine Science
Faculty of Mathematics and Natural Sciences
Sriwijaya University
Jalan Raya Palembang-Prabumulih KM 32, Indralaya
Ogan Ilir, Sumatera Selatan, Indonesia, Pos Code: 30862
Email: rozirwan@unsri.ac.id, rozirwan@gmail.com

---

2 lampiran

Author(s)` Answers to Reviewer.doc
37K

Manuscript-Revision1.doc
4525K

Smujo Editors <editors@smujo.id> 8 Oktober 2024 pukul 18.19
Kepada: Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

Pls, send it through ojs.
[Kutipan teks disembunyikan]

Author(s)` Comments to Reviewer A:

Dear Reviewer,

We sincerely thank you for taking the time to thoroughly review our manuscript and for providing such insightful feedback, which will help improve the quality of our work. In response to your comments, we have made the necessary revisions to the manuscript. Please find our detailed responses to each of your suggestions below.

With kind regards,
The Authors

We greatly appreciate the reviewer's thoughtful comments. Based on the valuable feedback provided, we have revised the manuscript accordingly to address all the points raised.

Comments	Respons
Abstract is too brief. An abstract is required (about 200-300 words).	We have carefully considered the reviewer's suggestions and have made improvements to the abstract section of the manuscript, which now contains 215 words (Page, lines 12-23).
Keywords are about five words, covering scientific and local names (if any), research themes, and special methods used; and sorted from A to Z.	We have respectfully reordered the keywords in alphabetical order (Page 1, line 2) for clarity and consistency.
Running title is about 5-7 words.	In response to the reviewer's suggestion, we have included the running title on Page 1, line 25.
The introduction is too brief. An introduction is required (about 600-700 words).	We have respectfully expanded the introduction section by approximately 600 to 700 words (Page 2, lines 49-50) to further enrich the context and background of the study.
Materials and Methods should emphasize the procedures and data analysis	We have revised the "Materials and Methods" section to improve clarity and facilitate better reader understanding (Page 2, lines 65-117).
Figures and tables must be mentioned in the body text	We have revised the manuscript to ensure that "figures and tables" are appropriately referenced within the body text.
For non mother tongue, a Certificate	We sincerely appreciate your valuable

of Proofreading from USA, UK, Canada or Australia is needed.	feedback regarding the necessity of a Certificate of Proofreading from an English-speaking country. While we acknowledge the importance of ensuring linguistic accuracy and clarity in our manuscript, we have made every effort to comply with American English guidelines and have conducted comprehensive internal reviews to enhance the quality of the text. We trust that these measures sufficiently support the clarity and comprehensibility of our work.
All manuscripts must be written in clear and grammatically correct English (U.S.).	We have made every effort to compose the English narration following American English guidelines. Additionally, we have diligently reviewed the sentences and grammar to ensure clarity and accuracy.
Please write all the citations and references based on the author's guidelines (https://smujo.id/biodiv/guidance-for-author), include DOI. Kindly see the example below: e.g., Mukkun L, Kleden YL, Simamora AV. 2021. Detection of Spodoptera frugiperda (J.E. Smith) (Lepidoptera: Noctuidae) in maize field in East Flores District, East Nusa Tenggara Province, Indonesia. Intl J Trop Drylands 5: 20-26. DOI: 10.13057/tropdrylands/t050104. The usage of "et al." in long author lists will also be accepted. For example, if the number of authors is more than 20, then it is permissible to use "et al."; if there are less than 20, writing all the authors' names is recommended.	We have revised the manuscript to improve the overall referencing format (last page)

Unsri Google Apps

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

1 pesan

Smujo Editors via SMUJO <support@smujo.com> 27 Oktober 2024 pukul 16.43
Balas Ke: Smujo Editors <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

Rozirwan Rozirwan:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Implication of microplastics presence in sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia". **Complete your revision with a Table of Responses containing your answers to reviewer comments (for multiple comments) and/or enable Track Changes**. We are waiting for your revision in the system (https://smujo.id/biodiv), do not send it via email.

Our decision is: Revisions Required

Reviewer L:

Reviewer Comments

Here is a detailed review of the manuscript:

The study’s focus on the bioaccumulation of microplastics in blood clams, particularly in a specific location like the Musi River Estuary, contributes to a growing body of research that is both timely and relevant. This localized approach can help fill a gap in current knowledge.

Introduction: Highlighting the economic significance of blood clams adds an important angle that underscores the study's relevance to local communities and ecosystems.

Suggestions for Improvement:

Briefly summarize the potential implications of your research findings earlier in the text; Simplify complex sentences where possible to ensure the information is easily digestible; Avoid redundancy in discussing microplastic accumulation, which may detract from the impact of your findings.

1) Lines 22 – 23: I suggest that the authors expand on the origins of microplastics by including other significant pathways, such as the direct release of microplastics from products like cosmetics, clothing, and industrial processes. This addition would provide a more comprehensive overview of the various sources of microplastics, enhancing the depth of the discussion on their environmental impact.

2) Lines 34 – 35: In "which leads to significant microplastic uptake," you might specify "which can lead to" to indicate that this is a possibility rather than a certainty.

3) Lines 41 – 42: The phrase "microplastics is a significant factor in the accumulation of microplastics" is repetitive. You might rephrase it for clarity, e.g., "microplastics is a significant factor contributing to their accumulation in benthic animals."

4) Lines 45 – 46: The statement "Due to high levels of anthropogenic activity, a variety of pollutants have contaminated both the watershed and the estuary" could be simplified to improve clarity. For instance: "High levels of human activity have led to various pollutants contaminating both the watershed and the estuary."

5) Line 78: The authors do not specify whether the salt used for the saline solution was filtered to remove impurities. Clarifying this detail would be beneficial, as it ensures that the solution used for density separation was free from contaminants that could affect the results. Including this information would enhance the reproducibility and accuracy of the methodology.

6) " Procedures for quality assurance and contamination prevention" Section – It is essential to include a dedicated quality control section in every stage of the study. In addition to adopting widely accepted methods for contamination prevention, it is crucial to analyze samples alongside appropriate controls. Subtracting the particles identified in the controls from the sample dataset is an indispensable measure to avoid inaccurate assessments and ensure the integrity of the results.

7) Please, pay attention to the spacing between topics and figures.

8) Images of equations can be problematic for people with visual impairments who use screen readers. You can provide a textual description or an alternative accessible format. There are tools that allow you to create equations in formats that are both visually appealing and accessible. LaTeX, for example, is a widely used language for writing scientific documents that allows you to create equations in an efficient and accessible way.

9) Suggested reorganization: To improve the flow and clarity of your paper, I recommend combining the Results and Discussion statements into a single section, titled “Results and Discussion.” This approach allows the results to be immediately contextualized and interpreted, making them easier for the reader to understand. Despite having this section in the paper, the authors separate the discussion from the results by creating a new section called "Discussion". This information can be confusing to the reader.

10) Terminology Consistency: Be consistent with the terms used to describe microplastics (e.g., “items,” “particles,” “fragments”). This will prevent confusion and improve clarity.

11) While you mention human activities contributing to microplastic pollution, a deeper exploration of local sources and their specific impacts on the estuarine ecosystem would enhance the environmental perception of your work.

12) While you compare your findings to other regions, it would be beneficial to draw more explicit connections regarding why the Musi River Estuary exhibits different levels of microplastic contamination. Discuss potential socio-economic or environmental factors influencing these differences.

13) Expand on the ecological implications of microplastic pollution, particularly how it affects local species and ecosystems. Discuss potential long-term impacts on biodiversity, food webs, and human health.

14) The risk assessment section should more clearly articulate what the identified risk values mean for local ecosystems and communities. Consider discussing the potential health risks for consumers of blood clams and the broader implications for local fisheries.

15) While you mention hydrodynamic conditions, consider elaborating on how seasonal variations or climatic events might influence microplastic distribution and accumulation in the estuary.

16) I suggest that the authors consider including recommendations for mitigating microplastic pollution based on their findings. Providing actionable insights for local stakeholders could enhance the practical relevance of the study and contribute to more effective environmental protection efforts in the region.

17) Conclude with a succinct summary of your key findings and their significance. Emphasize the urgency for monitoring and management strategies to address microplastic pollution in the Musi River Estuary.

Recommendation: Revisions Required

Biodiversitas Journal of Biological Diversity

Author(s)` Response to Reviewer L:

Dear Reviewer,

We sincerely thank you for taking the time to thoroughly review our manuscript and for providing such insightful feedback, which will help improve the quality of our work. In response to your comments, we have made the necessary revisions to the manuscript. Please find our detailed responses to each of your suggestions below.

With kind regards,
The Authors

Table of Author(s)` Response

No	Comments	Respons
1.	Lines 22 – 23: I suggest that the authors expand on the origins of microplastics by including other significant pathways, such as the direct release of microplastics from products like cosmetics, clothing, and industrial processes. This addition would provide a more comprehensive overview of the various sources of microplastics, enhancing the depth of the discussion on their environmental impact.	Thank you for your valuable feedback and insightful suggestion. In response to your recommendation, we have revised the manuscript on Lines 22–23 to include additional significant pathways for microplastic origins, such as direct releases from products like cosmetics, clothing, and industrial processes. (Now: Lines 27-40, P1) We would like to thank you for your guidance in enhancing the clarity and depth of our study.
2.	Lines 34 – 35: In "which leads to significant microplastic uptake," you might specify "which can lead to" to indicate that this is a possibility rather than a certainty	We have revised the phrase on lines 34–35 as per your recommendation. The wording now reads “which can lead to significant microplastic uptake” to better reflect the possibility rather than a certainty.
3.	Lines 41 – 42: The phrase "microplastics is a significant factor in the accumulation of microplastics" is repetitive. You might rephrase it for clarity, e.g., "microplastics is a significant factor contributing to their accumulation in benthic animals."	The suggested revision has been made to improve clarity. The phrase in lines 41–42 has been rephrased to read, "microplastics is a significant factor contributing to their accumulation in benthic animals," as per your recommendation
4.	Lines 45 – 46: The statement "Due to high levels of anthropogenic activity, a variety of pollutants have contaminated both the watershed and the estuary" could be simplified to improve clarity. For instance: "High levels of human activity have led to various pollutants contaminating both the watershed and the estuary."	We have carefully revised the manuscript to incorporate the suggested changes. Specifically, we have simplified the statement Lines 45-46 for clarity as recommended.
5.	Line 78: The authors do not specify whether the salt used for the saline solution was filtered to remove impurities. Clarifying this detail would be beneficial, as it ensures that the solution used for density separation was free from contaminants that could affect the results. Including this information would enhance the reproducibility and accuracy of the methodology.	We have carefully revised the manuscript to address your concern. We have clarified that the salt used for the saline solution was indeed filtered to remove impurities. This detail has been included to ensure that the solution used for density separation was free from contaminants, thereby enhancing the reproducibility and accuracy of our methodology. (Now: “Microplastic extraction from sediment”(Lines 89-

		103)
6.	Procedures for quality assurance and contamination prevention" Section – It is essential to include a dedicated quality control section in every stage of the study. In addition to adopting widely accepted methods for contamination prevention, it is crucial to analyze samples alongside appropriate controls. Subtracting the particles identified in the controls from the sample dataset is an indispensable measure to avoid inaccurate assessments and ensure the integrity of the results.	In the "Procedures for Quality Assurance and Prevention of Contamination" section, we have now included a dedicated quality control section, as recommended, to detail the steps taken at each stage of the study to ensure data integrity.
7.	Please, pay attention to the spacing between topics and figures.	We have carefully revised the spacing between topics and figures in accordance with your recommendations to ensure clarity and readability.
8.	Images of equations can be problematic for people with visual impairments who use screen readers. You can provide a textual description or an alternative accessible format. There are tools that allow you to create equations in formats that are both visually appealing and accessible. LaTeX, for example, is a widely used language for writing scientific documents that allows you to create equations in an efficient and accessible way.	Thank you very much for your very useful feedback on the accessibility of the equations in our manuscript. We have taken into consideration the reviewer's suggestions to ensure that the document is fully accessible, especially for readers with visual impairments. However, since the submitted file is (.doc), we are unable to enter the formulas accurately as the equation feature is not supported in this instrument. As a result, the formula is still in the form of an image. In response, we described the formula in a text statement in the manuscript. In addition, we added LaTex-based equations to the comment feature when needed for publication.
9.	Suggested reorganization: To improve the flow and clarity of your paper, I recommend combining the Results and Discussion statements into a single section, titled "Results and Discussion." This approach allows the results to be immediately contextualized and interpreted, making them easier for the reader to understand. Despite having this section in the paper, the authors separate the discussion from the results by creating a new section called "Discussion". This information can be confusing to the reader.	We have carefully revised the manuscript according to your suggestion to combine the Results and Discussion sections into a single, integrated section titled "Results and Discussion".
10.	Terminology Consistency: Be consistent with the terms used to describe microplastics (e.g., "items," "particles," "fragments"). This will prevent confusion and improve clarity.	We have revised the manuscript to ensure consistency in the terminology used to describe microplastics. Specifically, we have standardized terms (e.g., "object," "particle," and "fragment") throughout the manuscript, with the term "particle". We are conforming to our previous publications, for consistency throughout our work on microplastics.

11.	While you mention human activities contributing to microplastic pollution, a deeper exploration of local sources and their specific impacts on the estuarine ecosystem would enhance the environmental perception of your work.	we have revised the manuscript to include a more detailed analysis of the local sources contributing to microplastic contamination. We believe this additional information enhances the environmental context of the study and provides a clearer understanding of the specific impacts on the estuarine ecosystem. (Lines 205-223)
12.	While you compare your findings to other regions, it would be beneficial to draw more explicit connections regarding why the Musi River Estuary exhibits different levels of microplastic contamination. Discuss potential socio-economic or environmental factors influencing these differences.	We have revised the manuscript to address your suggestions. In the updated version, we have expanded the discussion on potential socio-economic and environmental factors that could contribute to differences in microplastic contamination levels in the Musi River Estuary compared to other areas. (Lines 244-271)
13.	Expand on the ecological implications of microplastic pollution, particularly how it affects local species and ecosystems. Discuss potential long-term impacts on biodiversity, food webs, and human health.	We have carefully revised the manuscript to expand on the ecological implications of microplastic pollution, particularly its effects on local species and ecosystems. We have included a more detailed discussion on the potential long-term impacts on biodiversity, food webs, and human health, as you recommended. (Lines 430-448)
14.	The risk assessment section should more clearly articulate what the identified risk values mean for local ecosystems and communities. Consider discussing the potential health risks for consumers of blood clams and the broader implications for local fisheries.	We have carefully revised the risk assessment section in accordance with your recommendation. The revised version now provides a clearer explanation of what the identified risk values mean for local ecosystems and communities. Additionally, we have included a discussion on the potential health risks for consumers of blood clams and elaborated on the broader implications for local fisheries. (Lines 449 - 461)
15.	While you mention hydrodynamic conditions, consider elaborating on how seasonal variations or climatic events might influence microplastic distribution and accumulation in the estuary.	We have elaborated on this aspect in the revised manuscript, discussing how these factors may influence the behavior of microplastics in estuarine environments, including the influence of seasonality. (Lines 302-321)
16.	I suggest that the authors consider including recommendations for mitigating microplastic pollution based on their findings. Providing actionable insights for local stakeholders could enhance the practical relevance of the study and contribute to more effective environmental protection efforts in the region.	As per your suggestion, we have revised the manuscript to incorporate actionable insights for local stakeholders. We believe these additions will enhance the practical relevance of the study and contribute to more effective environmental protection efforts in the region. (Lines 462-482)
17.	Conclude with a succinct summary of your key findings and their significance. Emphasize the urgency for monitoring and management strategies to address microplastic pollution in the Musi River Estuary.	A concise summary of our key findings has been provided, which emphasizes the significant presence of microplastics in sediments and blood clams in the Musi River Estuary. We also highlighted

	the urgency of implementing effective monitoring and management strategies to address the growing problem of microplastic pollution in the region. (Lines 483-493).

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

1 pesan

Smujo Editors via SMUJO <support@smujo.com> 18 November 2024 pukul 06.38
Balas Ke: Smujo Editors <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

Rozirwan Rozirwan:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Implication of microplastics presence in sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia". **Complete your revision with a Table of Responses containing your answers to reviewer comments (for multiple comments) and/or enable Track Changes**. We are waiting for your revision in the system (https://smujo.id/biodiv), do not send it via email.

Our decision is: Revisions Required

Reviewer A:

Dear author

This article needs some work. All comments are available in the text. Send the revision file along with a rebuttal letter in a separate file

Recommendation: Revisions Required

Biodiversitas Journal of Biological Diversity

A-19666 1.doc
4704K

Author(s)` Response to Reviewer :

Dear Reviewer,

We sincerely thank you for taking the time to thoroughly review our manuscript and for providing such insightful feedback, which will help improve the quality of our work. In response to your comments, we have made the necessary revisions to the manuscript. Please find our detailed responses to each of your suggestions below.

With kind regards,
The Authors

Table of Author(s)` Response

No	**Comments**	**Respons**
1.	Title in Lines 1; Title change from "Implication of microplastics presence in sediment and blood clams *Anadara granosa* (Linnaeus, 1758) (Molusca: Bivalvia) in the Musi Estuary, Indonesia " to: "Implication of microplastics presence in sediment and blood clams *Anadara granosa* (Linnaeus, 1758) (Molusca: Bivalvia) in the Musi Estuary, Indonesia	We agree with your suggested title revision and have updated it to: Implication of microplastic presence in sediment and blood clams (*Anadara granosa*, Linnaeus 1758) (Mollusca: Bivalvia) in the Musi Estuary, Indonesia."
2.	The introduction starts from: 1. General condition of the estuary ecosystem 2. The importance of macrozoobenthos as a bioindicator 3. Then go into general pollution before getting into the topic of microplastics	We have revised the introduction to follow the structure as outlined: 1. General condition of the estuary ecosystem 2. The importance of macrozoobenthos as a bioindicator 3. A discussion on general pollution, leading into the topic of microplastics. The order of the introduction has been revised significantly, as suggested by the reviewer.
3.	Lines 44; Add reference for: Blood clams *Anadara granosa* are benthic bivalves commonly consumed as seafood	Due to the change in the order of the introduction, we have rearranged the sentences to eliminate any ambiguity Lines 49: Among these, *A. granosa* is a prominent bivalve species that plays a crucial role in maintaining ecosystem stability and generating substantial economic benefits for coastal communities (Yulinda et al. 2020; Prasetiyono et al. 2022; Mahary et al. 2023). G
4.	Delete `blood clams` for the next text. Only use Anadara granosa or A. granosa	We have removed the term "blood clam" as requested and have only used it at the beginning as an introductory term. From that point onward, we refer to the species as *A. granosa*.
5.	Mention as *A. granosa* for the next text	We have removed the term "blood clam" as requested and have only used it at the beginning as an introductory term. From

		that point onward, we refer to the species as *A. granosa*.
6.	Provide all detailed location in the Table, such as coordinates dan description of the sites	We have added the coordinates and descriptions to the table as requested. Additionally, we have adjusted the numbering of the table on entry.
7.	Method Chapter: Provide all detailed references for the extraction	We have revised the manuscript to include all detailed references related to the extraction process as requested.
8.	Data analysis; Pollution Load Index; See guideline of cites	We have revised the reference writing and refer to the guidelines. Lines 203
9.	Provide the figures of sample	We have included the sample figures as requested and have updated the manuscript accordingly (Line 400).
10.	is the reference font size appropriate?	We have reviewed the font size of the references and confirmed that it complies with the journal's guidelines. If any adjustments are needed, we will be happy to make the necessary changes.

Implication of microplastics presence in sediment and blood clams ~~(~~*Anadara granosa* (Linnaeus, 1758) (Molusca: Bivalvia)~~)~~ in the Musi Estuary, Indonesia

Abstract. Microplastic pollution poses a serious risk to estuarine ecosystems, affecting sediments and benthic species. Blood clams (*Anadara granosa*) represent a significant commercial seafood product in Indonesia, including those from the Musi River Estuary. This study investigated the risks associated with microplastic contamination in sediments and blood clams (*Anadara granosa*) in the Musi River Estuary, located in South Sumatra, Indonesia. Sediment samples were extracted using sodium chloride (NaCl, 1.2 g cm^{-3}) and hydrogen peroxide (30% H_2O_2). In contrast, blood clam samples were digested with 10% KOH for microplastic extraction. The abundance and shape of microplastics were identified from both samples. Pollution risk assessment was conducted through the calculation of Pollution Load Index (PLI), Nemerow Pollution Index (NPI), and Bioconcentration Factor (BCF). The results showed the presence of microplastics in sediments, with a mean abundance of 1.31±0.41 particles/g dw, while in blood clams, it was 21.05±10.31 particles/ind. Both samples exhibited high microplastic bioaccumulation (NPI > 2), although the pollution load remained relatively low (minor category, PLI < 10). The bioconcentration factor between blood clams and sediment was determined to be 23.28, indicating that microplastics present in the sediment were absorbed by the blood clams. These findings highlight the significant bioaccumulation potential of microplastics in blood clams within the Musi River Estuary. It is important for the community and local government to establish mitigations for future microplastic management efforts.

Keywords: Bioaccumulation, blood clams, microplastics, Musi Estuary, sediment

Running title: Microplastics in Sediment and Blood Clams

INTRODUCTION

Commented [VH1]: The introduction starts from:
1.General condition of the estuary ecosystem
2. The importance of macrozoobenthos as a bioindicator
3. Then go into general pollution before getting into the topic of microplastics

Plastic waste contamination in aquatic ecosystems has become a major global issue in recent decades (Borrelle et al. 2020; Hecker et al. 2023). Over the past five decades, the widespread use of single-use plastic products has skyrocketed, leading to their fragmentation in the environment (Zhang et al. 2021; Walker and Fequet 2023). As plastics degrade, they form microplastics that range in size from 1 µm to 5 mm (Frias and Nash 2019). Various sources, including products like facial cleansers, scrubs, and toothpaste that intentionally contain these particles, introduce these microplastics into the environment (Napper et al. 2015; Praveena et al. 2018). Washing synthetic clothing releases fine fibers into water systems, significantly contributing to microplastic pollution (Belzagui and Gutiérrez-Bouzán 2022). Moreover, washing synthetic clothing releases fine fibers into water systems, significantly contributing to microplastic pollution (Gan et al. 2023). Microplastics are particularly concerning because they release toxic additives and serve as vectors for organic pollutants and heavy metals (Caruso 2019; Fu et al. 2021; Issac and Kandasubramanian 2021; Ta and Babel 2023). As a consequence, microplastics have the potential to disrupt food chains, alter nutrient cycling, change habitats, and affect the genetic composition of organisms (Thacharodi et al. 2024). Given these characteristics, microplastics pose a growing threat to ecosystems worldwide, particularly aquatic ecosystems (Patria et al. 2023).

The presence of microplastics has become pervasive in almost all global environments, including sediments (C. Wang et al. 2021). It is estimated that approximately 3.05 million tons of microplastics have been deposited in marine sediments to date (Harris et al. 2023). Estuaries are particularly vulnerable to microplastic deposition, ranking as the second largest sink for microplastics after fjords (Harris 2020). Estuaries serve as major conduits for plastic waste entering the ocean, with approximately 70% of microplastics transported through estuaries ending up in marine sediments (Frias et al. 2016). High levels of microplastics in estuarine sediments can threaten aquatic ecosystems, especially benthic organisms that depend on sediments for their habitat. Various studies around the world have shown that benthic organisms, especially bivalves, are filter feeders, which can lead to significant microplastic uptake (Ward et al. 2019; Theerachat et al. 2020; Ding et al. 2021; Bonifacio et al. 2022). Blood clams ~~(~~*Anadara granosa* (Lennaeus, 1758)~~)~~ are benthic bivalves commonly consumed as seafood (Theerachat et al. 2020). In Indonesia, these clams hold substantial economic value and contribute significantly to coastal area economies (Yulinda et al. 2020; Prasetiyono et al. 2022; Mahary et al. 2023). Due to their filter-feeding mechanism, blood clams are prone to accumulating microplastics from sediments in their digestive tracts (Fitri and Patria 2019; Saleh et al. 2023; Rahmatin et al. 2024). Consequently, the presence of microplastics in both sediment and clams raises ecological concerns and poses health risks for humans who consume these clams. .

Commented [VH2]: Add references

Blood clams are commonly found in coastal areas and estuaries across Indonesia, including the Musi River Estuary. This estuary serves as a fishing ground and a habitat for various benthic species (Rozirwan et al. 2021; Rozirwan et al. 2022). However, intense human activity has resulted in the contamination of both the watershed and the estuary with various pollutants (Rahutami et al. 2022; Rozirwan et al. 2024). Plastic contamination is one of the biggest ecosystem

Commented [VH3]: Add references

threats in these areas. Previous research has shown that the Musi River Estuary waters are polluted by microplastics, with concentrations ranging from 467.67 ± 127.84 particles/m³ during flood tide to 723.67 ± 112.05 particles/m³ during ebb tide (Diansyah et al. 2024). Additionally, harmful heavy metals like lead (Pb) and copper (Cu) have been detected on the surfaces of these microplastics (Purwiyanto et al. 2022). However, research on the presence of microplastics in sediments and their bioaccumulation in benthic species used as bioindicators remains limited. This study aims to investigate the bioaccumulation and risks of microplastic pollution in sediments and blood clams ~~(~~*A. ~~nadara~~ granosa*~~)~~ in the Musi River Estuary, Indonesia. It is expected to provide deeper insights into microplastic bioaccumulation in benthic organisms, especially blood clams, and its potential health risks for local seafood consumers.

Commented [VH4]: Delete `blood clams` for the next text. Only use Anadara granosa or A. granosa

Commented [VH5]: Mention as *A. granosa* for the next text

MATERIALS AND METHODS

Study Area and Sample Collection

Commented [VH6]: Provide all detailed location in the Table, such as coordinates dan description of the sites

The Musi River estuary, located on the east coast of South Sumatra, is where seawater from the Bangka Strait mixes with freshwater from the Musi River. The Musi River is an important area for fisheries and benthic habitats in South Sumatra, Indonesia (Rozirwan et al. 2021; Rozirwan et al. 2022). Sample sites were selected based on the flow direction and the possibility of sediment deposition in the estuary. Sediment and blood clams were collected during low tide from the Musi River Estuary, South Sumatra, Indonesia. Locations of the sampling sites are shown in Figure 1. Sediment samples were collected from ten sampling points, and a Peterson Grab was used at each station (Dwiyitno et al. 2024). Samples were placed in glass jars that had been rinsed with pure distilled water and covered using aluminum foil to avoid contamination. Samples were placed in a cool box (±4℃) for further analysis in the laboratory.

Blood clam samples (*Anadara granosa*) were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). Twenty adult blood clams (7.48–11.44 cm) were collected from fishermen's catch in the Musi River Estuary. Blood clam samples (*Anadara granosa*) were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). The mussels were rinsed with pure distilled water to remove any dirt. Blood clams were wrapped in aluminum foil and stored in a cooler at approximately 4 °C to preserve their freshness. After that, they were transported to the laboratory and frozen at -20°C before further analysis (Ding et al. 2021).

Formatted: Highlight

Formatted: Highlight

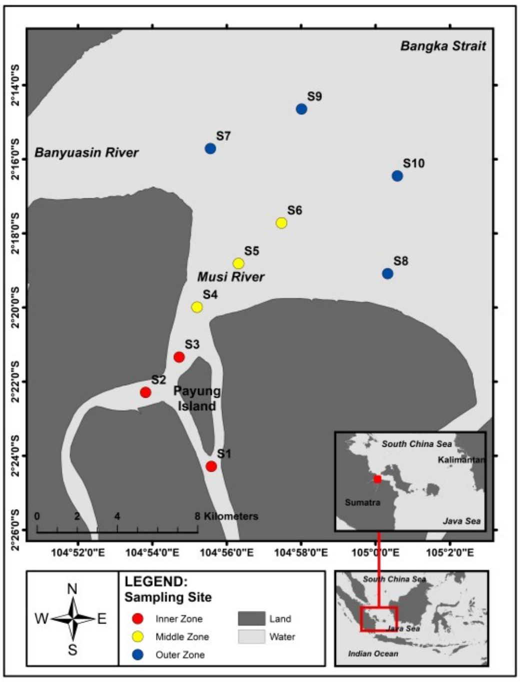

Figure 1. Study site at the Musi River Estuary, Indonesia

Microplastic extraction from sediment

Commented [VH7]: Provide all detailed references for the extraction

Microplastics in sediments were extracted using methods of density separation and organic matter removal. A total of 500 g of wet sediment samples were placed in a beaker glass covered with aluminum foil. The samples were dried in an oven at 60 ℃ for 48 hours, or until they reached a constant mass. The sediment samples were pulverized and sieved through a 5 mm steel sieve. A portion of 100 g of dried sediment was taken from the sieve, placed into a glass cup, and covered with aluminum foil to prevent external contamination. The sample was suspended in 400 mL of saturated NaCl solution (1.2 g cm^{-3}), which is four times the sample weight, using a magnetic stirrer. This NaCl solution was prepared by dissolving pure NaCl crystals (Merck Millipore EMSURE®) in filtered distilled water that was free from contaminants. The selection of a NaCl solution for the separation of microplastics from sediments was based on the premise that this method is cost-effective and environmentally friendly (Perumal and Muthuramalingam 2022). Stirring was carried out for 5 minutes until completely dissolved, and the mixture was allowed to stand for 1 hour. After one hour, 10 mL of 30% H_2O_2 was added to assist in the breakdown of organic matter, followed by stirring for an additional five minutes. Hydrogen peroxide (H_2O_2) is commonly used in similar studies and is regarded as highly effective for organic matter removal (Lee et al. 2023). The sample was allowed to stand for 24 hours, covered with aluminum foil. The samples were then filtered using the Whatman No. 42 filter paper (mesh size 0.45 µm, Φ = 90 mm), assisted by a vacuum pump at 17 kPa to isolate the microplastics. The collected samples were deposited into petri dishes for identification.

Microplastic extraction from blood clams

Commented [VH8]: Provide all detailed references for the extraction

The previously frozen blood clam samples were defrosted under controlled conditions at room temperature (± 25℃) for 1 hour. After the ice melted, the blood clams were washed with pure distilled water to eliminate contamination from other objects, such as sediment. The length and wet weight of the blood clams were measured using an analytical balance (0.01 g). The digestive tract was carefully removed from the blood clams using sterile stainless steel utensils that had been rinsed with distilled water. The extraction of microplastics from the digestive tract of the blood clams was adapted from previous studies (Ding et al. 2018; Ding et al. 2021). The digestive tract was transferred into an Erlenmeyer flask, and 100 mL of KOH solution (10%) was added. The use of KOH is regarded as a more efficacious method for the digestion of biological material, and it has no impact on the integrity of the plastic polymer (Karami et al. 2017). The sample was covered with aluminum foil and stirred for 5 minutes using a 150 rpm magnetic stirrer. The supernatant was incubated at room temperature (±25ºC) until complete digestion of organic matter occurred. The sample was then filtered through Whatman 42 filter paper (mesh size 0.45 µm, Φ = 90 mm) to isolate microplastic. The filter paper was dried in an oven at 40℃ for 5 hours and stored in petri dishes for subsequent identification of microplastic content.

Microplastic identification and quantification

Commented [VH9]: Provide all detailed references for the extraction

Identification and quantification of microplastics from sediments and blood clam were performed using the same method. Microplastic identification was performed using an Olympus CX23 microscope with 10 x 10 or 4 x 10 magnification to visually detect microplastics. The filter paper was observed closely and carefully to avoid contaminants that could enter the filter paper. Microplastics were identified based on the number and form of microplastics (fragment, film, fiber, and foam). The data obtained were recorded by sample type and station/individual for statistical purposes. To prevent contamination, personnel wear cotton lab coats, latex gloves, and cotton masks. Furthermore, access to the detection room is restricted to prevent outside contact during observations.

Procedures for quality assurance and contamination prevention

Commented [VH10]: Provide all detailed references for the extraction

The quality and contamination control measures were implemented to prevent any alterations to the microplastics in the samples. Before sampling, glass jars and aluminum foil were rinsed with filtered distilled water. Although the samples were in a cool box, they were stored in a place that was not exposed to direct sunlight to keep the samples in good condition. Personnel are also required to wear latex gloves during sampling. During the study, from sampling to laboratory analysis, the use of plastic equipment was minimized to avoid unintentional fragmentation of the microplastics. The distilled water used was filtered with filter paper (0.45 µm,) to prevent microplastics from entering our materials. All equipment was washed with filtered distilled water to remove potential contamination from external particles. We prepared two controls by filtering each solution we used to avoid contaminants from materials, equipment, and air. No microplastics were found contaminating the instrument. The sterilized equipment was wrapped in aluminum foil to prevent any input of contaminants from outside. Laboratory personnel were required to wear latex gloves, lab coats, and masks throughout the analysis. Access to the laboratory was restricted during the analysis to minimize external interference that could lead to protocol errors.

Data analysis

Pollution Load Index (PLI)

PLI was calculated using a pollutant load approach, which assesses the total concentration of contaminants relative to a baseline level, to evaluate its significance. Equations were utilized to quantify the level of microplastic pollution in both sediments and the blood clam population in the Musi River Estuary (G. Wang et al. 2021).

Commented [VH11]: See guideline of cites

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics 27. Descriptive statistics, including total, mean, standard deviation, percentage, minimum, and maximum, were utilized to assess data variation. A one-way ANOVA was applied to analyze differences in microplastic abundance between estuarine zones when the data met normality assumptions. For non-normal data, the Kruskal-Wallis test was employed to assess the significance of differences between zones. All tests were carried out with a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Commented [VH12]: Provide the figures of sample

Microplastic presence in sediment from Musi River Estuary

The results of this study indicate that microplastics were detected at all sampling stations, as shown in Figure 2. A total of 1,308 microplastic particles were identified, with concentrations ranging from 66 to 178 particles per 100 g of dry sediment (dry weight, dw). The average abundance of microplastics was 1.31 ± 0.41 particles/g dw, with the highest concentration found at station S1 (1.78 particles/g dw) and the lowest at station S8 (0.66 particles/g dw). High levels of human activity in the upstream area of Muara Musi, which flows downstream to the estuary and ultimately into the ocean, are responsible for the presence of microplastics (Rozirwan et al. 2021; Diansyah et al. 2024). Urban activities in close proximity to the Musi River Watershed, particularly in Palembang City, significantly contribute to the generation of plastic waste. Increased population density near riverbanks enhances the potential for plastic pollution. Furthermore, population density is a crucial factor in the entry of microplastics into rivers (Eo et al. 2023; Dwiyitno et al. 2024). As a result, plastic pollutants from domestic activities, such as the disposal of food packaging and plastic bags, can be transported through stormwater drains and eventually end up in rivers (Kunz et al. 2023). Fishing activities around Muara Musi can contribute to microplastic pollution, primarily through fibers released from fishing nets (Z. Li et al. 2022; Fauziyah et al. 2023). This increases anthropogenic pressure at river mouths, which can lead to greater accumulation of microplastics (Castro-Jiménez et al. 2024). Additionally, tidal fluctuation influences water flow, which facilitates the deposition of microplastics in sediment at these locations (Harris 2020). The findings of this study indicate that anthropogenic activities are responsible for high levels of microplastic deposition in the sediments of Musi Estuary. Microplastic particles that accumulate in sediments serve as a habitat for benthic organisms, which can have long-term implications for ecosystem health and balance (Rahmatin et al. 2024). As vectors for pollutants, microplastics can exacerbate toxicity, potentially endangering various populations (Caruso 2019; Fu et al. 2021; Issac and Kandasubramanian 2021; Ta and Babel 2023). Furthermore, the processes of bioaccumulation and biomagnification in benthic organisms present heightened risks to these animals, potentially leading to human consumption (Unuofin and Igwaran 2023). Therefore, it is crucial for local governments to address the handling and prevention of further microplastic accumulation.

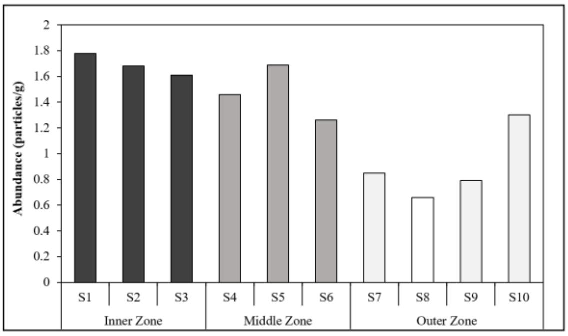

Figure 2. Distribution of microplastics from sediments in Musi Estuary, Indonesia.

stricter waste management practices, particularly for plastic disposal, to reduce further contamination. A comprehensive strategy is essential to controlling plastic waste throughout the river system—from source to estuary. Effective measures should include coordinated waste management practices, public education on the impact of pollution, and cross-sector collaboration to preserve estuarine health. Such initiatives are crucial to protecting ecosystem health and sustaining local fisheries, ensuring these resources continue to support community well-being.

ACKNOWLEDGEMENTS

The authors disclose receipt of the following financial support for the research, authorship, and publication of this article: Directorate of Research, Technology, and Community Service Directorate General of Higher Education, Research, and Technology under the Contract for Implementation of the State Higher Education Operational Assistance Program Research Program for Fiscal Year 2024 Number: 090/E5/PG.02.00.PL/2024.

REFERENCES

Commented [VH13]: is the reference font size appropriate?

Abd Rahman NN, Mazlan N, Shukhairi SS, Nazahuddin MNA, Shawel AS, Harun H, Baktir A. 2024. Evaluation of the microplastics in bivalves and water column at Pantai Teluk Likas, North Borneo, Malaysia. Environ Sci Pollut Res 31 (15): 23178–23192. DOI: 10.1007/s11356-024-32628-z.

Abelouah MR, Ben-Haddad M, Hajji S, Nouj N, Ouheddou M, Mghili B, De-la-Torre GE, Costa LL, Banni M, Ait Alla A. 2024. Exploring marine biofouling on anthropogenic litter in the Atlantic coastline of Morocco. Mar Pollut Bull 199 (December 2023): 115938. DOI: 10.1016/j.marpolbul.2023.115938.

Alam MJ, Shammi M, Tareq SM. 2023. Distribution of microplastics in shoreline water and sediment of the Ganges River Basin to Meghna Estuary in Bangladesh. Ecotoxicol Environ Saf 266: 115537. DOI: 10.1016/j.ecoenv.2023.115537.

Barnes DKA, Galgani F, Thompson RC, Barlaz M. 2009. Accumulation and fragmentation of plastic debris in global environments. Philos Trans R Soc B Biol Sci 364 (1526): 1985–1998. DOI: 10.1098/rstb.2008.0205.

Barrientos M, Vásquez Lavín F, Ponce Oliva RD, Nayga RM, Gelcich S. 2024. Microplastics in seafood: Consumer preferences and valuation for mitigation technologies. Food Res Int 187: 114342. DOI: 10.1016/j.foodres.2024.114342.

Bayo J, Rojo D, Olmos S. 2022. Weathering indices of microplastics along marine and coastal sediments from the harbor of Cartagena (Spain) and its adjoining urban beach. Mar Pollut Bull 178 (February): 113647. DOI: 10.1016/j.marpolbul.2022.113647.

Belzagui F, Gutiérrez-Bouzán C. 2022. Review on alternatives for the reduction of textile microfibers emission to water. J Environ Manage 317: 115347. DOI: 10.1016/j.jenvman.2022.115347.

Bonifacio PSP, Metillo EB, Romano EF. 2022. Microplastic in Sediments and Ingestion Rates in Three Edible Bivalve Mollusc Species in a Southern Philippine Estuary. Water Air Soil Pollut 233 (11):. DOI: 10.1007/s11270-022-05926-w.

Borrelle SB, Ringma J, Law KL, Monnahan CC, Lebreton L, McGivern A, Murphy E, Jambeck J, Leonard GH, Hilleary MA, et al. 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science (80-) 369 (6510): 1515–1518. DOI: 10.1126/science.aba3656.

Caruso G. 2019. Microplastics as vectors of contaminants. Mar Pollut Bull 146: 921–924. DOI: 10.1016/j.marpolbul.2019.07.052.

Castro-Jiménez J, Aminot Y, Bely N, Pollono C, Idjaton BIT, Bizzozero L, Pierre-Duplessix O, Phuong NN, Gasperi J. 2024. Organophosphate ester additives and microplastics in benthic compartments from the Loire estuary (French Atlantic coast). Mar Pollut Bull 201 (February): DOI: 10.1016/j.marpolbul.2024.116256.

Cheng Z, Ma Y, Fan X, Wang Q, Liu Y, You Z. 2024. Historical behaviors of microplastic in estuarine and riverine reservoir sediment. Mar Pollut Bull 202 (September 2023): DOI: 10.1016/j.marpolbul.2024.116331.

Costa MB da, Otegui MBP, Zamprogno GC, Caniçali FB, dos Reis Cozer C, Pelletier E, Graceli JB. 2023. Abundance, composition, and distribution of microplastics in intertidal sediment and soft tissues of four species of Bivalvia from Southeast Brazilian urban beaches. Sci Total Environ 857 (October 2022): 159352. DOI: 10.1016/j.scitotenv.2022.159352.

Dai L, Wang Z, Guo T, Hu L, Chen Y, Chen C, Yu G, Ma LQ, Chen J. 2022. Pollution characteristics and source analysis of microplastics in the Qiantang River in southeastern China. Chemosphere 293: 133576. DOI: 10.1016/j.chemosphere.2022.133576.

Diansyah G, Rozirwan, Rahman MA, Nugroho RY, Syakti AD. 2024. Dynamics of microplastic abundance under tidal fluctuation in Musi estuary, Indonesia. Mar Pollut Bull 203: 116431. DOI: doi.org/10.1016/j.marpolbul.2024.116431.

Ding J-F, LI J-X, Sun C-J, He C-F, Jiang F-H, Gao F-L, Zheng L. 2018. Separation and Identification of Microplastics in Digestive System of Bivalves. Chinese J Anal Chem 46 (5): 690–697. DOI: 10.1016/S1872-2040(18)61086-2.

Ding J, Sun C, He C, Li J, Ju P, Li F. 2021. Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. Sci Total Environ 782: 146830. DOI: 10.1016/j.scitotenv.2021.146830.

Dwiyitno D, Schwanen C, Januar HI, Ariyani F, Irianto HE, Schwarzbauer J. 2024. Microplastic profile in the sediment of Jakarta Bay estuary, Indonesia: Characterization based on size fraction and the potential risk to the ecosystem. Reg Stud Mar Sci 73 (November 2023): 103465. DOI: 10.1016/j.rsma.2024.103465.

Eo S, Hong SH, Cho Y, Song YK, Han GM, Shim WJ. 2023. Spatial distribution and historical trend of microplastic pollution in sediments from enclosed bays of South Korea. Mar Pollut Bull 193 (May): 115121. DOI: 10.1016/j.marpolbul.2023.115121.

Fauziyah, Nurjuliasti Ningsih E, Arnando E, Fatimah, Agustriani F, Supriyadi F. 2023. Effect of hauling and soaking time of stationary lift nets on fish aggregation using a hydroacoustic monitoring approach. Egypt J Aquat Res 49 (3): 339–346. DOI: 10.1016/j.ejar.2023.05.003.

Feng Q, An C, Chen Z, Lee K, Wang Z. 2023. Identification of the driving factors of microplastic load and morphology in estuaries for improving monitoring and management strategies: A global meta-analysis. Environ Pollut 333: 122014. DOI: 10.1016/j.envpol.2023.122014.

Feng Q, Chen Z, An C, Yang X, Wang Z. 2023. Tide-induced infiltration and resuspension of microplastics in shorelines: Insights from tidal tank experiments. Water Res 236: 119970. DOI: 10.1016/j.watres.2023.119970.

Firdaus M, Trihadiningrum Y, Lestari P. 2020. Microplastic pollution in the sediment of Jagir Estuary, Surabaya City, Indonesia. Mar Pollut Bull 150: 110790. DOI: 10.1016/j.marpolbul.2019.110790.

Fitri S, Patria MP. 2019. Microplastic contamination on Anadara granosa Linnaeus 1758 in Pangkal Babu mangrove forest area, Tanjung Jabung Barat district, Jambi. J Phys Conf Ser 1282 (1):. DOI: 10.1088/1742-6596/1282/1/012109.

Frias JPGL, Gago J, Otero V, Sobral P. 2016. Microplastics in coastal sediments from Southern Portuguese shelf waters. Mar Environ Res 114: 24–30. DOI: 10.1016/j.marenvres.2015.12.006.

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

1 pesan

Smujo Editors via SMUJO <support@smujo.com> 18 Januari 2025 pukul 20.37
Balas Ke: Smujo Editors <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

Rozirwan Rozirwan:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Implication of microplastics presence in sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia". **Complete your revision with a Table of Responses containing your answers to reviewer comments (for multiple comments) and/or enable Track Changes**. We are waiting for your revision in the system (https://smujo.id/biodiv), do not send it via email.

Our decision is: Revisions Required

Reviewer A:

This article has interesting and structured content but needs some revision. All suggestions are available in the text. Send revised files accompanied by track changes and a letter of objection in a separate file

Recommendation: Revisions Required

Biodiversitas Journal of Biological Diversity

A-19666-Article Text-1148787-1-4-20250116.doc
5484K

Author(s)` Response to Reviewer :

Dear Reviewer,

We sincerely appreciate your time and effort in reviewing our manuscript and providing valuable feedback. Your insightful comments have been instrumental in improving the quality of our work. In response, we have carefully revised the manuscript accordingly. Please find our detailed responses to each of your suggestions below.

With kind regards,
The Author (s)

Table of Author(s)` Response

No	Comments	Respons
1.	Add references in Introduction	Thank you for your valuable suggestion. We have added relevant references in the Introduction section to support our statements and provide a stronger foundation for our study **(Lines 29-41).**
2.	Need justification and reference that this species is also a food source for local communities	We have provided justification and added relevant references to support that this species is a food source for local communities. The revised manuscript now includes citations highlighting its consumption and nutritional importance **(Lines 49-50).**
3.	Full name for the start of the sentence	Thank you for your comment. We have revised the manuscript to ensure that the full scientific name, *Anadara granosa*, is used at the beginning of sentences, while the abbreviated form (*A. granosa*) is used appropriately thereafter **(Every occurrence of *Anadara granosa* at the beginning of a sentence)**
4.	Add a brief description of the conditions of each site	We have added a brief description of the environmental conditions in each sampling zone in the revised manuscript **(Lines 103-104).**
5.	Provide the figure of general condition of the sampling site	We have included a figure illustrating the general environmental conditions of the sampling site in the revised manuscript. **(Lines 247-250).**
6.	Add references in last result	We have added relevant references in result section to support our statements and provide a stronger foundation for our study **(Lines 495-514)**
7.	See guideline of references	We have revised the references to ensure they comply with the journal's guidelines **(Lines 523-Last)**

COVERING LETTER

Dear **Editor-in-Chief,**

I herewith enclosed a research article,

- ☑ The submission has not been previously published, nor is it before another journal for consideration (or an explanation has been provided in Comments to the Editor).
- ☑ The submission file is in OpenOffice, Microsoft Word (DOC, not DOCX), or RTF document file format.
- ☑ The text is single-spaced; uses a 10-point font; employs italics, rather than underlining (except with URL addresses); and all illustrations, figures, and tables are placed within the text at the appropriate points, rather than at the end.
- ☑ The text adheres to the stylistic and bibliographic requirements outlined in the Author Guidelines.
- ☑ Most of the references come from current scientific journals (c. 80% published in the last 10 years), except for taxonomic papers.
- ☑ Where available, DOIs for the references have been provided.
- ☑ When available, a certificate for proofreading is included.

SUBMISSION CHECKLIST

Ensure that the following items are present:

The first corresponding author must be accompanied with contact details:

- ☑ E-mail address
- ☑ Full postal address (incl street name and number (location), city, postal code, state/province, country)
- ☑ Phone and facsimile numbers (incl country phone code)

All necessary files have been uploaded, and contain:

- ☑ Keywords
- ☑ Running titles
- ☑ All figure captions
- ☑ All tables (incl title and note/description)

Further considerations

- ☑ Manuscript has been "spell & grammar-checked" Better, if it is revised by a professional science editor or a native English speaker
- ☑ References are in the correct format for this journal
- ☑ All references mentioned in the Reference list are cited in the text, and vice versa
- ☑ Colored figures are only used if the information in the text may be losing without those images
- ☑ Charts (graphs and diagrams) are drawn in black and white images; use shading to differentiate

Title:

Implication of microplastic presence in sediment and blood clams *Anadara granosa* (Linnaeus, 1758) (Mollusca: Bivalvia) in the Musi Estuary, Indonesia

Author(s) name:

M. AKBAR RAHMAN[1], ICA DELYA [2], ROZIRWAN[2♥], WIKE EKA AYU PUTRI[2], GUSTI DIANSYAH[2], MELKI [2]

Address

(Fill in your institution's name and address, your personal cellular phone and email)

[1]Environmental Management Study Program, Graduate Program, Universitas Sriwijaya, Palembang 30139, South Sumatra, Indonesia

[2]Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, Ogan Ilir 30662, South Sumatra, Indonesia. Tel./fax.: +62-813-7171-1885, ♥email: rozirwan@unsri.ac.id

For possibility publication on the journal:

(fill in *Biodiversitas* or *Nusantara Bioscience* or *mention the others*)

- [x] Biodiversitas Journal of Biological Diversity
- [ ] Nusantara Bioscience
- [ ] Prosiding Seminar Nasional Masyarakat Biodiversitas Indonesia
- [ ] Asian Journal of Agriculture
- [ ] Asian Journal of Ethnobiology
- [ ] Asian Journal of Forestry
- [ ] Asian Journal of Natural Product Biochemistry
- [ ] Asian Journal of Tropical Biotechnology
- [ ] International Journal of Bonorowo Wetlands
- [ ] Cell Biology and Development
- [ ] Indo Pacific Journal of Ocean Life
- [ ] International Journal of Tropical Drylands

Novelty:

(state your claimed novelty of the findings versus current knowledge)

This research is groundbreaking because there is currently no information available on the abundance of microplastics in sediments of the Musi Estuary, Indonesia. This article provides a comprehensive review of recent research on microplastics in the sediments of the Musi Estuary and their impact on benthic animals (*Anadara granosa*), one of the seafood from the Musi Estuary.

Statements:

This manuscript has not been published and is not under consideration for publication in any other journal or any other type of publication (including web hosting) either by me or any of my co-authors.
Author (s) has been read and agreed to the Ethical Guidelines.

List of five potential reviewers

(Fill in names of five potential reviewers **that agree to review your manuscpt** and their **email** addresses. He/she should have Scopus ID and come from different institution with the authors; and from at least three different countries)

1. Mohamad Fawzi Mahomoodally
Department of Health Sciences, Faculty of Science, University of Mauritius, 230 Réduit, Mauritius
Email f.mahomoodally@uom.ac.mu
Scopus ID: 9537009000
His skills and expertise in Phytochemicals, Natural Products, and Medicinal Plants are very benefical for reviewing our articles

2. Muthu Thiruvengadam, Ph.D
Department of Applied Bioscience, Konkuk University, Seoul
Email muthu@konkuk.ac.kr
Scopus ID: 13606231700
His skills and expertise in Natural Product, Medicinal and Pharmaceutical, Drug Discovery is very helpful for reviewing our articles

3. Benjamin Boucherle, Ph.D
Université Grenoble Alpes · Departement de Pharmacochimie Moléculaire
His skills and expertise in Natural Product, Medicinal and Pharmaceutical, Drug Discovery is very helpful for reviewing our articles
Benjamin.boucherle@univ-grenoble-alpes.fr
Scopus ID: 19638352500

4. Rodrigo Egydio Barreto, Ph.D
São Paulo State University, Departamento de Fisiologia, Centro De Aquicultura Da UNESP
His skills and expertise in marine biology are very helpful for reviewing our articles
rodrigo.egydio@unesp.br
Scopus ID: 7004866217

5. Prof. Dr. Bintal Amin
Marine Science Department, Faculty of fisheries and marine Science, University of Riau
bintal.amin@lecturer.unri.ac.id
Scopus ID: 23491429700

Place and date:

Palembang, September 30, 2024

Sincerely yours,
(fill in your name, no need scanned autograph)

Rozirwan

Implication of microplastic presence in sediment and blood clams *Anadara granosa* (Linnaeus, 1758) (Mollusca: Bivalvia) in the Musi Estuary, Indonesia

M. AKBAR RAHMAN[1], ICA DELYA[2], ROZIRWAN[2♥], WIKE EKA AYU PUTRI[2], GUSTI DIANSYAH[2], MELKI[2]

[1]Environmental Management Study Program, Graduate Program, Universitas Sriwijaya, Palembang 30139, South Sumatra, Indonesia
[2]Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, Ogan Ilir 30662, South Sumatra, Indonesia.
Tel./fax.: +62-813-7171-1885, ♥email: rozirwan@unsri.ac.id

Manuscript received: 30 September 2024. Revision accepted: .... 2024.

Abstract. Microplastic pollution poses a serious risk to estuarine ecosystems, affecting sediments and benthic species. Blood clams (*Anadara granosa* Linnaeus, 1758; Mollusca: Bivalvia) represent a significant commercial seafood product in Indonesia, including those from the Musi Estuary. This study investigated the risks associated with microplastic contamination in sediments and *A. granosa* in the Musi Estuary, located in South Sumatra, Indonesia. Sediment samples were extracted using sodium chloride (NaCl, 1.2 g cm^{-3}) and hydrogen peroxide (30% H_2O_2). In contrast, *A. granosa* samples were digested with 10% KOH for microplastic extraction. The abundance and shape of microplastics were analyzed from both samples. Pollution risk assessment was conducted through the calculation of the Pollution Load Index (PLI), Nemerow Pollution Index (NPI), and Bioconcentration Factor (BCF). The results revelved the presence of microplastics in sediments, with a mean abundance of 1.31 ± 0.41 particles/g dw, while in *A. granosa*, it was 21.05 ± 10.31 particles/ind. Both samples exhibited high microplastic bioaccumulation (NPI > 2), although the pollution load remained relatively low (minor category, PLI < 10). The bioconcentration factor between *A. granosa* and sediment was determined to be 23.28, indicating that microplastics present in the sediment were absorbed by the *A. granosa*. These findings highlight the significant bioaccumulation potential of microplastics in blood clams within the Musi Estuary. It is crucial for the local community and government to establish mitigations for future microplastic management efforts.

Keywords: Bioaccumulation, blood clams, microplastics, Musi Estuary, sediment

Running title: Microplastics in sediment and blood clams

INTRODUCTION

River estuaries are intricate and dynamic ecosystems that play a vital role in ecological sustainability and support a variety of socio-economic activities (Boerema and Meire 2017; Retnaningdyah et al. 2022). These ecosystems provide essential habitats for diverse species and act as focal points for human activities, including urbanization, recreation, and commercial enterprises (Lonsdale et al. 2022). Among the major estuaries in Sumatra, the Musi Estuary holds significant ecological and economic importance (Sudradjat et al. 2024; Surbakti et al. 2023). It serves as a critical habitat for various fish species and benthic organisms, which in turn sustain the livelihoods of local communities through the utilization of water resources (Fauziyah et al. 2022; Rozirwan, Fauziyah, Wulandari, et al. 2022; Rozirwan et al. 2021; Fauziyah et al. 2023). Nevertheless, the intensification of human activities within and surrounding the Musi Estuary has resulted in significant environmental deterioration (Maherlsa et al. 2019).Major contributors to this issue include heavy metal and microplastic contamination, which pose a substantial threat to ecosystem health (Diansyah et al. 2024; Rahutami et al. 2022; Rozirwan et al. 2024; Purwiyanto et al. 2022; Fitria et al. 2023; Rozirwan, Khotimah, et al. 2023). These pollutants endanger the ecological equilibrium of the estuary, with the potential to affect its biodiversity and the livelihoods dependent upon it.

Macrozoobenthos are considered pivotal components in preserving the equilibrium of estuarine ecosystems (Isroni et al. 2023; Sari et al. 2022; Rimadiyani et al. 2019). These organisms play a crucial role in the food web and nutrient cycling, thereby supporting a variety of marine species (Griffiths et al. 2017). Moreover, macrozoobenthos are highly sensitive to environmental changes, making them reliable bioindicators of ecological degradation (Sahidin et al. 2018). Research worldwide highlights that macrozoobenthos, including bivalves such as blood clams (*Anadara granosa* Linnaeus, 1758; Mollusca: Bivalvia) are often used as bioindicators because they can take in and store pollutants from their environment through filter-feeding(Ding J et al. 2021; Ward et al. 2019; Bonifacio et al. 2022; Saleh et al. 2023; Fitri and Patria 2019; Rahmatin et al. 2024). *Anadara granosa* is widely consumed by the general public as a nutrient-rich seafood, particularly among local communities (Rozirwan, Nugroho, et al. 2022; Rozirwan, Ramadani, et al. 2023) Among these, *A. granosa* is a prominent bivalve species that plays a crucial role in maintaining ecosystem stability and generating substantial economic benefits for coastal communities (Prasetiyono et al. 2022; Yulinda et al. 2020; Mahary et al. 2023). Given its ecological importance and economic value within coastal and estuarine systems, it is imperative to investigate pollutant contamination in *A. granosa* to comprehensively understand the broader impacts of environmental pollution.

Various pollutants, including heavy metals, hydrocarbons, pesticides, and microplastics, have been identified as significant contaminants of estuarine ecosystems, with many of these pollutants accumulating in sediments (Kılıç et al. 2023; Han et al. 2024; Jacq et al. 2024; Zhao J et al. 2015). Among these, plastic pollution has emerged as a critical concern due to its pervasive impact on aquatic environments (Hecker et al. 2023; Borrelle et al. 2020). Over the last five decades, the widespread reliance on single-use plastics has led to extensive accumulation and fragmentation of plastic materials across diverse ecosystems (Walker and Fequet 2023; Zhang K et al. 2021). As plastics degrade, they break down into microplastics, defined as particles ranging in size from 1 µm to 5 mm (Frias and Nash 2019). These microplastics enter aquatic ecosystems through various pathways, such as the fragmentation of discarded plastic products, the release of synthetic fibers during washing, and the intentional addition of microbeads in personal care products (Belzagui and Gutiérrez-Bouzán 2022; Gan et al. 2023; Napper et al. 2015; Praveena et al. 2018). Microplastics pose multiple threats by releasing toxic additives and acting as carriers of hazardous organic pollutants and heavy metals (Caruso 2019; Issac and Kandasubramanian 2021; Fu et al. 2021; Ta and Babel 2023). These impacts are multifaceted, disrupting food webs, altering nutrient cycles, modifying habitats, and potentially inducing genetic changes in aquatic organisms (Thacharodi et al. 2024).

Prior research has quantified microplastic concentrations in the waters of the Musi Estuary, with reported levels of 467.67 ± 127.84 particles/m³ during flood tide and 723.67 ± 112.05 particles/m³ at ebb tide (Diansyah et al. 2024). These microplastics are frequently associated with toxic heavy metals, such as lead (Pb) and copper (Cu), which exacerbate their harmful environmental effects (Purwiyanto et al. 2022). In the water column, microplastics tend to settle into estuarine sediments, which have been identified as the second-largest global reservoir for microplastics after fjords (Harris 2020). The accumulation of microplastics in estuarine sediments poses significant ecological challenges, particularly due to their ingestion by benthic organisms, including *Anadara granosa* (Mohan et al. 2024; Saleh et al. 2023; Fitri and Patria 2019; Rahmatin et al. 2024). While numerous studies have examined microplastic concentrations in the water column, research on their distribution in sediments and bioaccumulation in benthic species, particularly Anadara granosa, remains limited..

This study aims to investigate the bioaccumulation and risks of microplastic pollution in sediments and *A. granosa* in the Musi Estuary, Indonesia. The findings are expected to enhance understanding ofbenthic organisms, especially *A. granosa*, and its potential health risks for local seafood consumers.

MATERIALS AND METHODS

Study Area and Sample Collection

The Musi Estuary, located on the east coast of South Sumatra, is where seawater from the Bangka Strait mixes with freshwater from the Musi River. The Musi Estuary is an important area for fisheries and benthic habitats in South Sumatra, Indonesia (Rozirwan et al. 2021; Rozirwan, Fauziyah, Wulandari, et al. 2022). Sampling locations were selected based on hydrodynamic conditions influencing microplastic transport and deposition, considering salinity variations and water mass interactions (Cheng et al. 2024; Diansyah et al. 2024). Locations of the sampling sites are shown in Figure 1 and Table 1. Sediment and *A. granosa* were collected during low tide from the Musi Estuary, South Sumatra, Indonesia Sediment samples were collected from ten sampling points using a Peterson Grab at each station (Dwiyitno et al. 2024). Samples were placed in glass jars that had been rinsed with pure distilled water and covered using aluminum foil to avoid contamination. Samples were placed in a cool box (±4℃) for further analysis in the laboratory.

Anadara granosa samples were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). Twenty adult *A. granosa* (7.48–11.44 cm) were collected from fishermen's catch in the Musi Estuary. *Anadara granosa* samples were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). The mussels were rinsed with pure distilled water to remove any dirt. *A. granosa* were wrapped in aluminum foil and stored in a cooler at approximately 4 °C to preserve their freshness. After that, they were transported to the laboratory and frozen at -20°C before further analysis (Ding J et al. 2021).

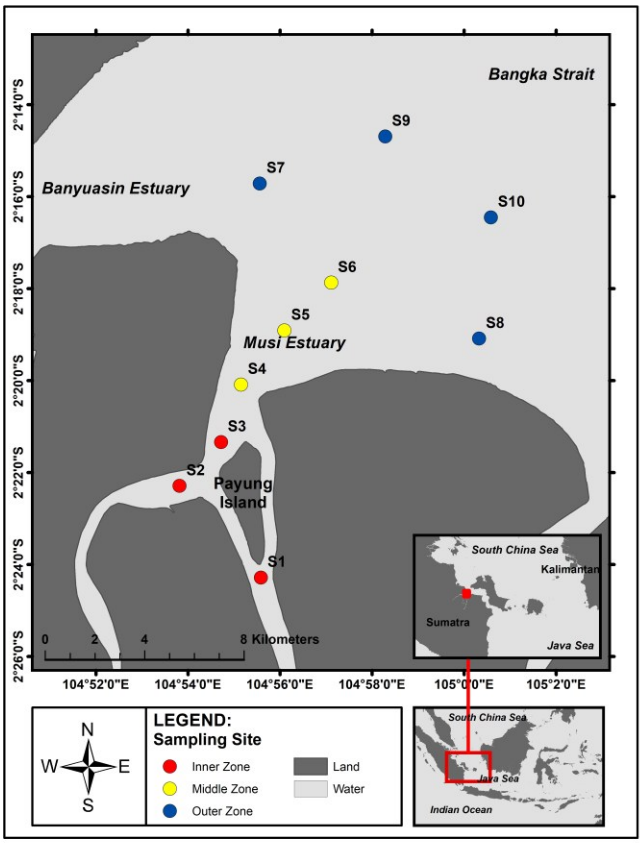

Figure 1. Study site at the Musi Estuary, Indonesia.

Table 1. Coordinates of the sampling location.

Estuary Zone	Description	Station	Latitude (ºS)	Longitude (ºE)
Inner Zone	Predominantly influenced by freshwater, with low salinity (<10 PSU)	S1	2.40470	104.92643
		S2	2.37144	104.89695
		S3	2.35558	104.91200
Middle Zone	A mixing zone of freshwater and seawater, with salinity ranging from 10 to 20 PSU	S4	2.33316	104.92003
		S5	2.31353	104.93862
		S6	2.29524	104.95794
Outer Zone	Primarily dominated by seawater, with high salinity (>20 PSU)	S7	2.26183	104.92603
		S8	2.31807	105.00547
		S9	2.24403	104.96686
		S10	2.27413	105.00978

Microplastic extraction from sediment

Microplastics in sediments were extracted using the standard method of density separation and organic matter removal with minor modifications (Thompson et al. 2004; Liebezeit and Dubaish 2012). A total of 500 g of wet sediment samples were placed in a beaker glass covered with aluminum foil. The samples were dried in an oven at 60 °C for 48 hours, or until they reached a constant mass (Patria et al. 2023). The sediment samples were pulverized and sieved through a 5 mm steel sieve. A portion of 100 g of dried sediment was taken from the sieve, placed into a beaker glass, and covered with aluminum foil to prevent external contamination. The sample was suspended in 400 mL of saturated NaCl solution (1.2 g cm^{-3}), which is four times the sample weight, using a magnetic stirrer. This NaCl solution was prepared by dissolving pure NaCl crystals (Merck Millipore EMSURE®) in filtered distilled water that was free from contaminants. The selection of a NaCl solution for the separation of microplastics from sediments was based on the premise that this method is cost-effective and environmentally friendly (Perumal and Muthuramalingam 2022). Stirring was carried out for 5 minutes until completely dissolved, and the mixture was allowed to stand for 1 hour. After one hour, 10 mL of 30% H_2O_2 was added to assist in the breakdown of organic matter, followed by stirring for an additional five minutes. Hydrogen peroxide (H_2O_2) is commonly used in similar studies and is regarded as highly effective for organic matter removal (Lee et al. 2023). The sample was allowed to stand for 24 hours, covered with aluminum foil. The samples were then filtered using the Whatman No. 42 filter paper (mesh size 0.45 µm, Φ = 90 mm), assisted by a vacuum pump at 17 kPa to isolate the microplastics. The collected samples were deposited into petri dishes for identification.

Microplastic extraction from *Anadara granosa*

The previously frozen *A. granosa* samples were defrosted under controlled conditions at room temperature (± 25°C) for 1 hour. After the ice melted, the *A. granosa* were washed with pure distilled water to eliminate contamination from other objects, such as sediment. The length and wet weight of the *A. granosa* were measured using an analytical balance (0.01 g). The digestive tract was carefully removed from the *A. granosa* using sterile stainless steel utensils that had been rinsed with distilled water. The extraction of microplastics from the digestive tract of the *A. granosa* was adapted from previous studies with minor modifications (Ding J-F et al. 2018; Ding J et al. 2021). The digestive tract was transferred into an Erlenmeyer flask, and 100 mL of KOH solution (10%) was added. The use of KOH is regarded as a more efficacious method for the digestion of biological material, and it has no impact on the integrity of the plastic polymer (Karami et al. 2017). The sample was covered with aluminum foil and stirred for 5 minutes using a 150 rpm magnetic stirrer. The supernatant was incubated at room temperature (±25ºC) until complete digestion of organic matter occurred. The sample was then filtered through Whatman 42 filter paper (mesh size 0.45 µm, Φ = 90 mm) to isolate microplastic. The filter paper was dried in an oven at 40℃ for 5 hours and stored in petri dishes for subsequent identification of microplastic content.

Microplastic identification and quantification

Identification and quantification of microplastics from sediments and *A. granosa* were performed using the same method. Microplastic identification was performed using an Olympus CX23 microscope with 10 x 10 or 4 x 10 magnification to visually detect microplastics (Diansyah et al. 2024). The filter paper was observed closely and carefully to avoid contaminants that could enter the filter paper. Microplastics were identified based on the number and form of microplastics (fragment, film, fiber, and foam). The data obtained were recorded by sample type and station/individual for statistical purposes. To prevent contamination, personnel wear cotton lab coats, latex gloves, and cotton masks. Furthermore, access to the detection room is restricted to prevent outside contact during observations.

Procedures for quality assurance and contamination prevention

The quality and contamination control measures were implemented to prevent any alterations to the microplastics in the samples. Before sampling, glass jars and aluminum foil were rinsed with filtered distilled water. Although the samples were in a cool box, they were stored in a place that was not exposed to direct sunlight to keep the samples in good condition. Personnel are also required to wear latex gloves during sampling. During the study, from sampling to laboratory analysis, the use of plastic equipment was minimized to avoid unintentional fragmentation of the microplastics. The distilled water used was filtered with filter paper (0.45 µm,) to prevent microplastics from entering our materials. All equipment was washed with filtered distilled water to remove potential contamination from external particles (Ding J et al. 2021). We prepared two controls by filtering each solution we used to avoid contaminants from materials, equipment, and air. No microplastics were found contaminating the instrument. The sterilized equipment was wrapped in aluminum foil to prevent any input of contaminants from outside. Laboratory personnel were required to wear latex gloves, lab coats, and masks throughout the analysis. Access to the laboratory was restricted during the analysis to minimize external interference that could lead to protocol errors.

Data analysis

Pollution Load Index (PLI)

PLI was calculated using a pollutant load approach, which assesses the total concentration of contaminants relative to a baseline level, to evaluate its significance. Equations were utilized to quantify the level of microplastic pollution in both sediments and *Anadara granosa* in the Musi Estuary, with the method adapted accordingly (Tomlinson et al. 1980; Xu P et al. 2018; Wang G et al. 2021).

$$CF_i = \frac{C_i}{C_{0i}}$$

This equation shows that the concentration factor (CF_i) at a particular sample is obtained by dividing the current concentration (C_i) by the initial concentration (C_{0i}). Ci indicates the quantified presence of microplastics at each sampling location or within each clam (individual), while C_{0i} denotes the background concentration, defined as the lowest value recorded across all sampling locations. Given the lack of previously published research on microplastics in sediments or *A. granosa* in the Musi Estuary, we determined C_{0i} values from minimum concentrations across sampling stations.

$$PLI = \sqrt{CF_i}$$

This equation shows that the Pollution Load Index (PLI) is generated by calculating the square root of the Concentration Factor (CF). The PLI value of microplastics is derived from the contaminant factor (CF_i) calculated for each station/individual.

$$PLI_{zone} = \sqrt[n]{PLI_1 \times PLI_2 \times \dots\ PLI_n}$$

Pollution Load Index for a Zone (PLI_{zone}) is determined by taking the square root of the product of individual PLI values from multiple sites within the zone. This method integrates data from several measurement points, providing a more comprehensive assessment of microplastic contamination within the analyzed. A PLI_{zone} is used to assess pollution based on specific estuary zones as well as the overall estuary area. PLI values are categorized into four predefined categories of pollution load, as shown in Table 2.

Table 2. Microplastic pollution load categories

Definition	Value			
Value of the pollution load index (PLI)	<10	10-20	20-30	>30
Risk category	I	II	III	IV
Keterangan	Minor	Middle	High	Extreme

Nemerow Pollution Index (NPI)

NPI is designed to assess the bioavailability of microplastics in sediments and *A. granosa*. This index was adapted from equations used in prior studies evaluating heavy metal contamination (Alam et al. 2023).

$$NPI = \sqrt{\frac{\left(\frac{C_i}{S_i}\right) max^2 + \left(\frac{C_i}{S_i}\right) ave^2}{2}}$$

The NPI value is calculated using the square root of the mean squared deviation, incorporating both the maximum and average concentration ratios relative to the background concentration (S_i). The formula includes the sum of the squares of the maximum concentration ratio ($C_{i\ max}/S_i$) and the average concentration ratio ($C_{i\ ave}$). The C_i value represents the concentration of microplastics found in the sediment or clams at a specific station or individual, while the Si value denotes the background level of microplastics, determined as the lowest concentration recorded across all sample types. The NPI provides a measure of microplastic bioavailability in sediments and *A. granosa*, with values below 2 indicating low bioavailability and values above 2 indicating high bioavailability.

Bioconcentration Factor (BCF)

The Bioconcentration Factor (BCF) quantifies the extent to which microplastics accumulate in biota relative to their environmental concentration and is calculated using the following equation (Li Z et al. 2022).

$$BCF = \frac{C\ biota_{\ ave}}{C\ sediment_{\ ave}}$$

In this equation, BCF represents the bioconcentration factor, which is derived from the calculation of the average concentration of microplastic in biota (*A. granosa*) divided by the average concentration of microplastic in its environment (sediment). This value is intended to assess how much microplastic is concentrated in the biota.

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics 27. Descriptive statistics, including total, mean, standard deviation, percentage, minimum, and maximum, were utilized to assess data variation. A one-way ANOVA was applied to analyze differences in microplastic abundance between estuarine zones when the data met normality assumptions. For non-normal data, the Kruskal-Wallis test was employed to assess the significance of differences between zones. All tests were carried out with a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Microplastic presence in sediment from Musi Estuary

The results of this study indicate that microplastics were detected at all sampling stations, as shown in Figure 3. A total of 1,308 microplastic particles were identified, with concentrations ranging from 66 to 178 particles per 100 g of dry sediment (dry weight, dw). The average abundance of microplastics was 1.31 ± 0.41 particles/g dw, with the highest concentration found at station S1 (1.78 particles/g dw) and the lowest at station S8 (0.66 particles/g dw). High levels of human activity in the upstream area of Muara Musi, which flows downstream to the estuary and ultimately into the ocean, are responsible for the presence of microplastics (Diansyah et al. 2024; Rozirwan et al. 2021). Urban activities in close proximity to the Musi River Watershed, particularly in Palembang City, significantly contribute to the generation of plastic waste. Increased population density near riverbanks enhances the potential for plastic pollution. Furthermore, population density is a crucial factor in the entry of microplastics into rivers (Dwiyitno et al. 2024; Eo et al. 2023). As a result, plastic pollutants from domestic activities, such as the disposal of food packaging and plastic bags, can be transported through stormwater drains and eventually end up in rivers (Kunz et al. 2023). Fishing activities around Muara Musi can contribute to microplastic pollution, primarily through fibers released from fishing nets (Li Z et al. 2022; Fauziyah et al. 2023). This increases anthropogenic pressure at river mouths, which can lead to greater accumulation of microplastics (Castro-Jiménez et al. 2024). Additionally, tidal fluctuation influences water flow, which facilitates the deposition of microplastics in sediment at these locations (Harris 2020). The findings of this study indicate that anthropogenic activities are responsible for high levels of microplastic deposition in the sediments of Musi Estuary. Microplastic particles that accumulate in sediments serve as a habitat for benthic organisms, which can have long-term implications for ecosystem health and balance (Rahmatin et al. 2024). As vectors for pollutants, microplastics can exacerbate toxicity, potentially endangering various populations (Caruso 2019; Issac and Kandasubramanian 2021; Fu et al. 2021; Ta and Babel 2023). Furthermore, the processes of bioaccumulation and biomagnification in benthic organisms present heightened risks to these animals, potentially leading to human consumption (Unuofin and Igwaran 2023). Therefore, it is crucial for local governments to address the handling and prevention of further microplastic accumulation.

Figure 2. General conditions in the Musi estuary**.** A. Coastal Settlements; B. Shipping Activities; C. Fisheries; D. Mangrove Ecosystem.

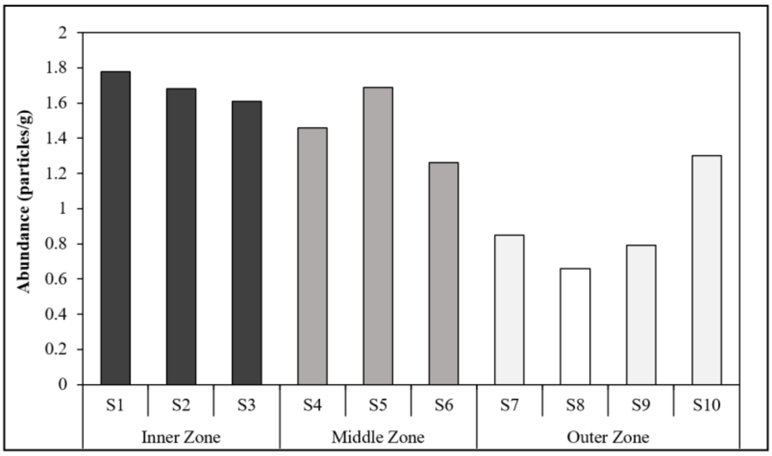

Figure 3. Distribution of microplastics from sediments in Musi Estuary, Indonesia.

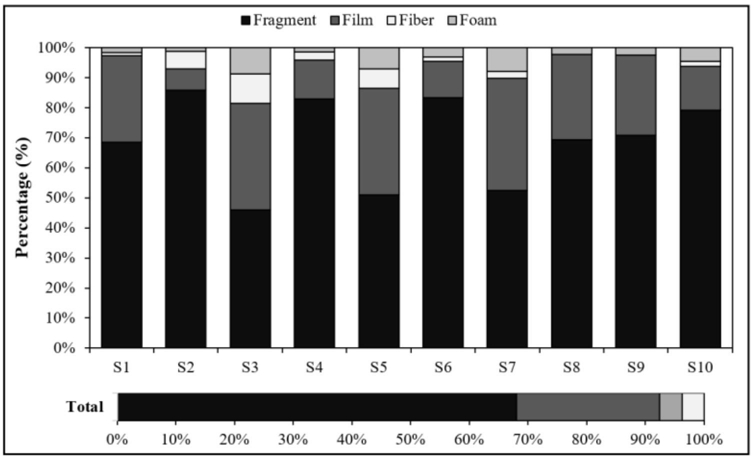

Figure 4. Percentage abundance of microplastic shapes form sediments in Musi Estuary, Indonesia

The microplastics identified in the sediments were predominantly fragments (68.92%), followed by films (23.86%), fibers (4.05%), and foams (3.17%) (Figure 4). The dominance of fragments, which are a common form of secondary microplastics, occurs as a result of macroplastic degradation (Barnes et al. 2009). Fragments represented the most common type across all sediment samples analyzed. This dominance of fragments in estuarine sediments aligns with findings from various studies conducted in other estuarine environments. Research indicates that estuarine sediments globally tend to accumulate diverse microplastic forms, particularly fibers (Samuels et al. 2024; Firdaus et al. 2020; Santucci et al. 2024; Alam et al. 2023), with many studies also reporting a predominance of fragment types (Zhou et al. 2021; Suteja et al. 2024). These observations corroborate the literature, which consistently shows that fibers and fragments constitute the majority of microplastic pollution in estuarine ecosystems (Feng, An, et al. 2023).

This study reveals notable variations in microplastic concentrations compared to similar research in estuaries globally. Our findings indicate that the Musi Estuary has lower microplastic concentrations than those reported in several other Indonesian and international estuaries. For example, the Jakarta Bay Estuary exhibits concentrations nearly ten times higher, ranging from 1,184 to 1,337 particles per 100 grams of river sediment and 804 to 1,055 particles per 100 grams of beach sediment (Dwiyitno et al. 2024). Such elevated levels are likely due to increased anthropogenic activities along Jakarta's rivers, which substantially contribute to plastic waste flow. In another comparison, the Pearl River Estuary in China also shows higher microplastic densities, with concentrations between 2.05×10^3 and 7.75×10^3 particles per kilogram of dry weight sediment (Xu K et al. 2024). This estuary's coastal regions experience high human activity, enhancing the potential for microplastic deposition. Similarly, the Meghna Estuary in Bangladesh, which receives sediment from the Ganges River Basin, reports even higher microplastic levels at $4{,}014.66 \pm 1{,}717.59$ particles per kilogram dry weight (Alam et al. 2023). These findings underscore the significant role of anthropogenic influences on microplastic accumulation in global estuarine sediments, including the Musi Estuary. Other environmental factors, like location, sampling period, sediment depth, sediment composition, and local hydrodynamic conditions, may also affect these changes in the amount of microplastics found (Feng, Chen, et al. 2023; Zheng et al. 2020; Yuan B et al. 2023).

In contrast, the abundance of microplastics in the sediments of the Musi Estuary surpasses levels reported in other regions, both within Indonesia and globally. Concentrations in the Musi Estuary are notably higher than those in the

Zandvlei River Watershed and estuarine areas of South Africa (70.23 ± 7.36 particles/kg dw) (Samuels et al. 2024), the Claromecó Estuary in Argentina (299 ± 114 particles/kg dw) (Truchet et al. 2021), and the upper sediment layer (0-5 cm) of the Fuhe River Estuary in Northern China (1049 ± 462 particles/kg dw) (Zhou et al. 2021). These numbers are also higher than those found in coastal Río de la Plata (547.83 ± 620.06 particles/kg dw) (Santucci et al. 2024), Benoa Bay, Bali (31.08 ± 21.53 particles/kg dw) (Suteja et al. 2024), the Jagir Estuary in Surabaya (up to 590 particles/kg dw) (Firdaus et al. 2020), and the Pekalongan River Estuary in Java (0.77 to 1.01 particles/g dw) (Ismanto et al. 2023). The high microplastic concentration in the Musi Estuary is likely due to extensive plastic waste disposal in the river basin by the surrounding community. Research supports that plastic debris forms a substantial part of the macro-waste in the Musi River (Maherlsa et al. 2019). Additionally, local communities frequently establish settlements along the river, relying on it for water access and transportation. Consequently, domestic waste, including plastic, often enters the river directly. This local waste management issue reflects a broader trend, with Indonesia identified as the world's second-largest contributor to oceanic plastic pollution, following China (Jambeck et al. 2015).

Spatial distribution microplastic in Sediments

The study revealed that the abundance of microplastics was significantly higher in the inner and middle zones when compared to the outer zone. The mean abundances were 1.69±0.08 particles/g dw in the inner zone, 1.47±0.22 particles/g dw in the middle zone, and 0.9±0.28 particles/g dw in the outer zone. Significant differences in mean microplastic abundance between zones were revealed by the one-way ANOVA ($p < 0.05$), as illustrated in Figure 5. The Tukey HSD test revealed no significant difference in mean microplastic abundance between the inner and middle zones However, we observed a significant difference in the outer zone compared to both the middle and outer zones. Our results indicate that the inner and middle estuary regions exhibit greater mean concentrations of microplastics compared to the outer estuary. Natural factors, particularly the effects of currents and wave action in coastal and estuarine environments, significantly influence this phenomenon by altering microplastic distribution. The influx of freshwater promotes the sedimentation and prolonged retention of high-density microplastics within the system (Li G et al. 2024) Furthermore, the sedimentation process is affected by the density and buoyancy of microplastics, with increased salinity in estuarine waters enhancing buoyancy forces and influencing distribution patterns (Cheng et al. 2024). Our findings align with research from the Liaohe Estuary in China, revealing a higher accumulation of microplastics in inner river sediments compared to the outer estuary (Xu Q et al. 2020). Additionally, sampling depth plays a critical role in accurately measuring microplastics in surface waters, bottom layers, and sediments (Feng, An, et al. 2023).

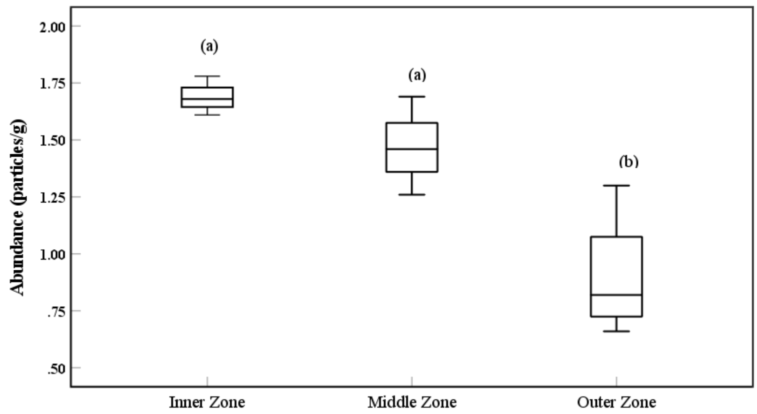

Figure 5. The difference in microplastic abundance between zones in the sediments

The spatial analysis revealed distinct patterns of microplastic accumulation between the two sides of the coast adjacent to the estuary. Notably, Site S7 exhibited higher concentrations compared to Site S8, likely due to its proximity to other pollution sources. Specifically, S7 is located near the Banyuasin Estuary, which is believed to significantly contribute to the deposition of microplastics in the surrounding sediments. Costa's (2023), research confirms that nearby sources of pollution heavily influence microplastic deposition in coastal regions. The accumulation of microplastics at the mouth of the adjacent river further exacerbates this phenomenon, facilitating the settlement of microplastics within the sediment. Additionally, studies suggest that the depth of the sampling locations significantly influences microplastic deposition, revealing a greater abundance of microplastics at deeper water levels (Bayo et al. 2022). The substantial accumulation of microplastics in sediments is attributed to their persistent characteristics as well as the protective conditions offered by deeper environments, which are shielded from UV light, maintain lower temperatures, and exhibit lower oxygen levels, thus slowing biodegradation processes (Zhang K et al. 2021).

Our findings confirm the presence of microplastics in the sediments of the Musi Estuary, likely originating from suspended microplastics that eventually settle from the water's surface. Previous research has found that there are 467.67 ± 127.84 particles/m^3 and 723.67 ± 112.05 particles/m^3 of microplastic in surface waters during ebb and flow conditions, respectively (Diansyah et al. 2024). Hydrodynamic conditions in the estuary and processes like aggregation and biofouling, which increase microplastic density, influence the deposition of these particles (Malli et al. 2022). The specific properties of the microplastics and the water dynamics of the estuary strongly influence microplastic deposition. For instance, biofouling can make microplastics denser, accelerating their descent into sediments (Lin et al. 2023). Since microplastics often have higher densities than water, they can remain suspended in the water column before eventually settling (Dai et al. 2022). High Total Suspended Solids (TSS) in the Musi Estuary have the potential to cause aggregation of microplastics (Rahutami et al. 2022). High TSS levels make it easier for sediments and other suspended particles to stick together on microplastic surfaces, which speeds up their deposition (Yang et al. 2022). However, microplastics can also become resuspended in the water column (Tang et al. 2020). Stirring forces in estuarine environments can lift microplastics back into the water, where turbulence and bioturbation may redistribute them (Malli et al. 2022). Therefore, additional studies are required to fully characterize the mechanisms of microplastic deposition in the Musi Estuary. Climate factors also influence microplastic distribution in Musi Estuary sediments. In Indonesia, where regions such as the Musi Estuary experience distinct rainy and dry seasons, seasonal changes affect water dynamics and microplastic transport. During the rainy season, increased river velocity may carry microplastics upward from sediments, while in the dry season, slower flows facilitate microplastic accumulation at the water's surface (Zhao X et al. 2020). Currently, there are no studies specifically examining the seasonal impact on microplastic presence in the Musi Estuary, underscoring the need for further research to address this gap.

Bioaccumulation of microplastics in *Anadara granosa*

We extracted 133 microplastic particles from the digestive tracts of twenty samples of *A. granosa*. Each sample from the Musi Estuary had accumulated microplastics, ranging from 6 to 49 particles/ind (ind) or 8 to 69.01 particles/g ww, as shown in Figure 7 and Figure 8. The mean abundance of microplastics found in the digestive tracts was 21.05±10.31 particles/ind or 30.46±16.7 particles/g ww. Several factors contribute to the increased microplastic inputs in bivalve species, including human activities, tourism, fishing equipment, freshwater runoff, and wastewater discharge, combined with the area's hydrodynamic conditions (Vital et al. 2021). The elevated levels of microplastics found in *A. granosa* from the Musi Estuary suggest a significant degree of contamination in their habitat, including both water and sediment, which may adversely affect the health of these organisms and disrupt local ecological balances. This observation aligns with existing literature, which indicates a strong correlation between the abundance of microplastics in bivalves, such as mussels, and their sediment environments (Narmatha Sathish et al. 2020), reinforcing the need for monitoring these pollutants in aquatic ecosystems.

Figure 6. Morphology of *Anadara granosa* from Musi Estuary, Indonesia.

Microplastics were observed in three morphological forms: film, fiber, and fragment. Film accounted for the majority of microplastics (59.38%), followed by fiber (31.59%) and fragments (9.03%), as shown in Figure 9. The digestive tracts of the *A. granosa* studied did not contain any pellets or foam. Statistical analysis using the Kruskal-Wallis test revealed significant differences in the abundance of the three microplastic forms ($p < 0.05$). This predominance of film microplastics in *A. granosa* is likely attributable to the extensive use of disposable plastic packaging within the community, which subsequently degrades into microplastics. Although fragments dominate the sediment substrate, *A. granosa* predominantly absorb film microplastics. The lower density of film microplastics may facilitate their accumulation in the upper sediment layer, making them susceptible to resuspension in the overlying water column. This phenomenon is consistent with the feeding behavior of *A. granosa*, which frequently filter water from the sediment surface, resulting in the accumulation of film microplastics within their digestive tracts.

Our findings indicate a higher abundance of microplastics in *A. granosa* from the Musi Estuary compared to certain other regions globally. For instance, *A. granosa* from the Chanthaburi estuarine ecosystem in eastern Thailand contained 0.40±0.16 particles/g ww (Potipat et al. 2024), while samples from Peninsular Malaysia showed concentrations of 0.20 ± 0.08 particles/g ww and 1.54 ± 0.30 particles/ind ww (Mohan et al. 2024). Additionally, microplastic levels in *A. granosa* from Pao Village, Tarowang District, Jeneponto Regency, Indonesia, were measured at 0.0144 particles/g ww (Namira et al. 2023), and those from Likas Bay Beach in North Borneo, Malaysia, at 24.4 ± 0.6 particles/g ww (Abd Rahman et al. 2024). In contrast, the *A. granosa* analyzed in this study accumulated lower microplastic concentrations than those reported in several other studies. For instance, *A. granosa* from the Pangkal Babu mangrove forest area in Tanjung Jabung Barat district, Jambi, exhibited 434 ± 97.05 particles/ind (Fitri and Patria 2019), while those from Lada Bay in Pandeglang, Banten, had concentrations of 618.8 ± 121.4 particles/ind (Ukhrowi et al. 2021). Overall, this study shows that microplastics have contaminated the sediment environment of the Musi Estuary, South Sumatra, indicating that *A. granosa* can serve as effective bioindicators of this pollution.

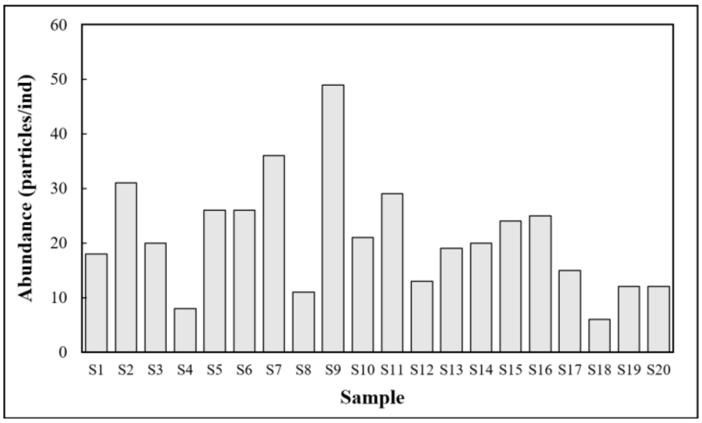

Figure 7. Microplastic abundance of *Anadara granosa* from the Musi Estuary

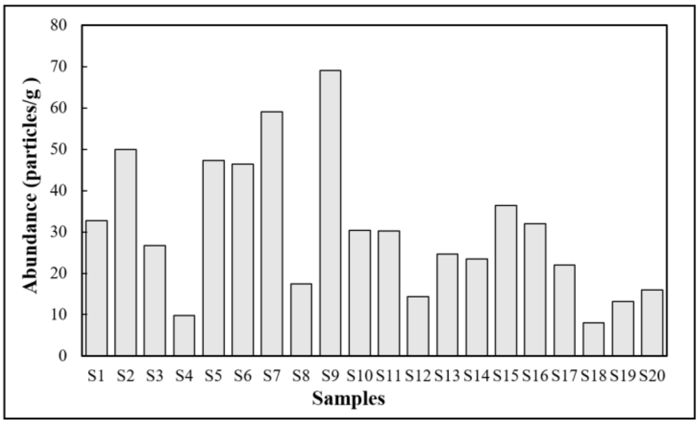

Figure 8. Microplastic abundance (in particles/g) of *Anadara granosa* from the Musi Estuary

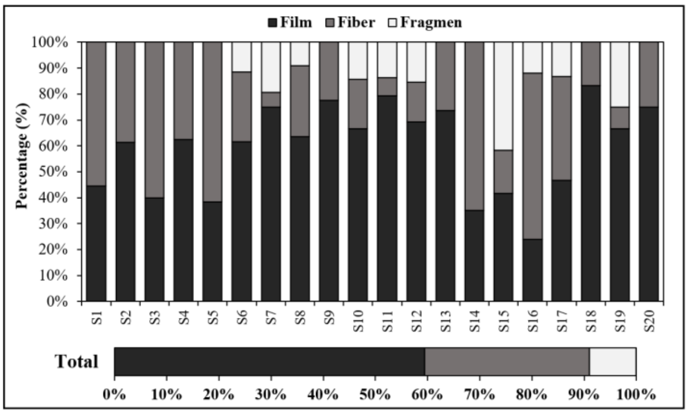

Figure 9. Shape of microplastics in *Anadara granosa* from the Musi Estuary

Risk assessment of microplastics in sediments and *Anadara granosa*

A risk assessment of microplastic contamination in the Musi River Estuary was carried out by calculating the Pollution Load Index (PLI), the Nemerow Pollution Index (NPI), and the Bioconcentration Factor (BCF). The PLI values across all sediment samples indicate that the estuarine sediment is subject to minor pollution, with values ranging between 1.00 and 1.64, as shown in Table 3. In the three zones of the estuary (inner, middle, and outer), the PLI values were 1.60, 1.49, and 1.20, respectively. We calculated the overall average PLI for the Musi Estuary to be 1.37. All zones reported PLI values below 3.00, which suggests that the area experiences only minor microplastic pollution. The analysis of microplastic presence in sediment samples revealed a significantly high concentration of microplastics, with an NPI value of 2.37. This suggests a substantial bioavailability of microplastics in the estuarine environment. This elevated NPI underscores the ecological risk posed by microplastic contamination, despite the relatively low PLI observed across the study area.

Table 3. The microplastic risk factor in sediments of Musi Estuary

Sediment Station	CF	PLI	PLI Zone	PLI Sediment	NPI
S1	2.70	1.64			
S2	2.55	1.60	Inner Zone 1.60		
S3	2.44	1.56			
S4	2.21	1.49			
S5	2.56	1.60	Middle Zone 1.49		
S6	1.91	1.38		1.37	2.37
S7	1.29	1.13			
S8	1.00	1.00	Outer Zone 1.20		
S9	1.20	1.09			
S10	1.97	1.40			

Anadara granosa analyzed in this study exhibited significant risk values associated with microplastic contamination. The PLI for these clams ranged from 1 to 2.86, with an overall mean PLI value of 1.77 for the entire sample, as shown in Table 4. This indicates that the pollution load in *A. granosa* falls within the minor category (PLI < 3). Furthermore, the bioavailability of microplastics in *A. granosa* was significantly higher, with an NPI value of 6.29, indicating a high bioavailability. The bioconcentration factor of microplastics from sediment to *A. granosa* was measured at 23.28, suggesting a significant potential for the transfer of microplastics from sediment to *A. granosa* in the Musi Estuary.

Our findings demonstrated that the bioavailability of microplastics in sediments and *A. granosa* was categorized as high (NPI = 2.37; NPI > 2). In comparison, the bioavailability of microplastics in *A. granosa* was even higher, with an NPI value of 9.89. The elevated bioavailability in sediments suggests a greater potential for absorption by aquatic organisms, particularly benthic animals. Furthermore, the bioconcentration factor (BCF) calculated for *A. granosa* in sediment was 23.28, indicating a significant transfer of microplastics from sediments to these organisms in the Musi Estuary. This high BCF value is attributed to the non-discriminatory feeding process of *A. granosa*, allowing them to ingest microplastics along with other particles. When compared to several benthic species from the Yangtze River Estuary, which exhibited a BCF of 29.48 ± 6.52 (Li Z et al. 2022), the BCF of *A. granosa* in the Musi Estuary remains lower. Nonetheless, both sediments and *A. granosa* from the Musi Estuary are classified within the minor pollution risk index category (PLI < 10). The bioaccumulation of microplastics by benthic animals like *A. granosa* poses a significant risk to human health for those consuming these clams (Winiarska et al. 2024; Wang Y et al. 2023). Therefore, periodic assessments are crucial to evaluate the risk of microplastic contamination in sediments and *A. granosa*, providing essential information to understand the ecological and health implications in the Musi Estuary.

The impact of high bioaccumulation extends beyond the toxicity of microplastic materials; it also facilitates the accumulation of other pollutants. Previous research has detected heavy metals, such as lead (Pb) and copper (Cu), adhering to the surfaces of microplastics in the Musi Estuary (Purwiyanto et al. 2020). Additionally, various hazardous heavy metals, including iron (Fe), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn), were identified with high bioavailability in the aquatic environment of the Musi Estuary (Rahutami et al. 2022). This accumulation allows for the deposition of significant quantities of heavy metals on microplastic surfaces, thereby increasing the risk of microplastic toxicity for estuarine ecosystems. Moreover, the involvement of microorganism vectors, misidentification in aquatic organisms' diets, and their harmful toxicological effects on benthic animals heighten the risk associated with microplastics (Gong and Xie 2020). Consequently, the high output of microplastics from the Musi Estuary has the potential to jeopardize the condition of the surrounding aquatic environment, including fisheries and migratory birds, which are critical to the ecosystem (Rozirwan et al. 2019; Rozirwan, Fauziyah, Nugroho, et al. 2022).

Table 4. Risk factors for microplastics in *Anadara granosa* from the Musi Estuary

A. granosa sample	CF	PLI	PLI *A. granosa*	NPI	BCF
S1	3.00	1.73			
S2	5.17	2.27			
S3	3.33	1.83			
S4	1.33	1.15			
S5	4.33	2.08			
S6	4.33	2.08			
S7	6.00	2.45			
S8	1.83	1.35			
S9	8.17	2.86			
S10	3.50	1.87	1.77	6.29	23.28
S11	4.83	2.20			
S12	2.17	1.47			
S13	3.17	1.78			
S14	3.33	1.83			
S15	4.00	2.00			
S16	4.17	2.04			
S17	2.50	1.58			
S18	1.00	1.00			
S19	2.00	1.41			
S20	2.00	1.41			

This study holds significant ecological implications for the Musi Estuary ecosystem, as the presence of microplastics poses a long-term threat to ecosystem stability. Previous studies have shown that microplastics can affect the physicochemical properties of sediments, such as electrical conductivity, organic matter content, and nutrients, and well as impact enzymatic activity in sediment bacteria (Yuan B et al. 2022; Rillig 2012; Li W et al. 2022). These changes can lead to structural and functional alterations in aquatic habitats (Li W et al. 2022). Microplastics can also enter various levels of the food chain through bioaccumulation and biomagnification processes. For example, microplastics in plankton can cause a decline in zooplankton populations, which impacts food availability for small fish and predatory species at higher trophic levels (Malinowski et al. 2023). The accumulation of microplastics in *A. granosa* in this study indicates that the pressure of plastic waste in the Musi Estuary is already quite high. Microplastics can act as vectors for other pollutants, such as microorganisms, heavy metals, and other inorganic pollutants can increase the risk of toxicity for aquatic organisms, including *A. granosa* (Rafa et al. 2024; Purwiyanto et al. 2020). Research indicates that exposure to microplastics can lead to behavioral and physiological changes in aquatic organisms, including changes in diet and reproductive success (Guo et al. 2020; Liang et al. 2023). Moreover, microplastics disrupt endocrine functions and metabolic pathways, causing oxidative stress, cell necrosis, and apoptosis, which can ultimately lead to mortality (Pannetier et al. 2020; Jeyavani et al. 2021). Disruption of any component of the food chain can trigger a domino effect, threatening the balance of the Musi Estuary ecosystem. However, this study only examines microplastic pollution in sediment and *A. granosa* as environmental indicators. Additional research is needed to understand microplastic buildup in other species, such as fish, shrimp, and benthic organisms, for a more complete picture of microplastic pollution in the Musi Estuary and its impact on the global marine environment.

Microplastic contamination of *A. granosa* in the Musi Estuary poses a significant threat to local communities, particularly clam fishers. Microplastics that accumulate in *A. granosa* may pose health risks to community members who consume them regularly as a primary source of protein. Long-term exposure to microplastics can potentially disrupt various human body systems, including the digestive, respiratory, reproductive, nervous, and cardiovascular systems (Li Y et al. 2024). Furthermore, microplastics may cause both acute and subchronic toxicity and are considered potentially carcinogenic and disruptive to human development (Yuan Z et al. 2022). Once in the bloodstream, microplastics can be transported to the liver, the primary organ responsible for detoxification. Accumulation in the liver may trigger adverse physiological reactions, including increased oxidative stress, liver fibrosis, and impaired lipid metabolism. In addition to health risks, microplastic contamination in *A. granosa* in the Musi Estuary may reduce consumer confidence and decrease market demand due to food safety concerns (Unuofin and Igwaran 2023). The long-term effect could weaken local economic resilience as marine products in the region are perceived to be contaminated with microplastics (Barrientos et al.

2024). Therefore, it is crucial for governments and communities to recognize these risks and collaborate on mitigation efforts to protect ecosystems, public health, and local economies.

The presence of microplastics in sediments and *A. granosa* in the Musi Estuary poses a significant threat to the ecosystem's sustainability. To address microplastic pollution effectively, collaboration between governmental bodies and local communities is essential. Several strategies can be implemented to reduce microplastic pollution in aquatic environments, including the following measures:

1. Educating the public on the importance of controlling plastic waste (Evode et al. 2021).
2. Reducing single-use plastic consumption and encouraging the use of environmentally friendly alternatives.
3. Banning plastic microbeads in personal care products and cosmetics (Zhang Z et al. 2022).
4. Promoting sustainable plastic recycling at individual, community, national, and international levels (Babaremu et al. 2022; Thu Nguyen 2024)
5. Strengthening waste management policies for product packaging and disposal practices within the industrial sector (Wu et al. 2023).
6. Enforcing stricter regulations on wastewater treatment facilities and implementing comprehensive plastic waste management through mechanical, physical, chemical, and biological methods to reduce microplastics (Meiyerani et al. 2024; Ragaert et al. 2017).
7. Prioritizing microplastic control by evaluating land-use contributions in urban areas, focusing on those with the highest pollution impact (Jin et al. 2022).

Furthermore, seafood hygiene practices in local communities and fishing industries can help reduce microplastic contamination (Kandeyaya et al. 2023). For example, *Anadara granosa* and other seafood, when thoroughly cleaned by repeated washing and clam removal before cooking, may reduce microplastic intake (Li J et al. 2022). The concentration of microplastics in shellfish is significantly lower after boiling and steaming compared to frying, suggesting that cooking methods affect microplastic retention in seafood (Evode et al. 2021).This method can also be applied to shrimp, fish, and other shellfish to lower the risk of microplastic exposure. Implementing these recommendations will help reduce microplastic pollution and provide long-term benefits for public health, ecosystem stability, and the economic resilience of local fisheries.

In conclusion, this study demonstrates the significant presence of microplastics in the sediment and *A. granosa* of the Musi Estuary, Indonesia. These findings indicate a serious threat to the aquatic ecosystem and to local public health, as microplastics can enter the food chain and potentially harm organisms across trophic levels, including humans (Ningrum and Patria 2022; Edwin et al. 2023; Patria et al. 2023). This pollution heightens environmental risks, particularly for species integral to both the community's diet and economy (Jeong et al. 2024). The microplastics likely originate from human activities, especially urban waste from upstream areas that flows downstream and accumulates in the estuary (Diansyah et al. 2024). These results highlight the urgent need for routine monitoring and stricter waste management practices, particularly for plastic disposal, to reduce further contamination. A comprehensive strategy is essential to controlling plastic waste throughout the river system—from source to estuary. Effective measures should include coordinated waste management practices, public education on the impact of pollution, and cross-sector collaboration to preserve estuarine health. Such initiatives are crucial to protecting ecosystem health and sustaining local fisheries, ensuring these resources continue to support community well-being.

ACKNOWLEDGEMENTS

The authors disclose receipt of the following financial support for the research, authorship, and publication of this article: Directorate of Research, Technology, and Community Service Directorate General of Higher Education, Research, and Technology under the Contract for Implementation of the State Higher Education Operational Assistance Program Research Program for Fiscal Year 2024 Number: 090/E5/PG.02.00.PL/2024.

REFERENCES

Abd Rahman NN, Mazlan N, Shukhairi SS, Nazahuddin MNA, Shawel AS, Harun H, Baktir A. 2024. Evaluation of the microplastics in bivalves and water column at Pantai Teluk Likas, North Borneo, Malaysia. *Environ. Sci. Pollut. Res.* 31: 23178–23192. DOI: 10.1007/s11356-024-32628-z.

Abelouah MR, Ben-Haddad M, Hajji S, Nouj N, Ouheddou M, Mghili B, De-la-Torre GE, Costa LL, Banni M, Ait Alla A. 2024. Exploring marine biofouling on anthropogenic litter in the Atlantic coastline of Morocco. *Mar. Pollut. Bull.* 199: 115938. DOI: 10.1016/j.marpolbul.2023.115938.

Alam MJ, Shammi M, Tareq SM. 2023. Distribution of microplastics in shoreline water and sediment of the Ganges River Basin to Meghna Estuary in Bangladesh. *Ecotoxicol. Environ. Saf.* 266: 115537. DOI: 10.1016/j.ecoenv.2023.115537.

Babaremu KO, Okoya SA, Hughes E, Tijani B, Teidi D, Akpan A, Igwe J, Karera S, Oyinlola M, Akinlabi ET. 2022. Sustainable plastic waste management in a circular economy. *Heliyon* 8: e09984. DOI: doi.org/10.1016/j.heliyon.2022.e09984.

Barnes DKA, Galgani F, Thompson RC, Barlaz M. 2009. Accumulation and fragmentation of plastic debris in global environments. *Philos. Trans. R. Soc. B Biol. Sci.* 364: 1985–1998. DOI: 10.1098/rstb.2008.0205.

Barrientos M, Vásquez Lavín F, Ponce Oliva RD, Nayga RM, Gelcich S. 2024. Microplastics in seafood: Consumer preferences and valuation for mitigation technologies. *Food Res. Int.* 187: 114342. DOI: 10.1016/j.foodres.2024.114342.

Bayo J, Rojo D, Olmos S. 2022. Weathering indices of microplastics along marine and coastal sediments from the harbor of Cartagena (Spain) and its adjoining urban beach. *Mar. Pollut. Bull.* 178: 113647. DOI: 10.1016/j.marpolbul.2022.113647.

Belzagui F, Gutiérrez-Bouzán C. 2022. Review on alternatives for the reduction of textile microfibers emission to water. *J. Environ. Manage.* 317: 115347. DOI: 10.1016/j.jenvman.2022.115347.

Boerema A, Meire P. 2017. Management for estuarine ecosystem services: A review. *Ecol. Eng.* 98: 172–182. DOI: doi.org/10.1016/j.ecoleng.2016.10.051.

Bonifacio PSP, Metillo EB, Romano EF. 2022. Microplastic in Sediments and Ingestion Rates in Three Edible Bivalve Mollusc Species in a Southern Philippine Estuary. *Water. Air. Soil Pollut.* 233. DOI: 10.1007/s11270-022-05926-w.

Borrelle SB, Ringma J, Law KL, Monnahan CC, Lebreton L, McGivern A, Murphy E, et al. 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science (80-.).* 369: 1515–1518. DOI: 10.1126/science.aba3656.

Caruso G. 2019. Microplastics as vectors of contaminants. *Mar. Pollut. Bull.* 146: 921–924. DOI: 10.1016/j.marpolbul.2019.07.052.

Castro-Jiménez J, Aminot Y, Bely N, Pollono C, Idjaton BIT, Bizzozero L, Pierre-Duplessix O, Phuong NN, Gasperi J. 2024. Organophosphate ester additives and microplastics in benthic compartments from the Loire estuary (French Atlantic coast). *Mar. Pollut. Bull.* 201. DOI: 10.1016/j.marpolbul.2024.116256.

Cheng Z, Ma Y, Fan X, Wang Q, Liu Y, You Z. 2024. Historical behaviors of microplastic in estuarine and riverine reservoir sediment. *Mar. Pollut. Bull.* 202. DOI: 10.1016/j.marpolbul.2024.116331.

Costa MB da, Otegui MBP, Zamprogno GC, Caniçali FB, dos Reis Cozer C, Pelletier E, Graceli JB. 2023. Abundance, composition, and distribution of microplastics in intertidal sediment and soft tissues of four species of Bivalvia from Southeast Brazilian urban beaches. *Sci. Total Environ.* 857: 159352. DOI: 10.1016/j.scitotenv.2022.159352.

Dai L, Wang Z, Guo T, Hu L, Chen Y, Chen C, Yu G, Ma LQ, Chen J. 2022. Pollution characteristics and source analysis of microplastics in the Qiantang River in southeastern China. *Chemosphere* 293: 133576. DOI: 10.1016/j.chemosphere.2022.133576.

Diansyah G, Rozirwan, Rahman MA, Nugroho RY, Syakti AD. 2024. Dynamics of microplastic abundance under tidal fluctuation in Musi estuary, Indonesia. *Mar. Pollut. Bull.* 203: 116431. DOI: doi.org/10.1016/j.marpolbul.2024.116431.

Ding J-F, LI J-X, Sun C-J, He C-F, Jiang F-H, Gao F-L, Zheng L. 2018. Separation and Identification of Microplastics in Digestive System of Bivalves. *Chinese J. Anal. Chem.* 46: 690–697. DOI: 10.1016/S1872-2040(18)61086-2.

Ding J, Sun C, He C, Li J, Ju P, Li F. 2021. Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. *Sci. Total Environ.* 782: 146830. DOI: 10.1016/j.scitotenv.2021.146830.

Dwiyitno D, Schwanen C, Januar HI, Ariyani F, Irianto HE, Schwarzbauer J. 2024. Microplastic profile in the sediment of Jakarta Bay estuary, Indonesia: Characterization based on size fraction and the potential risk to the ecosystem. *Reg. Stud. Mar. Sci.* 73: 103465. DOI: 10.1016/j.rsma.2024.103465.

Edwin T, Primasari B, Annisa Purnama R. 2023. Characterization of microplastic in trawl fish caught in Padang City (Indonesia) coastal area. *Biodiversitas* 24: 516–522. DOI: 10.13057/biodiv/d240160.

Eo S, Hong SH, Cho Y, Song YK, Han GM, Shim WJ. 2023. Spatial distribution and historical trend of microplastic pollution in sediments from enclosed bays of South Korea. *Mar. Pollut. Bull.* 193: 115121. DOI: 10.1016/j.marpolbul.2023.115121.

Evode N, Qamar SA, Bilal M, Barceló D, Iqbal HMN. 2021. Plastic waste and its management strategies for environmental sustainability. *Case Stud. Chem. Environ. Eng.* 4: 100142. DOI: doi.org/10.1016/j.cscee.2021.100142.

Fauziyah, Nurjuliasti Ningsih E, Arnando E, Fatimah, Agustriani F, Supriyadi F. 2023. Effect of hauling and soaking time of stationary lift nets on fish aggregation using a hydroacoustic monitoring approach. *Egypt. J. Aquat. Res.* 49: 339–346. DOI: 10.1016/j.ejar.2023.05.003.

Fauziyah, Setiawan A, Agustriani F, Rozirwan, Melki, Nurjuliasti Ningsih E, Ulqodry TZ. 2022. Distribution pattern of potential fishing zones in the Bangka Strait waters: An application of the remote sensing technique. *Egypt. J. Remote Sens. Sp. Sci.* 25: 257–265. DOI: doi.org/10.1016/j.ejrs.2021.12.003.

Feng Q, An C, Chen Z, Lee K, Wang Z. 2023. Identification of the driving factors of microplastic load and morphology in estuaries for improving monitoring and management strategies: A global meta-analysis. *Environ. Pollut.* 333: 122014. DOI: 10.1016/j.envpol.2023.122014.

Feng Q, Chen Z, An C, Yang X, Wang Z. 2023. Tide-induced infiltration and resuspension of microplastics in shorelines: Insights from tidal tank experiments. *Water Res.* 236: 119970. DOI: 10.1016/j.watres.2023.119970.

Firdaus M, Trihadiningrum Y, Lestari P. 2020. Microplastic pollution in the sediment of Jagir Estuary, Surabaya City, Indonesia. *Mar. Pollut. Bull.* 150: 110790. DOI: 10.1016/j.marpolbul.2019.110790.

Fitri S, Patria MP. 2019. Microplastic contamination on Anadara granosa Linnaeus 1758 in Pangkal Babu mangrove forest area, Tanjung Jabung Barat district, Jambi. *J. Phys. Conf. Ser.* 1282. DOI: 10.1088/1742-6596/1282/1/012109.

Fitria Y, Fitrani M, Nugroho RY, Putri WAE. 2023. Gastropods as bioindicators of heavy metal pollution in the Banyuasin estuary shrimp pond area, South Sumatra, Indonesia. *Acta Ecol. Sin.* 43: 1129–1137.

Frias JPGL, Nash R. 2019. Microplastics: Finding a consensus on the definition. *Mar. Pollut. Bull.* 138: 145–147. DOI: 10.1016/j.marpolbul.2018.11.022.

Fu L, Li J, Wang G, Luan Y, Dai W. 2021. Adsorption behavior of organic pollutants on microplastics. *Ecotoxicol. Environ. Saf.* 217: 112207. DOI: 10.1016/j.ecoenv.2021.112207.

Gan Q, Cui J, Jin B. 2023. Environmental microplastics: Classification, sources, fates, and effects on plants. *Chemosphere* 313: 137559. DOI: 10.1016/j.chemosphere.2022.137559.

Gong J, Xie P. 2020. Research progress in sources, analytical methods, eco-environmental effects, and control measures of microplastics. *Chemosphere* 254: 126790. DOI: 10.1016/j.chemosphere.2020.126790.

Griffiths JR, Kadin M, Nascimento FJA, Tamelander T, Törnroos A, Bonaglia S, Bonsdorff E, Brüchert V, Gårdmark A, Järnström M. 2017. The importance of benthic–pelagic coupling for marine ecosystem functioning in a changing world. *Glob. Chang. Biol.* 23: 2179–2196.

Guo J-J, Huang X-P, Xiang L, Wang Y-Z, Li Y-W, Li H, Cai Q-Y, Mo C-H, Wong M-H. 2020. Source, migration and toxicology of microplastics in soil. *Environ. Int.* 137: 105263. DOI: 10.1016/j.envint.2019.105263.

Han X, Wu H, Li Q, Cai W, Hu S. 2024. Assessment of heavy metal accumulation and potential risks in surface sediment of estuary area: A case study of Dagu river. *Mar. Environ. Res.* 196: 106416. DOI: doi.org/10.1016/j.marenvres.2024.106416.

Harris PT. 2020. The fate of microplastic in marine sedimentary environments: A review and synthesis. *Mar. Pollut. Bull.* 158: 111398. DOI: 10.1016/j.marpolbul.2020.111398.

Hecker M, Peijnenburg W, Lam PKS, Brinkmann M. 2023. Emerging issues in aquatic toxicology – Plastic pollution. *Aquat. Toxicol.* 264. DOI: 10.1016/j.aquatox.2023.106729.

Ismanto A, Hadibarata T, Kristanti RA, Sugianto DN, Widada S, Atmodjo W, Satriadi A, Anindita MA, Al-Mohaimeed AM, Abbasi AM. 2023. A novel report on the occurrence of microplastics in Pekalongan River Estuary, Java Island, Indonesia. *Mar. Pollut. Bull.* 196: 115563. DOI: 10.1016/j.marpolbul.2023.115563.

Isroni W, Sari PDW, Sari LA, Daniel K, South J, Islamy RA, Wirabuana PYAP, Hasan V. 2023. Checklist of mangrove snails (Gastropoda: Mollusca) on the coast of Lamongan District, East Java, Indonesia. *Biodiversitas* 24: 1676–1685. DOI: 10.13057/biodiv/d240341.

Issac MN, Kandasubramanian B. 2021. Effect of microplastics in water and aquatic systems. *Environ. Sci. Pollut. Res.* 28: 19544–19562. DOI: 10.1007/s11356-021-13184-2.

Jacq K, Debret M, Gardes T, Demarest M, Humbert K, Portet-Koltalo F. 2024. Spatial distribution of polycyclic aromatic hydrocarbons in sediment deposits in a Seine estuary tributary by hyperspectral imaging. *Sci. Total Environ.* 950: 175306. DOI: doi.org/10.1016/j.scitotenv.2024.175306.

Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL. 2015. Plastic waste inputs from land into the ocean. *Science (80-.).* 347: 768–771.

Jeong E, Lee J-Y, Redwan M. 2024. Animal exposure to microplastics and health effects: A review. *Emerg. Contam.* 10: 100369. DOI: doi.org/10.1016/j.emcon.2024.100369.

Jeyavani J, Sibiya A, Shanthini S, Ravi C, Vijayakumar S, Rajan DK, Vaseeharan B. 2021. A Review on Aquatic Impacts of Microplastics and Its Bioremediation Aspects. *Curr. Pollut. Reports* 7: 286–299. DOI: 10.1007/s40726-021-00188-2.

Jin X, Fu X, Lu W, Wang H. 2022. Fugitive release and influencing factors of microplastics in urbanized watersheds: A case study of the central area of Suzhou City. *Sci. Total Environ.* 837: 155653. DOI: 10.1016/j.scitotenv.2022.155653.

Kandeyaya KBKDK, Ranatunga S, Ranatunga RRMKP. 2023. Occurrence of microplastics in some commercially important seafood varieties from Negombo, Sri Lanka. *Reg. Stud. Mar. Sci.* 62: 102958. DOI: doi.org/10.1016/j.rsma.2023.102958.

Karami A, Golieskardi A, Choo CK, Romano N, Ho Y Bin, Salamatinia B. 2017. A high-performance protocol for extraction of microplastics in fish. *Sci. Total Environ.* 578: 485–494. DOI: 10.1016/j.scitotenv.2016.10.213.

Kılıç S, Kılıç Ö, Belivermiş M, Ergül HA. 2023. Chronology of PAH and PCB pollution using sediment core in the Golden Horn estuary (Sea of Marmara). *Mar. Pollut. Bull.* 187: 114570. DOI: doi.org/10.1016/j.marpolbul.2023.114570.

Kunz A, Schneider F, Anthony N, Lin H-T. 2023. Microplastics in rivers along an urban-rural gradient in an urban agglomeration: Correlation with land use, potential sources and pathways. *Environ. Pollut.* 321: 121096. DOI: 10.1016/j.envpol.2023.121096.

Lee H, Kim S, Sin A, Kim G, Khan S, Nadagouda MN, Sahle-Demessie E, Han C. 2023. Pretreatment methods for monitoring microplastics in soil and freshwater sediment samples: A comprehensive review. *Sci. Total Environ.* 871: 161718. DOI: 10.1016/j.scitotenv.2023.161718.

Li G, Chen Z, Bowen M, Coco G. 2024. Transport and retention of sinking microplastics in a well-mixed estuary. *Mar. Pollut. Bull.* 203: 116417. DOI: 10.1016/j.marpolbul.2024.116417.

Li J, Zhang L, Dang X, Su L, Jabeen K, Wang H, Wang Z. 2022. Effects of cooking methods on microplastics in dried shellfish. *Sci. Total Environ.* 837: 155787. DOI: doi.org/10.1016/j.scitotenv.2022.155787.

Li W, Wang Z, Li W, Li Z. 2022. Impacts of microplastics addition on sediment environmental properties, enzymatic activities and bacterial diversity. *Chemosphere* 307: 135836. DOI: 10.1016/j.chemosphere.2022.135836.

Li Y, Chen L, Zhou N, Chen Y, Ling Z, Xiang P. 2024. Microplastics in the human body: A comprehensive review of exposure, distribution, migration mechanisms, and toxicity. *Sci. Total Environ.* 946: 174215. DOI: 10.1016/j.scitotenv.2024.174215.

Li Z, Chao M, He X, Lan X, Tian C, Feng C, Shen Z. 2022. Microplastic bioaccumulation in estuary-caught fishery resource. *Environ. Pollut.* 306: 119392. DOI: 10.1016/j.envpol.2022.119392.

Liang W, Li B, Jong M-C, Ma C, Zuo C, Chen Q, Shi H. 2023. Process-oriented impacts of microplastic fibers on behavior and histology of fish. *J. Hazard. Mater.* 448: 130856. DOI: 10.1016/j.jhazmat.2023.130856.

Liebezeit G, Dubaish F. 2012. Microplastics in beaches of the East Frisian islands Spiekeroog and Kachelotplate. *Bull. Environ. Contam. Toxicol.* 89: 213–217.

Lin L, Zhang X, Yuan B, Li H, Lu H, Liu J, Hong H, Yan C. 2023. Effects of Biofouling on the Properties and Sinking Behavior of Disposable Face Masks in Seawater: A Systematic Comparison with Microplastic Films and Particles. *Environ. Sci. Technol. Lett.* 10: 792–797. DOI: 10.1021/acs.estlett.3c00460.

Lonsdale J-A, Leach C, Parsons D, Barkwith A, Manson S, Elliott M. 2022. Managing estuaries under a changing climate: A case study of the Humber Estuary, UK. *Environ. Sci. Policy* 134: 75–84. DOI: doi.org/10.1016/j.envsci.2022.04.001.

Mahary A, Effendi I, Hendrik H, Darwis D. 2023. Strategy for development of blood cockles (Anadara granosa) cultivation in Batubara Regency, North Sumatera, Indonesia. *AACL Bioflux* 16: 1636–1647.

Maherlsa R, Purwiyanto AIS, Agustriani F, Putri WAE, Fauziyah, Ferdiansyah. 2019. Identification of surface macro debrisin river flow and estuary of Musi River, South Sumatera Province, Indonesia. *J. Phys. Conf. Ser.* 1282: 12106. DOI: 10.1088/1742-6596/1282/1/012106.

Malinowski CR, Searle CL, Schaber J, Höök TO. 2023. Microplastics impact simple aquatic food web dynamics through reduced zooplankton feeding and potentially releasing algae from consumer control. *Sci. Total Environ.* 904: 166691. DOI: 10.1016/j.scitotenv.2023.166691.

Malli A, Corella-Puertas E, Hajjar C, Boulay AM. 2022. Transport mechanisms and fate of microplastics in estuarine compartments: A review. *Mar. Pollut. Bull.* 177: 113553. DOI: 10.1016/j.marpolbul.2022.113553.

Meiyerani J, Melki M, Aryawati R, Rozirwan R, Ningsih EN, Wulandari TNM, Nugroho RY. 2024. 16S rRNA gen analysis of plastic destruction bacteries, South Sumatra, Indonesia. *J. Ecol. Eng.* 25.

Mohan P, Shahul Hamid F, Furumai H, Nishikawa K. 2024. Beneath the surface: Exploring microplastic intricacies in Anadara granosa. *Mar. Environ. Res.* 199: 106581. DOI: 10.1016/j.marenvres.2024.106581.

Namira N, Daud A, Mallongi A, Amqam H, Wahyu A, Irwandy I. 2023. Risk Analysis of Microplastic Exposure Through Consumption of Anadara Granosa at Coastal Area. *Pharmacogn. J.* 15: 558–562. DOI: 10.5530/pj.2023.15.119.

Napper IE, Bakir A, Rowland SJ, Thompson RC. 2015. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. *Mar. Pollut. Bull.* 99: 178–185. DOI: 10.1016/j.marpolbul.2015.07.029.

Narmatha Sathish M, Immaculate Jeyasanta K, Patterson J. 2020. Monitoring of microplastics in the clam Donax cuneatus and its habitat in Tuticorin coast of Gulf of Mannar (GoM), India. *Environ. Pollut.* 266: 115219. DOI: 10.1016/j.envpol.2020.115219.

Ningrum EW, Patria MP. 2022. Microplastic contamination in Indonesian anchovies from fourteen locations. *Biodiversitas* 23: 125–134. DOI: 10.13057/biodiv/d230116.

Pannetier P, Morin B, Le Bihanic F, Dubreil L, Clérandeau C, Chouvellon F, Van Arkel K, Danion M, Cachot J. 2020. Environmental samples of microplastics induce significant toxic effects in fish larvae. *Environ. Int.* 134: 105047. DOI: doi.org/10.1016/j.envint.2019.105047.

Patria MP, Kholis N, Anggreini D, Buyong F. 2023. Abundance and distribution of microplastics in seawater, sediment, and macroalgae sea grapes Caulerpa racemosa from Semak Daun Island, Jakarta Bay, Indonesia. *Biodiversitas J. Biol. Divers.* 24. DOI: 10.13057/biodiv/d240638.

Perumal K, Muthuramalingam S. 2022. Global sources, abundance, size, and distribution of microplastics in marine sediments - A critical review. *Estuar. Coast. Shelf Sci.* 264: 107702. DOI: 10.1016/j.ecss.2021.107702.

Potipat J, Srimoon R, Mekprayoon S. 2024. Microplastic contamination in the Chanthaburi estuarine ecosystem, Eastern part of Thailand. *J. Environ. Biol.* 45: 152–160. DOI: 10.22438/jeb/45/2/MRN-5210.

Prasetiyono E, Nirmala K, Supriyono E, Sukenda, Hastuti YP. 2022. Analysis of environmental quality, production performance and economic feasibility of Anadara granosa cultivation in Sukal, Bangka Belitung Province. *AACL Bioflux* 15: 2881–2891.

Praveena SM, Shaifuddin SNM, Akizuki S. 2018. Exploration of microplastics from personal care and cosmetic products and its estimated emissions to marine environment: An evidence from Malaysia. *Mar. Pollut. Bull.* 136: 135–140. DOI: 10.1016/j.marpolbul.2018.09.012.

Purwiyanto AIS, Prartono T, Riani E, Koropitan AF, Naulita Y, Takarina ND, Cordova MR. 2022. The contribution of estuaries to the abundance of microplastics in Jakarta Bay, Indonesia. *Mar. Pollut. Bull.* 184: 114117. DOI: 10.1016/j.marpolbul.2022.114117.

Purwiyanto AIS, Suteja Y, Trisno, Ningrum PS, Putri WAE, Rozirwan, Agustriani F, Fauziyah, Cordova MR, Koropitan AF. 2020. Concentration and adsorption of Pb and Cu in microplastics: Case study in aquatic environment. *Mar. Pollut. Bull.* 158: 111380. DOI: 10.1016/j.marpolbul.2020.111380.

Rafa N, Ahmed B, Zohora F, Bakya J, Ahmed S, Ahmed SF, Mofijur M, Chowdhury AA, Almomani F. 2024. Microplastics as carriers of toxic

pollutants: Source, transport, and toxicological effects. *Environ. Pollut.* 343: 123190. DOI: 10.1016/j.envpol.2023.123190.
Ragaert K, Delva L, Van Geem K. 2017. Mechanical and chemical recycling of solid plastic waste. *Waste Manag.* 69: 24–58. DOI: doi.org/10.1016/j.wasman.2017.07.044.
Rahmatin NM, Soegianto A, Irawan B, Payus CM, Indriyasari KN, Marchellina A, Mukholladun W, Irnidayanti Y. 2024. The spatial distribution and physico-chemical characteristic of microplastics in the sediment and cockle (Anadara granosa) from the coastal waters of East Java, Indonesia, and the health hazards associated with cockle consumption. *Mar. Pollut. Bull.* 198. DOI: 10.1016/j.marpolbul.2023.115906.
Rahutami S, Said M, Ibrahim E, Herpandi. 2022. Actual Status Assessment and Prediction of the Musi River Water Quality, Palembang, South Sumatra, Indonesia. *J. Ecol. Eng.* 23: 68–79. DOI: 10.12911/22998993/152284.
Retnaningdyah C, Febriansyah SC, Hakim L. 2022. Evaluation of the quality of mangrove ecosystems using macrozoobenthos as bioindicators in the Southern Coast of East Java, Indonesia. *Biodiversitas* 23: 6480–6491. DOI: 10.13057/biodiv/d231247.
Rillig MC. 2012. Microplastic in Terrestrial Ecosystems and the Soil? *Environ. Sci. Technol.* 46: 6453–6454. DOI: 10.1021/es302011r.
Rimadiyani W, Krisanti M, Sulistiono S. 2019. Macrozoobenthos community structure in the Western Segara Anakan Lagoon, Central Java, Indonesia. *Biodiversitas J. Biol. Divers.* 20.
Rozirwan, Az-Zahrah SAF, Khotimah NN, Nugroho RY, Putri WAE, Fauziyah, Melki, Agustriani F, Siregar YI. 2024. Ecological Risk Assessment of Heavy Metal Contamination in Water, Sediment, and Polychaeta (Neoleanira Tetragona) from Coastal Areas Affected by Aquaculture, Urban Rivers, and Ports in South Sumatra. *J. Ecol. Eng.* 25: 303–319. DOI: 10.12911/22998993/175365.
Rozirwan, Fauziyah, Wulandari PI, Nugroho RY, Agutriani F, Agussalim A, Supriyadi F, Iskandar I. 2022. Assessment distribution of the phytoplankton community structure at the fishing ground, Banyuasin estuary, Indonesia. *Acta Ecol. Sin.* 42: 670–678. DOI: 10.1016/j.chnaes.2022.02.006.
Rozirwan, Iskandar I, Hendri M, Apri R, Supardi, Azhar N, Mardiansyah W. 2019. Distribution of phytoplankton diversity and abundance in Maspari island waters, South Sumatera, Indonesia. *J. Phys. Conf. Ser.* 1282: 012105. DOI: 10.1088/1742-6596/1282/1/012105.
Rozirwan, Melki, Apri R, Fauziyah, Agussalim A, Hartoni, Iskandar I. 2021. Assessment the macrobenthic diversity and community structure in the Musi Estuary, South Sumatra, Indonesia. *Acta Ecol. Sin.* 41: 346–350. DOI: 10.1016/J.CHNAES.2021.02.015.
Rozirwan, Nugroho RY, Hendri M, Fauziyah, Putri WAE, Agussalim A. 2022. Phytochemical profile and toxicity of extracts from the leaf of Avicennia marina (Forssk.) Vierh. collected in mangrove areas affected by port activities. *South African J. Bot.* 150: 903–919. DOI: 10.1016/J.SAJB.2022.08.037.
Rozirwan R, Fauziyah F, Nugroho RY, Melki M, Ulqodry TZ, Agustriani F, Ningsih EN, Putri WAE, Absori A, Iqbal M. 2022. An ecological assessment of crab's diversity among habitats of migratory birds at Berbak-Sembilang National Park Indonesia. *Int. J. Conserv. Sci.* 13: 961–972.
Rozirwan R, Khotimah NN, Putri WAE, Fauziyah F, Aryawati R, Damiri N, Isnaini I, Nugroho RY. 2023. Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment. *Biodiversitas J. Biol. Divers.* 24. DOI: doi.org/10.13057/biodiv/d241236.
Rozirwan R, Ramadani S, Putri WAE, Fauziyah, Khotimah NN, Nugroho RY. 2023. Evaluation of Calcium and Phosphorus content in Scallop Shells (Placuna placenta) and Blood Cockle Shells (Anadara granosa) from Banyuasin Waters, South Sumatra. *Egypt. J. Aquat. Biol. Fish.* 27: 1053–1068. DOI: 10.21608/EJABF.2023.309326.
Sahidin A, Zahidah Z, Herawati H, Wardianto Y, Setyobudiandi I, Partasasmita R. 2018. Macrozoobenthos as bioindicator of ecological status in Tanjung Pasir Coastal, Tangerang District, Banten Province, Indonesia. *Biodiversitas J. Biol. Divers.* 19: 1123–1129. DOI: 10.13057/biodiv/d190347.
Saleh R, Daud A, Ishak H, Amqam H, Wahyu A, Stang, Birawida AB, Mallongi A. 2023. Spatial Distribution of Microplastic Contamination in Blood Clams (Anadara granosa) on the Jeneponto Coast, South Sulawesi. *Pharmacogn. J.* 15: 680–690. DOI: 10.5530/pj.2023.15.137.
Samuels W, Awe A, Sparks C. 2024. Microplastic pollution and risk assessment in surface water and sediments of the Zandvlei Catchment and estuary, Cape Town, South Africa. *Environ. Pollut.* 342: 122987. DOI: 10.1016/j.envpol.2023.122987.
Santucci L, Fernández-Severini MD, Rimondino GN, Colombo C V., Prieto G, Forero-López AD, Carol ES. 2024. Assessment of meso- and microplastics distribution in coastal sediments and waters at the middle estuary of the Rio De La Plata, Argentina (SW Atlantic Ocean). *Sci. Total Environ.* 914. DOI: 10.1016/j.scitotenv.2024.170026.
Sari A, Tuwo A, Saru A, Rani C. 2022. Diversity of fauna species in the mangrove ecosystem of Youtefa Bay Tourism Park, Papua, Indonesia. *Biodiversitas* 23: 4490–4500. DOI: 10.13057/biodiv/d230915.
Sudradjat A, Muntalif BS, Marasabessy N, Mulyadi F, Firdaus MI. 2024. Relationship between chlorophyll-a, rainfall, and climate phenomena in tropical archipelagic estuarine waters. *Heliyon* 10: e25812. DOI: doi.org/10.1016/j.heliyon.2024.e25812.
Surbakti H, Nurjaya IW, Bengen DG, Pratanto T. 2023. Temporal variation of freshwater as control of mangrove in Banyuasin Estuary, South Sumatra, Indonesia. *Biodiversitas J. Biol. Divers.* 24.
Suteja Y, Purwiyanto AIS, Purbonegoro T, Cordova MR. 2024. Spatial and temporal trends of microplastic contamination in surface sediment of Benoa Bay: An urban estuary in Bali-Indonesia. *Mar. Pollut. Bull.* 202: 116357. DOI: 10.1016/j.marpolbul.2024.116357.
Ta AT, Babel S. 2023. Occurrence and spatial distribution of microplastic contaminated with heavy metals in a tropical river: Effect of land use and population density. *Mar. Pollut. Bull.* 191: 114919. DOI: 10.1016/j.marpolbul.2023.114919.
Tang C, Li Y, He C, Acharya K. 2020. Dynamic behavior of sediment resuspension and nutrients release in the shallow and wind-exposed Meiliang Bay of Lake Taihu. *Sci. Total Environ.* 708: 135131. DOI: 10.1016/j.scitotenv.2019.135131.
Thacharodi A, Meenatchi R, Hassan S, Hussain N, Bhat MA, Arockiaraj J, Ngo HH, Le QH, Pugazhendhi A. 2024. Microplastics in the environment: A critical overview on its fate, toxicity, implications, management, and bioremediation strategies. *J. Environ. Manage.* 349: 119433. DOI: 10.1016/j.jenvman.2023.119433.
Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, McGonigle D, Russell AE. 2004. Lost at sea: where is all the plastic? *Science (80-.).* 304: 838.
Thu Nguyen HT. 2024. Promoting sustainable consumption and circular economy: the intention of Vietnamese youth consumers to purchase products made from recycled plastics. *Chinese J. Popul. Resour. Environ.* 22: 194–203. DOI: doi.org/10.1016/j.cjpre.2024.06.011.
Tomlinson DL, Wilson JG, Harris CR, Jeffrey DW. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer Meeresuntersuchungen* 33: 566–575.
Truchet DM, López ADF, Ardusso MG, Rimondino GN, Buzzi NS, Malanca FE, Spetter CV, Severini MDF. 2021. Microplastics in bivalves, water and sediments from a touristic sandy beach of Argentina. *Mar. Pollut. Bull.* 173: 113023. DOI: 10.1016/j.marpolbul.2021.113023.
Ukhrowi HR, Wardhana W, Patria MP. 2021. Microplastic abundance in blood cockle Anadara granosa (linnaeus, 1758) at Lada Bay, Pandeglang, Banten. *J. Phys. Conf. Ser.* 1725: 012053. DOI: 10.1088/1742-6596/1725/1/012053.
Unuofin JO, Igwaran A. 2023. Microplastics in seafood: Implications for food security, safety, and human health. *J. Sea Res.* 194: 102410. DOI: 10.1016/j.seares.2023.102410.
Vital SA, Cardoso C, Avio C, Pittura L, Regoli F, Bebianno MJ. 2021. Do microplastic contaminated seafood consumption pose a potential risk to human health? *Mar. Pollut. Bull.* 171: 112769. DOI: 10.1016/j.marpolbul.2021.112769.
Walker TR, Fequet L. 2023. Current trends of unsustainable plastic production and micro(nano)plastic pollution. *TrAC - Trends Anal. Chem.* 160: 116984. DOI: 10.1016/j.trac.2023.116984.
Wang G, Lu J, Li W, Ning J, Zhou L, Tong Y, Liu Z, Zhou H, Xiayihazi N. 2021. Seasonal variation and risk assessment of microplastics in surface water of the Manas River Basin, China. *Ecotoxicol. Environ. Saf.* 208: 111477. DOI: 10.1016/j.ecoenv.2020.111477.

Wang Y, Wu Y, Pu Q, Sun P, Zhao W, Liu M, Li Y. 2023. Aquatic toxicity of tire microplastics on marine and freshwater organisms: An in silico approach. *Chemosphere* 313. DOI: 10.1016/j.chemosphere.2022.137523.

Ward JE, Zhao S, Holohan BA, Mladinich KM, Griffin TW, Wozniak J, Shumway SE. 2019. Selective Ingestion and Egestion of Plastic Particles by the Blue Mussel (Mytilus edulis) and Eastern Oyster (Crassostrea virginica): Implications for Using Bivalves as Bioindicators of Microplastic Pollution. *Environ. Sci. Technol.* 53: 8776–8784. DOI: 10.1021/acs.est.9b02073.

Winiarska E, Jutel M, Zemelka-Wiacek M. 2024. The potential impact of nano- and microplastics on human health: Understanding human health risks. *Environ. Res.* 251: 118535. DOI: 10.1016/j.envres.2024.118535.

Wu H, Hou J, Wang X. 2023. A review of microplastic pollution in aquaculture: Sources, effects, removal strategies and prospects. *Ecotoxicol. Environ. Saf.* 252: 114567. DOI: 10.1016/j.ecoenv.2023.114567.

Xu K, Shahab A, Rinklebe J, Xiao H, Li J, Ye F, Li Y, Wang D, Bank MS, Wei G. 2024. Spatial distribution, morphology, and risk assessment of microplastics in sediment from the Pearl River Estuary, China. *Emerg. Contam.* 10: 100383. DOI: 10.1016/j.emcon.2024.100383.

Xu P, Peng G, Su L, Gao Y, Gao L, Li D. 2018. Microplastic risk assessment in surface waters: A case study in the Changjiang Estuary, China. *Mar. Pollut. Bull.* 133: 647–654.

Xu Q, Xing R, Sun M, Gao Y, An L. 2020. Microplastics in sediments from an interconnected river-estuary region. *Sci. Total Environ.* 729: 139025. DOI: 10.1016/j.scitotenv.2020.139025.

Yang X, An C, Feng Q, Boufadel M, Ji W. 2022. Aggregation of microplastics and clay particles in the nearshore environment: Characteristics, influencing factors, and implications. *Water Res.* 224: 119077. DOI: 10.1016/j.watres.2022.119077.

Yuan B, Gan W, Sun J, Lin B, Chen Z. 2023. Depth profiles of microplastics in sediments from inland water to coast and their influential factors. *Sci. Total Environ.* 903: 166151. DOI: 10.1016/j.scitotenv.2023.166151.

Yuan B, Gan W, Sun J, Lin B, Chen Z, Li WW, Wang Z, Li WW, Li Z, Rillig MC. 2022. Depth profiles of microplastics in sediments from inland water to coast and their influential factors. *Environ. Sci. Technol.* 903: 6453–6454. DOI: 10.1016/j.scitotenv.2023.166151.

Yuan Z, Nag R, Cummins E. 2022. Human health concerns regarding microplastics in the aquatic environment - From marine to food systems. *Sci. Total Environ.* 823: 153730. DOI: 10.1016/j.scitotenv.2022.153730.

Yulinda E, Saad M, Yusuf M. 2020. A study on the economic potential of blood cockles (Anadara granosa) in Rokan Hilir, Riau Province, Indonesia. *AACL Bioflux* 13: 1504–1510.

Zhang K, Hamidian AH, Tubić A, Zhang Y, Fang JKH, Wu C, Lam PKS. 2021. Understanding plastic degradation and microplastic formation in the environment: A review. *Environ. Pollut.* 274. DOI: 10.1016/j.envpol.2021.116554.

Zhang Z, Cui Q, Chen L, Zhu X, Zhao S, Duan C, Zhang X, Song D, Fang L. 2022. A critical review of microplastics in the soil-plant system: Distribution, uptake, phytotoxicity and prevention. *J. Hazard. Mater.* 424: 127750. DOI: 10.1016/j.jhazmat.2021.127750.

Zhao J, Feng X, Shi X, Bai Y, Yu X, Shi X, Zhang W, Zhang R. 2015. Sedimentary organic and inorganic records of eutrophication and hypoxia in and off the Changjiang Estuary over the last century. *Mar. Pollut. Bull.* 99: 76–84. DOI: doi.org/10.1016/j.marpolbul.2015.07.060.

Zhao X, Chen H, Jia Q-L, Shen C-S, Zhu Y, Li L, Nie Y-H, Ye J-F. 2020. [Pollution Status and Pollution Behavior of Microplastic in Surface Water and Sediment of Urban Rivers]. *Huan Jing Ke Xue= Huanjing Kexue* 41: 3612–3620. DOI: 10.13227/j.hjkx.201912236.

Zheng Y, Li J, Cao W, Jiang F, Zhao C, Ding H, Wang M, Gao F, Sun C. 2020. Vertical distribution of microplastics in bay sediment reflecting effects of sedimentation dynamics and anthropogenic activities. *Mar. Pollut. Bull.* 152: 110885. DOI: 10.1016/j.marpolbul.2020.110885.

Zhou Z, Zhang P, Zhang G, Wang S, Cai Y, Wang H. 2021. Vertical microplastic distribution in sediments of Fuhe River estuary to Baiyangdian Wetland in Northern China. *Chemosphere* 280: 130800. DOI: 10.1016/j.chemosphere.2021.130800.

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

1 pesan

Smujo Editors via SMUJO <support@smujo.com> 18 Maret 2025 pukul 13.58
Balas Ke: Smujo Editors <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

Rozirwan Rozirwan:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Implication of microplastics presence in sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia". **Complete your revision with a Table of Responses containing your answers to reviewer comments (for multiple comments) and/or enable Track Changes**. We are waiting for your revision in the system (https://smujo.id/biodiv), do not send it via email.

Our decision is: Revisions Required

Reviewer A:

This article has interesting and structured content but needs some revision. all suggestions are available in the text. Send revised files accompanied by track changes and a letter of objection in a separate file

Recommendation: Revisions Required

Biodiversitas Journal of Biological Diversity

A-19666 a.doc
5545K

Author(s)` Response to Reviewer :

Dear Reviewer,

We sincerely appreciate your time and effort in reviewing our manuscript and providing valuable feedback. Your insightful comments have been instrumental in improving the quality of our work. In response, we have carefully revised the manuscript accordingly. Please find our detailed responses to each of your suggestions below.

With kind regards,
The Author (s)

Table of Author(s)` Response

No	Comments	Respons
1.	Add references in Introduction	Thank you for your valuable suggestion. We have added relevant references in the Introduction section to support our statements and provide a stronger foundation for our study **(Lines 29-32)**
2.	More detailed condition of each site, such as vegetation, substrate, near industry etc	We have provided more specific description to sampling location Table **(Table 1)**
3.	Provide the figure of microplastics	We have added the Various forms of microplastics as Figure 3 **(Line 262)**
4.	Specimens	We have revised Morphology to Specimens **(Lines 375)**
5.	Delete this section **Lines 481 - 496**	We have deleted this section
6.	See guideline of References	We have revised the references

COVERING LETTER

Dear **Editor-in-Chief,**

I herewith enclosed a research article,

- ☑ The submission has not been previously published, nor is it before another journal for consideration (or an explanation has been provided in Comments to the Editor).
- ☑ The submission file is in OpenOffice, Microsoft Word (DOC, not DOCX), or RTF document file format.
- ☑ The text is single-spaced; uses a 10-point font; employs italics, rather than underlining (except with URL addresses); and all illustrations, figures, and tables are placed within the text at the appropriate points, rather than at the end.
- ☑ The text adheres to the stylistic and bibliographic requirements outlined in the Author Guidelines.
- ☑ Most of the references come from current scientific journals (c. 80% published in the last 10 years), except for taxonomic papers.
- ☑ Where available, DOIs for the references have been provided.
- ☑ When available, a certificate for proofreading is included.

SUBMISSION CHECKLIST

Ensure that the following items are present:

The first corresponding author must be accompanied with contact details:

- ☑ E-mail address
- ☑ Full postal address (incl street name and number (location), city, postal code, state/province, country)
- ☑ Phone and facsimile numbers (incl country phone code)

All necessary files have been uploaded, and contain:

- ☑ Keywords
- ☑ Running titles
- ☑ All figure captions
- ☑ All tables (incl title and note/description)

Further considerations

- ☑ Manuscript has been "spell & grammar-checked" Better, if it is revised by a professional science editor or a native English speaker
- ☑ References are in the correct format for this journal
- ☑ All references mentioned in the Reference list are cited in the text, and vice versa
- ☑ Colored figures are only used if the information in the text may be losing without those images
- ☑ Charts (graphs and diagrams) are drawn in black and white images; use shading to differentiate

Title:

Implication of microplastic presence in sediment and blood clams (*Anadara granosa*, Linnaeus 1758) (Mollusca: Bivalvia) in the Musi Estuary, Indonesia

Author(s) name:

M. AKBAR RAHMAN[1], ROZIRWAN[2♥], WIKE EKA AYU PUTRI[2], GUSTI DIANSYAH[2], MELKI [2], ICA DELYA [2], REDHO YOGA NUGROHO[2]

Address

(Fill in your institution's name and address, your personal cellular phone and email)

[1]Environmental Management Study Program, Graduate Program, Universitas Sriwijaya, Palembang 30139, South Sumatra, Indonesia

[2]Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, Ogan Ilir 30662, South Sumatra, Indonesia. Tel./fax.: +62-813-7171-1885, ♥email: rozirwan@unsri.ac.id

For possibility publication on the journal:

(fill in *Biodiversitas* or *Nusantara Bioscience* or *mention the others*)

- ☑ Biodiversitas Journal of Biological Diversity
- ☐ Nusantara Bioscience
- ☐ Prosiding Seminar Nasional Masyarakat Biodiversitas Indonesia
- ☐ Asian Journal of Agriculture
- ☐ Asian Journal of Ethnobiology
- ☐ Asian Journal of Forestry
- ☐ Asian Journal of Natural Product Biochemistry
- ☐ Asian Journal of Tropical Biotechnology
- ☐ International Journal of Bonorowo Wetlands
- ☐ Cell Biology and Development
- ☐ Indo Pacific Journal of Ocean Life
- ☐ International Journal of Tropical Drylands

Novelty:

(state your claimed novelty of the findings versus current knowledge)

This research is groundbreaking because there is currently no information available on the abundance of microplastics in sediments of the Musi Estuary, Indonesia. This article provides a comprehensive review of recent research on microplastics in the sediments of the Musi Estuary and their impact on benthic animals (*Anadara granosa*), one of the seafood from the Musi Estuary.

Statements:

This manuscript has not been published and is not under consideration for publication in any other journal or any other type of publication (including web hosting) either by me or any of my co-authors.

Author (s) has been read and agreed to the Ethical Guidelines.

List of five potential reviewers

(Fill in names of five potential reviewers **that agree to review your manuscpt** and their **email** addresses. He/she should have Scopus ID and come from different institution with the authors; and from at least three different countries)

1. Mohamad Fawzi Mahomoodally

Department of Health Sciences, Faculty of Science, University of Mauritius, 230 Réduit, Mauritius

Email f.mahomoodally@uom.ac.mu

Scopus ID: 9537009000

His skills and expertise in Phytochemicals, Natural Products, and Medicinal Plants are very benefical for reviewing our articles

2. Muthu Thiruvengadam, Ph.D

Department of Applied Bioscience, Konkuk University, Seoul

Email muthu@konkuk.ac.kr

Scopus ID: 13606231700

His skills and expertise in Natural Product, Medicinal and Pharmaceutical, Drug Discovery is very helpful for reviewing our articles

3. Benjamin Boucherle, Ph.D
Université Grenoble Alpes · Departement de Pharmacochimie Moléculaire
His skills and expertise in Natural Product, Medicinal and Pharmaceutical, Drug Discovery is very helpful for reviewing our articles
Benjamin.boucherle@univ-grenoble-alpes.fr
Scopus ID: 19638352500

4. Rodrigo Egydio Barreto, Ph.D
São Paulo State University, Departamento de Fisiologia, Centro De Aquicultura Da UNESP
His skills and expertise in marine biology are very helpful for reviewing our articles
rodrigo.egydio@unesp.br
Scopus ID: 7004866217

5. Prof. Dr. Bintal Amin
Marine Science Department, Faculty of fisheries and marine Science, University of Riau
bintal.amin@lecturer.unri.ac.id
Scopus ID: 23491429700

Place and date:

Palembang, September 30, 2024

Sincerely yours,
(fill in your name, no need scanned autograph)

Rozirwan

Implication of microplastic presence in sediment and blood clams *Anadara granosa* (Linnaeus 1758) (Mollusca: Bivalvia) in the Musi Estuary, Indonesia

M. AKBAR RAHMAN[1], ROZIRWAN[2♥], WIKE EKA AYU PUTRI[2], GUSTI DIANSYAH[2], MELKI[2], ICA DELYA[2], REDHO YOGA NUGROHO[2]

[1]Environmental Management Study Program, Graduate Program, Universitas Sriwijaya, Palembang 30139, South Sumatra, Indonesia
[2]Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, Ogan Ilir 30662, South Sumatra, Indonesia.
Tel./fax.: +62-813-7171-1885, ♥email: rozirwan@unsri.ac.id

Manuscript received: 30 September 2024. Revision accepted: .... 2024.

Abstract. Microplastic pollution poses a serious risk to estuarine ecosystems, affecting sediments and benthic species. Blood clams (*Anadara granosa*, Linnaeus 1758~~; Mollusca: Bivalvia~~) represent a significant commercial seafood product in Indonesia, including those from the Musi Estuary. This study investigated the risks associated with microplastic contamination in sediments and *A. granosa* in the Musi Estuary, located in South Sumatra, Indonesia. Sediment samples were extracted using sodium chloride (NaCl, 1.2 g cm^{-3}) and hydrogen peroxide (30% H_2O_2). In contrast, *A. granosa* samples were digested with 10% KOH for microplastic extraction. The abundance and shape of microplastics were analyzed from both samples. Pollution risk assessment was conducted through the calculation of the Pollution Load Index (PLI), Nemerow Pollution Index (NPI), and Bioconcentration Factor (BCF). The results revelved the presence of microplastics in sediments, with a mean abundance of 1.31±0.41 particles/g dw, while in *A. granosa*, it was 21.05±10.31 particles/ind. Both samples exhibited high microplastic bioaccumulation (NPI > 2), although the pollution load remained relatively low (minor category, PLI < 10). The bioconcentration factor between *A. granosa* and sediment was determined to be 23.28, indicating that the *A. granosa* absorbed microplastics present in the sediment~~microplastics present in the sediment were absorbed by the *A. granosa*~~. These findings highlight the significant bioaccumulation potential of microplastics in blood clams within the Musi Estuary. It is important for the local community and government to establish mitigations for future microplastic management efforts.

Keywords: Bioaccumulation, blood clams, microplastics, Musi Estuary, sediment

Running title: Microplastics in sediment and blood clams

INTRODUCTION

River estuaries are intricate and dynamic ecosystems that play a vital role in ecological sustainability and support a variety of socio-economic activities (Boerema and Meire 2017; Hasan et al. 2022; Retnaningdyah et al. 2022; Hasan et al. 2023). These ecosystems provide essential habitats for diverse species and act as focal points for human activities, including urbanization, recreation, and commercial enterprises (Islamy and Hasan 2020; Lonsdale et al. 2022; Natsir et al. 2022; Aunurrahman et al. 2023). Among the major estuaries in Sumatra, the Musi Estuary holds significant ecological and economic importance (Surbakti et al. 2023). It serves as a critical habitat for various fish species and benthic organisms, which in turn sustain the livelihoods of local communities through the utilization of water resources (Rozirwan et al. 2021; Fauziyah et al. 2022; Rozirwan et al. 2022; Fauziyah et al. 2023). Nevertheless, the intensification of human activities within and surrounding the Musi Estuary has resulted in significant environmental deterioration (Maherlsa et al. 2019). Major contributors to this issue include heavy metal and microplastic contamination, which pose a substantial threat to ecosystem health (Purwiyanto et al. 2022; Rahutami et al. 2022; Fitria et al. 2023; R. Rozirwan et al. 2023; Diansyah et al. 2024; Rozirwan et al. 2024). These pollutants endanger the ecological equilibrium of the estuary, with the potential to affect its biodiversity and the livelihoods dependent upon it.

Macrozoobenthos are considered pivotal components in preserving the equilibrium of estuarine ecosystems (Sari et al. 2022; Isroni et al. 2023). These organisms play a crucial role in the food web and nutrient cycling, thereby supporting a variety of marine species (Griffiths et al. 2017). Moreover, macrozoobenthos are highly sensitive to environmental changes, making them reliable bioindicators of ecological degradation (Sahidin et al. 2018). Research worldwide highlights that macrozoobenthos, including bivalves such as blood clams *Anadara granosa* (Linnaeus 1758) are often used as bioindicators because they can take in and store pollutants from their environment through filter-feeding (Fitri and Patria 2019; Ward et al. 2019; Ding et al. 2021; Bonifacio et al. 2022; Saleh et al. 2023; Rahmatin et al. 2024). *Anadara granosa* is widely consumed by the general public as a nutrient-rich seafood, particularly among local communities

(Rozirwan, et al. 2023; Rozirwan, et al. 2023). Among these, *A. granosa* is a prominent bivalve species that plays a crucial role in maintaining ecosystem stability and generating substantial economic benefits for coastal communities (Yulinda et al. 2020; Prasetiyono et al. 2022; Mahary et al. 2023). Given its ecological importance and economic value within coastal and estuarine systems, it is imperative to investigate pollutant contamination in *A. granosa* to understand the broader impacts of environmental pollution comprehensively.~~comprehensively understand the broader impacts of environmental pollution.~~

Various pollutants, including heavy metals, hydrocarbons, pesticides, and microplastics, have been identified as significant contaminants of estuarine ecosystems, with many of these pollutants accumulating in sediments (Zhao et al. 2015; Kılıç et al. 2023; Han et al. 2024; Jacq et al. 2024). Among these, plastic pollution has emerged as a critical concern due to its pervasive impact on aquatic environments (Borrelle et al. 2020; Hecker et al. 2023). Over the last five decades, the widespread reliance on single-use plastics has led to extensive accumulation and fragmentation of plastic materials across diverse ecosystems (Zhang et al. 2021; Walker and Fequet 2023). As plastics degrade, they break down into microplastics, defined as particles ranging in size from 1 μm to 5 mm (Frias and Nash 2019). These microplastics enter aquatic ecosystems through various pathways, such as the fragmentation of discarded plastic products, the release of synthetic fibers during washing, and the intentional addition of microbeads in personal care products (Napper et al. 2015; Praveena et al. 2018; Belzagui and Gutiérrez-Bouzán 2022; Gan et al. 2023). Microplastics pose multiple threats by releasing toxic additives and acting as carriers of hazardous organic pollutants and heavy metals (Caruso 2019; Fu et al. 2021; Issac and Kandasubramanian 2021; Ta and Babel 2023). These impacts are multifaceted, disrupting food webs, altering nutrient cycles, modifying habitats, and potentially inducing genetic changes in aquatic organisms (Thacharodi et al. 2024).

Prior research has quantified microplastic concentrations in the waters of the Musi Estuary, with reported levels of 467.67 ± 127.84 particles/m³ during flood tide and 723.67 ± 112.05 particles/m³ at ebb tide (Diansyah et al. 2024). These microplastics are frequently associated with toxic heavy metals, such as lead (Pb) and copper (Cu), which exacerbate their harmful environmental effects (Purwiyanto et al. 2022). In the water column, microplastics tend to settle into estuarine sediments, which have been identified as the second-largest global reservoir for microplastics after fjords (Harris 2020). The accumulation of microplastics in estuarine sediments poses significant ecological challenges, particularly due to their ingestion by benthic organisms, including *A. granosa* (Fitri and Patria 2019; Saleh et al. 2023; Rahmatin et al. 2024; Mohan et al. 2024). While numerous studies have examined microplastic concentrations in the water column, research on their distribution in sediments and bioaccumulation in benthic species, particularly *A. granosa*, remains limited.

This study aims to investigate the bioaccumulation and risks of microplastic pollution in sediments and *A. granosa* in the Musi Estuary, Indonesia. The findings are expected to enhance understanding of benthic organisms, especially *A. granosa*, and its potential health risks for local seafood consumers.

MATERIALS AND METHODS

Study Area and Sample Collection

The Musi Estuary, located on the east coast of South Sumatra, is where seawater from the Bangka Strait mixes with freshwater from the Musi River. The Musi Esturay is an important area for fisheries and benthic habitats in South Sumatra, Indonesia (Rozirwan et al. 2021; Rozirwan et al. 2022). Sampling locations were selected based on hydrodynamic conditions influencing microplastic transport and deposition, considering salinity variations and water mass interactions (Cheng et al. 2024; Diansyah et al. 2024). Locations of the sampling sites are shown in Figure 1 and Table 1. Sediment and *A. granosa* were collected during low tide from the Musi Estuary, South Sumatra, Indonesia. Sediment samples were collected from ten sampling points using a Peterson Grab at each station (Dwiyitno et al. 2024). Samples were placed in glass jars that had been rinsed with pure distilled water and covered using aluminum foil to avoid contamination. Samples were placed in a cool box (±4 °C) for further analysis in the laboratory.

Anadara granosa samples were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). Twenty adult *A. granosa* (7.48–11.44 cm) were collected from fishermen's catch in the Musi Estuary. *Anadara granosa* samples were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). The mussels were rinsed with pure distilled water to remove any dirt. *Anadara granosa* were wrapped in aluminum foil and stored in a cooler at approximately 4 °C to preserve their freshness. After that, they were transported to the laboratory and frozen at -20°C before further analysis (Ding et al. 2021).

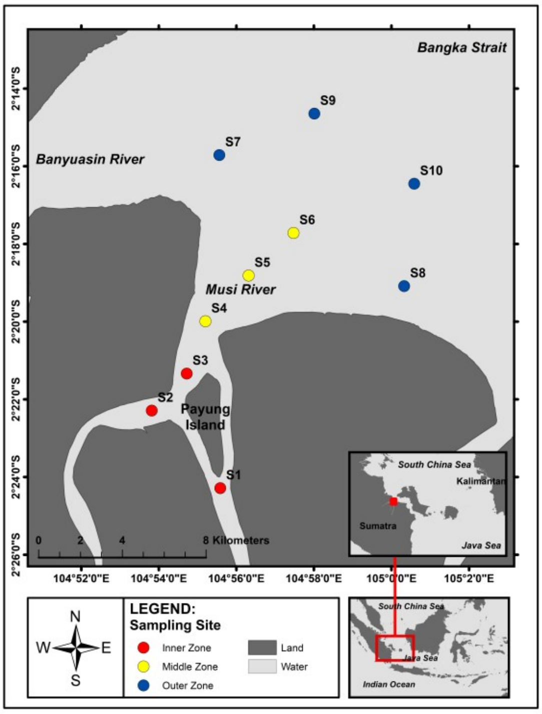

Figure 1. Study site at the Musi Estuary, Indonesia.

Table 1. Coordinates of the sampling location.

Estuary Zone	Description	Station	Latitude (ºS)	Longitude (ºE)
Inner Zone	~~(~~closest to the river body and~~, redominantly influenceed~~dominated by freshwater mangrove vegetation and muddy substrate near densely populated coastal village activities, shipping and fishing activities~~)~~	S1	2.40470	104.92643
		S2	2.37144	104.89695
		S3	2.35558	104.91200
Middle Zone	~~(~~between the inner zone and the outer zone~~, a mixing zone of freshwater and seawater~~ mangrove vegetation and muddy substrate shipping and fishing activities~~)~~	S4	2.33316	104.92003
		S5	2.31353	104.93862
		S6	2.29524	104.95794
Outer Zone	~~(~~closest to the ocean (at the sea), dominated by seawater, no vegetation, muddy substrate shipping and fishing activities~~)~~	S7	2.26183	104.92603
		S8	2.31807	105.00547
		S9	2.24403	104.96686
		S10	2.27413	105.00978

Microplastic extraction from sediment

Microplastics in sediments were extracted using the standard method of density separation and organic matter removal with minor modifications (Thompson et al. 2004; Liebezeit and Dubaish 2012). A total of 500 g of wet sediment samples were placed in a beaker glass covered with aluminum foil. The samples were dried in an oven at 60 ℃ for 48 hours, or until they reached a constant mass (Patria et al. 2023). The sediment samples were pulverized and sieved through a 5 mm steel sieve. A portion of 100 g of dried sediment was taken from the sieve, placed into a beaker glass, and covered with aluminum foil to prevent external contamination. The sample was suspended in 400 mL of saturated NaCl solution (1.2 g cm^{-3}), which is four times the sample weight, using a magnetic stirrer. This NaCl solution was prepared by dissolving pure NaCl crystals (Merck Millipore EMSURE®) in filtered distilled water that was free from contaminants. The selection of a NaCl solution for the separation of microplastics from sediments was based on the premise that this method is cost-effective and environmentally friendly (Perumal and Muthuramalingam 2022). Stirring was carried out for 5 minutes until completely dissolved, and the mixture was allowed to stand for 1 hour. After one hour, 10 mL of 30% H_2O_2 was added to assist in the breakdown of organic matter, followed by stirring for an additional five minutes. Hydrogen peroxide (H_2O_2) is commonly used in similar studies and is regarded as highly effective for organic matter removal (Lee et al. 2023). The sample was allowed to stand for 24 hours, covered with aluminum foil. The samples were then filtered using the Whatman No. 42 filter paper (mesh size 0.45 µm, Φ = 90 mm), assisted by a vacuum pump at 17 kPa to isolate the microplastics. The collected samples were deposited into petri dishes for identification.

Microplastic extraction from *Anadara granosa*

The previously frozen *A. granosa* samples were defrosted under controlled conditions at room temperature (± 25°C) for 1 hour. After the ice melted, the *A. granosa* were washed with pure distilled water to eliminate contamination from other objects, such as sediment. The length and wet weight of the *A. granosa* were measured using an analytical balance (0.01 g). The digestive tract was carefully removed from the *A. granosa* using sterile stainless steel utensils that had been rinsed with distilled water. The extraction of microplastics from the digestive tract of the *A. granosa* was adapted from previous studies with minor modifications (Ding et al. 2018; Ding et al. 2021). The digestive tract was transferred into an Erlenmeyer flask, and 100 mL of KOH solution (10%) was added. The use of KOH is regarded as a more efficacious method for the digestion of biological material, and it has no impact on the integrity of the plastic polymer (Karami et al. 2017). The sample was covered with aluminum foil and stirred for 5 minutes using a 150 rpm magnetic stirrer. The supernatant was incubated at room temperature (±25ºC) until complete digestion of organic matter occurred. The sample was then filtered through Whatman 42 filter paper (mesh size 0.45 µm, Φ = 90 mm) to isolate microplastic. The filter paper was dried in an oven at 40°C for 5 hours and stored in petri dishes for subsequent identification of microplastic content.

Microplastic identification and quantification

Identification and quantification of microplastics from sediments and *A. granosa* were performed using the same method. Microplastic identification was performed using an Olympus CX23 microscope with 10 x 10 or 4 x 10 magnification to visually detect microplastics (Diansyah et al. 2024). The filter paper was observed closely and carefully to avoid contaminants that could enter the filter paper. Microplastics were identified based on the number and form of microplastics (fragment, film, fiber, and foam). The data obtained were recorded by sample type and station/individual for statistical purposes. To prevent contamination, personnel wear cotton lab coats, latex gloves, and cotton masks. Furthermore, access to the detection room is restricted to prevent outside contact during observations.

Procedures for quality assurance and contamination prevention

The quality and contamination control measures were implemented to prevent any alterations to the microplastics in the samples. Before sampling, glass jars and aluminum foil were rinsed with filtered distilled water. Although the samples were in a cool box, they were stored in a place that was not exposed to direct sunlight to keep the samples in good condition. Personnel are also required to wear latex gloves during sampling. During the study, from sampling to laboratory analysis, the use of plastic equipment was minimized to avoid unintentional fragmentation of the microplastics. The distilled water used was filtered with filter paper (0.45 µm,) to prevent microplastics from entering our materials. All equipment was washed with filtered distilled water to remove potential contamination from external particles (Ding et al. 2021). We prepared two controls by filtering each solution we used to avoid contaminants from materials, equipment, and air. No microplastics were found contaminating the instrument. The sterilized equipment was wrapped in aluminum foil to prevent any input of contaminants from outside. Laboratory personnel were required to wear latex gloves, lab coats, and masks throughout the analysis. Access to the laboratory was restricted during the analysis to minimize external interference that could lead to protocol errors.

Data analysis

Pollution Load Index (PLI)

PLI was calculated using a pollutant load approach, which assesses the total concentration of contaminants relative to a baseline level, to evaluate its significance. Equations were utilized to quantify the level of microplastic pollution in both sediments and ~~*Anadara*~~ *A. granosa* in the Musi Estuary, with the method adapted accordingly (Tomlinson et al. 1980; Xu et al. 2018; Wang et al. 2021)

$$CF_i = \frac{C_i}{C_{0i}}$$

This equation shows that the concentration factor (CF_i) at a particular sample is obtained by dividing the current concentration (C_i) by the initial concentration (C_{0i}). Ci indicates the quantified presence of microplastics at each sampling location or within each clam (ind), while C_{0i} denotes the background concentration, defined as the lowest value recorded across all sampling locations. Given the lack of previously published research on microplastics in sediments or *A. granosa* in the Musi River Estuary, we determined C_{0i} values from minimum concentrations across sampling stations.

$$\boldsymbol{PLI = \sqrt{CF_i}}$$

This equation shows that the Pollution Load Index (PLI) is generated by calculating the square root of the Concentration Factor (CF). The PLI value of microplastics is derived from the contaminant factor (CF_i) calculated for each station/individual.

$$\boldsymbol{PLI_{zone} = \sqrt[n]{PLI_1 \times PLI_2 \times \ldots\ PLI_n}}$$

Pollution Load Index of Zone (PLI_{zone}) is determined by taking the square root of the product of individual PLI values from multiple sites within the zone. This method integrates data from several measurement points, providing a more comprehensive assessment of microplastic contamination within the analyzed. A PLI_{zone} is used to assess pollution based on specific estuary zones as well as the overall estuary area. PLI values are categorized into four predefined categories of pollution load, as shown in Table 2.

Table 2. Microplastic pollution load categories

Definition	Value			
Value of the pollution load index (PLI)	<10	10-20	20-30	>30
Risk category	I	II	III	IV
Keterangan	Minor	Middle	High	Extreme

Nemerow Pollution Index (NPI)

NPI is designed to assess the bioavailability of microplastics in sediments and *A. granosa*. This index was adapted from equations used in prior studies evaluating heavy metal contamination (Alam et al. 2023).

$$\boldsymbol{NPI = \sqrt{\frac{\left(\frac{C_i}{S_i}\right)max^2 + \left(\frac{C_i}{S_i}\right)ave^2}{2}}}$$

The NPI value is calculated using the square root of the mean squared deviation, incorporating both the maximum and average concentration ratios relative to the background concentration (S_i). The formula includes the sum of the squares of the maximum concentration ratio ($C_{i\ max}/S_i$) and the average concentration ratio ($C_{i\ ave}$). The Ci value represents the concentration of microplastics found in the sediment or clams at a specific station or individual, while the Si value denotes the background level of microplastics, determined as the lowest concentration recorded across all sample types. The NPI provides a measure of microplastic bioavailability in sediments and *A. granosa*, with values below 2 indicating low bioavailability and values above 2 indicating high bioavailability.

Bioconcentration Factor (BCF)

The Bioconcentration Factor (BCF) quantifies the extent to which microplastics accumulate in biota relative to their environmental concentration and is calculated using the following equation (Li et al. 2022).

$$\boldsymbol{BCF = \frac{C\ biota_{\ ave}}{C\ sediment_{\ ave}}}$$

In this equation, BCF represents the bioconcentration factor, which is derived from the calculation of the average concentration of microplastic in biota (*A. granosa*) divided by the average concentration of microplastic in its environment (sediment). This value is intended to assess how much microplastic is concentrated in the biota.

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics 27. Descriptive statistics, including total, mean, standard deviation, percentage, minimum, and maximum, were utilized to assess data variation. A one-way ANOVA was applied to analyze differences in microplastic abundance between estuarine zones when the data met normality assumptions. For non-normal data, the Kruskal-Wallis test was employed to assess the significance of differences between zones. All tests were carried out with a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Microplastic presence in sediment from Musi Estuary

The Musi Estuary in South Sumatra, Indonesia, is a dynamic brackish water environment where freshwater from the Musi River meets the saltwater of the Bangka Strait. Characterized by turbid waters and muddy sediments rich in organic matter, the estuary is fringed by mangrove forests that provide habitat for aquatic species, including the blood clam (*Anadara granosa*), a key species in local aquaculture (Rozirwan et al. 2023). Surrounded by urban and industrial areas, including Palembang, the estuary faces pollution from domestic, agricultural, and industrial waste, making it susceptible to microplastic accumulation in sediments and ingestion by benthic organisms like blood clams (Almiza and Patria 2021; Diansyah et al. 2024).

Figure 2. General conditions in the Musi estuary**.** A. Coastal Settlements; B. Shipping Activities; C. Fisheries; D. Mangrove Ecosystem

The results of this study indicate that microplastics were detected at all sampling stations, as shown in Figure 4. A total of 1,308 microplastic particles were identified, with concentrations ranging from 66 to 178 particles per 100 g of dry sediment (dry weight, dw). The average abundance of microplastics was 1.31 ± 0.41 particles/g dw, with the highest concentration found at station S1 (1.78 particles/g dw) and the lowest at station S8 (0.66 particles/g dw). High levels of human activity in the upstream area of Musi Estuary, which flows downstream to the estuary and ultimately into the ocean, are responsible for the presence of microplastics (Rozirwan et al. 2021; Diansyah et al. 2024). Urban activities in close proximity to the Musi River Watershed, particularly in Palembang City, significantly contribute to the generation of plastic waste. Increased population density near riverbanks enhances the potential for plastic pollution. Furthermore, population density is a crucial factor in the entry of microplastics into rivers (Eo et al. 2023; Dwiyitno et al. 2024). As a result, plastic pollutants from domestic activities, such as the disposal of food packaging and plastic bags, can be transported through stormwater drains and eventually end up in rivers (Kunz et al. 2023). Fishing activities around Musi Estuary can contribute to microplastic pollution, primarily through fibers released from fishing nets (Li et al. 2022; Fauziyah et al. 2023). This increases anthropogenic pressure at river mouths, which can lead to greater accumulation of microplastics (Castro-Jiménez et al. 2024). Additionally, tidal fluctuation influences water flow, which facilitates the deposition of microplastics in sediment at these locations (Harris 2020). The findings of this study indicate that anthropogenic activities are responsible for high levels of microplastic deposition in the sediments of Musi Estuary. Microplastic particles that accumulate in sediments serve as a habitat for benthic organisms, which can have long-term implications for ecosystem health and balance (Rahmatin et al. 2024). As vectors for pollutants, microplastics can exacerbate toxicity, potentially endangering various populations (Caruso 2019; Fu et al. 2021; Issac and Kandasubramanian 2021; Ta and Babel 2023). Furthermore, the processes of bioaccumulation and biomagnification in benthic organisms present heightened risks to these animals, potentially leading to human consumption (Unuofin and Igwaran 2023). Therefore, it is crucial for local governments to address the handling and prevention of further microplastic accumulation.

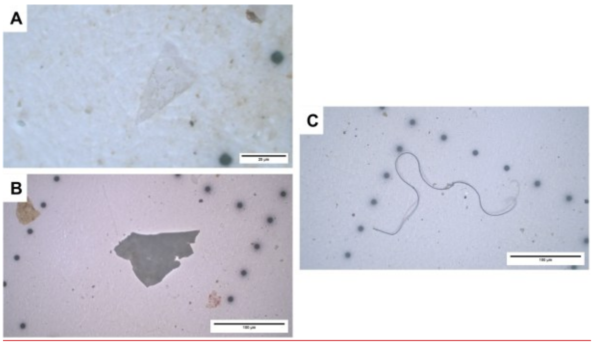

Figure 3. Various forms of microplastics, A. Film; B. Fragment; C. Fiber

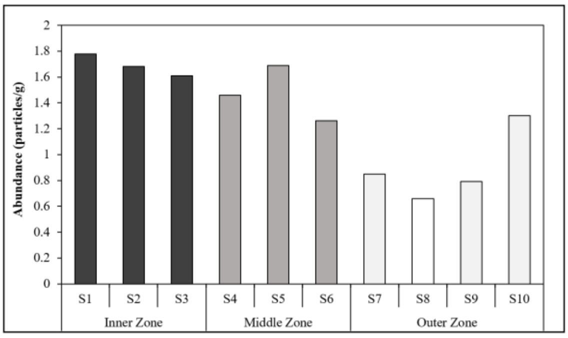

Figure 4. Distribution of microplastics from sediments in Musi Estuary, Indonesia.

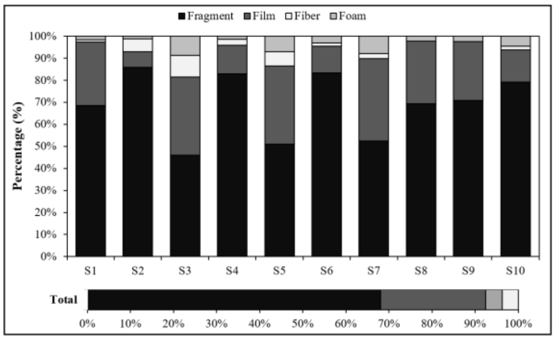

Figure 5. Percentage abundance of microplastic shapes form sediments in Musi Estuary, Indonesia

The microplastics identified in the sediments were predominantly fragments (68.92%), followed by films (23.86%), fibers (4.05%), and foams (3.17%) (Figure 3 and Figure 5). The dominance of fragments, which are a common form of secondary microplastics, occurs as a result of macroplastic degradation (Barnes et al. 2009). Fragments represented the most common type across all sediment samples analyzed. This dominance of fragments in estuarine sediments aligns with findings from various studies conducted in other estuarine environments. Research indicates that estuarine sediments globally tend to accumulate diverse microplastic forms, particularly fibers (Firdaus et al. 2020; Alam et al. 2023; Samuels et al. 2024; Santucci et al. 2024), with many studies also reporting a predominance of fragment types (Zhou et al. 2021; Suteja et al. 2024). These observations corroborate the literature, which consistently shows that fibers and fragments constitute the majority of microplastic pollution in estuarine ecosystems (Feng, An, et al. 2023).

This study reveals notable variations in microplastic concentrations compared to similar research in estuaries globally. Our findings indicate that the Musi Estuary has lower microplastic concentrations than those reported in several other Indonesian and international estuaries. For example, the Jakarta Bay Estuary exhibits concentrations nearly ten times higher, ranging from 1,184 to 1,337 particles per 100 grams of river sediment and 804 to 1,055 particles per 100 grams of beach sediment (Dwiyitno et al. 2024). Such elevated levels are likely due to increased anthropogenic activities along Jakarta's rivers, which substantially contribute to plastic waste flow. In another comparison, the Pearl River Estuary in China also shows higher microplastic densities, with concentrations between 2.05×10^3 and 7.75×10^3 particles per kilogram of dry weight sediment (Xu et al. 2024). This estuary's coastal regions experience high human activity, enhancing the potential for microplastic deposition. Similarly, the Meghna Estuary in Bangladesh, which receives sediment from the Ganges River Basin, reports even higher microplastic levels at 4,014.66 ± 1,717.59 particles per kilogram dry weight (Alam et al. 2023). These findings underscore the significant role of anthropogenic influences on microplastic accumulation in global estuarine sediments, including the Musi Estuary. Other environmental factors, like location, sampling period, sediment depth, sediment composition, and local hydrodynamic conditions, may also affect these changes in the amount of microplastics found (Zheng et al. 2020; Feng, Chen, et al. 2023; Yuan et al. 2023).

In contrast, the abundance of microplastics in the sediments of the Musi Estuary surpasses levels reported in other regions, both within Indonesia and globally. Concentrations in the Musi Estuary are notably higher than those in the Zandvlei River Watershed and estuarine areas of South Africa (70.23 ± 7.36 particles/kg dw) (Samuels et al. 2024), the Claromecó Estuary in Argentina (299 ± 114 particles/kg dw) (Truchet et al. 2021), and the upper sediment layer (0-5 cm) of the Fuhe River Estuary in Northern China (1049 ± 462 particles/kg dw) (Zhou et al. 2021). These numbers are also higher than those found in coastal Río de la Plata (547.83 ± 620.06 particles/kg dw) (Santucci et al. 2024), Benoa Bay, Bali (31.08 ± 21.53 particles/kg dw) (Suteja et al. 2024), the Jagir Estuary in Surabaya (up to 590 particles/kg dw) (Firdaus et al. 2020), and the Pekalongan River Estuary in Java (0.77 to 1.01 particles/g dw) (Ismanto et al. 2023). The high microplastic concentration in the Musi Estuary is likely due to extensive plastic waste disposal in the river basin by the surrounding community. Research supports that plastic debris forms a substantial part of the macro-waste in the Musi River (Maherlsa et al. 2019). Additionally, local communities frequently establish settlements along the river, relying on it for water access and transportation. Consequently, domestic waste, including plastic, often enters the river directly. This local waste management issue reflects a broader trend, with Indonesia identified as the world's second-largest contributor to oceanic plastic pollution, following China (Jambeck et al. 2015).

Spatial distribution microplastic in Sediments

The study revealed that the abundance of microplastics was significantly higher in the inner and middle zones when compared to the outer zone. The mean abundances were 1.69±0.08 particles/g dw in the inner zone, 1.47±0.22 particles/g dw in the middle zone, and 0.9±0.28 particles/g dw in the outer zone. Significant differences in mean microplastic abundance between zones were revealed by the one-way ANOVA ($p < 0.05$), as illustrated in Figure ~~5~~6. The Tukey HSD test revealed no significant difference in mean microplastic abundance between the inner and middle zones However, we observed a significant difference in the outer zone compared to both the middle and outer zones. Our results indicate that the inner and middle estuary regions exhibit greater mean concentrations of microplastics compared to the outer estuary. Natural factors, particularly the effects of currents and wave action in coastal and estuarine environments, significantly influence this phenomenon by altering microplastic distribution. The influx of freshwater promotes the sedimentation and prolonged retention of high-density microplastics within the system (G. Li et al. 2024). Furthermore, the sedimentation process is affected by the density and buoyancy of microplastics, with increased salinity in estuarine waters enhancing buoyancy forces and influencing distribution patterns (Cheng et al. 2024). Our findings align with research from the Liaohe Estuary in China, revealing a higher accumulation of microplastics in inner river sediments compared to the outer estuary (Xu et al. 2020). Additionally, sampling depth plays a critical role in accurately measuring microplastics in surface waters, bottom layers, and sediments (Feng, An, et al. 2023).

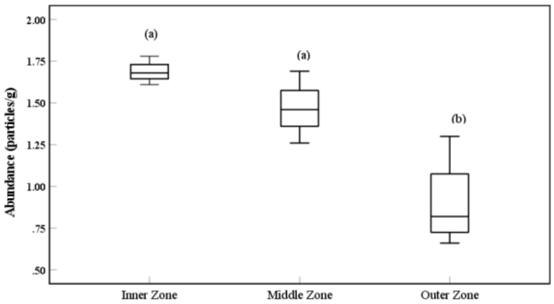

Figure ~~5~~6. The difference in microplastic abundance between zones in the sediments

The spatial analysis revealed distinct patterns of microplastic accumulation between the two sides of the coast adjacent to the estuary. Notably, Site S7 exhibited higher concentrations compared to Site S8, likely due to its proximity to other pollution sources. Specifically, S7 is located near the Banyuasin Estuary, which is believed to significantly contribute to the deposition of microplastics in the surrounding sediments. Based on Costa et al. (2023), confirmed that nearby sources of pollution heavily influence microplastic deposition in coastal regions. The accumulation of microplastics at the mouth of the adjacent river further exacerbates this phenomenon, facilitating the settlement of microplastics within the sediment. Additionally, studies suggest that the depth of the sampling locations significantly influences microplastic deposition, revealing a greater abundance of microplastics at deeper water levels (Bayo et al. 2022). The substantial accumulation of microplastics in sediments is attributed to their persistent characteristics as well as the protective conditions offered by deeper environments, which are shielded from UV light, maintain lower temperatures, and exhibit lower oxygen levels, thus slowing biodegradation processes (Zhang et al. 2021).

Our findings confirm the presence of microplastics in the sediments of the Musi Estuary, likely originating from suspended microplastics that eventually settle from the water's surface. Previous research has found that there are 467.67 ± 127.84 particles/m³ and 723.67 ± 112.05 particles/m³ of microplastic in surface waters during ebb and flow conditions, respectively (Diansyah et al. 2024). Hydrodynamic conditions in the estuary and processes like aggregation and biofouling, which increase microplastic density, influence the deposition of these particles (Malli et al. 2022). The specific properties of the microplastics and the water dynamics of the estuary strongly influence microplastic deposition. For instance, biofouling can make microplastics denser, accelerating their descent into sediments (Lin et al. 2023). Since microplastics often have higher densities than water, they can remain suspended in the water column before eventually settling (Dai et al. 2022). High Total Suspended Solids (TSS) in the Musi Estuary have the potential to cause aggregation of microplastics (Rahutami et al. 2022). High TSS levels make it easier for sediments and other suspended particles to stick together on microplastic surfaces, which speeds up their deposition (Yang et al. 2022). However, microplastics can also become resuspended in the water column (Tang et al. 2020). Stirring forces in estuarine environments can lift microplastics back into the water, where turbulence and bioturbation may redistribute them (Malli et al. 2022). Therefore, additional studies are required to fully characterize the mechanisms of microplastic deposition in the Musi Estuary. Climate factors also influence microplastic distribution in Musi Estuary sediments. In Indonesia, where regions such as the Musi Estuary experience distinct rainy and dry seasons, seasonal changes affect water dynamics and microplastic transport. During the rainy season, increased river velocity may carry microplastics upward from sediments, while in the dry season, slower flows facilitate microplastic accumulation at the water's surface (Zhao et al. 2020). Currently, there are no studies specifically examining the seasonal impact on microplastic presence in the Musi Estuary, underscoring the need for further research to address this gap.

Bioaccumulation of microplastics in *Anadara granosa*

We extracted 133 microplastic particles from the digestive tracts of twenty samples of *A. granosa* species presented in Figure 7~~6~~. Each sample from the Musi Estuary had accumulated microplastics, ranging from 6 to 49 particles/ind or 8 to 69.01 particles/g ww, as shown in Figure ~~7~~8 and Figure ~~8~~9. The mean abundance of microplastics found in the digestive tracts was 21.05±10.31 particles/ind or 30.46±16.7 particles/g ww. Several factors contribute to the increased microplastic inputs in bivalve species, including human activities, tourism, fishing equipment, freshwater runoff, and wastewater discharge, combined with the area's hydrodynamic conditions (Vital et al. 2021). The elevated levels of microplastics found in *A. granosa* from the Musi River Estuary suggest a significant degree of contamination in their habitat, including both water and sediment, which may adversely affect the health of these organisms and disrupt local ecological balances. This observation aligns with existing literature, which indicates a strong correlation between the abundance of microplastics in bivalves, such as mussels, and their sediment environments (Narmatha Sathish et al. 2020), reinforcing the need for monitoring these pollutants in aquatic ecosystems.

Figure 67. ~~Morphology~~ Specimens of *Anadara granosa* from Musi Estuary, Indonesia.

Microplastics were observed in three morphological forms: film, fiber, and fragment. Film accounted for the majority of microplastics (59.38%), followed by fiber (31.59%) and fragments (9.03%), as shown in Figure 109. The digestive tracts of the *A. granosa* studied did not contain any pellets or foam. Statistical analysis using the Kruskal-Wallis test revealed significant differences in the abundance of the three microplastic forms ($p < 0.05$). This predominance of film microplastics in *A. granosa* is likely attributable to the extensive use of disposable plastic packaging within the community, which subsequently degrades into microplastics. Although fragments dominate the sediment substrate, *A. granosa* predominantly absorb film microplastics. The lower density of film microplastics may facilitate their accumulation in the upper sediment layer, making them susceptible to resuspension in the overlying water column. This phenomenon is consistent with the feeding behavior of *A. granosa*, which frequently filter water from the sediment surface, resulting in the accumulation of film microplastics within their digestive tracts.

Our findings indicate a higher abundance of microplastics in *A. granosa* from the Musi Estuary compared to certain other regions globally. For instance, *A. granosa* from the Chanthaburi estuarine ecosystem in eastern Thailand contained 0.40±0.16 particles/g ww (Potipat et al. 2024), while samples from Peninsular Malaysia showed concentrations of 0.20 ± 0.08 particles/g ww and 1.54 ± 0.30 particles/ind ww (Mohan et al. 2024). Additionally, microplastic levels in *A. granosa* from Pao Village, Tarowang District, Jeneponto Regency, Indonesia, were measured at 0.0144 particles/g ww (Namira et al. 2023), and those from Likas Bay Beach in North Borneo, Malaysia, at 24.4 ± 0.6 particles/g ww (Abd Rahman et al. 2024). In contrast, the *A. granosa* analyzed in this study accumulated lower microplastic concentrations than those reported in several other studies. For instance, *A. granosa* from the Pangkal Babu mangrove forest area in Tanjung Jabung Barat district, Jambi, exhibited 434 ± 97.05 particles/ind (Fitri and Patria 2019), while those from Lada Bay in Pandeglang, Banten, had concentrations of 618.8 ± 121.4 particles/ind (Ukhrowi et al. 2021). Overall, this study shows that microplastics have contaminated the sediment environment of the Musi Estuary, South Sumatra, indicating that *A. granosa* can serve as effective bioindicators of this pollution.

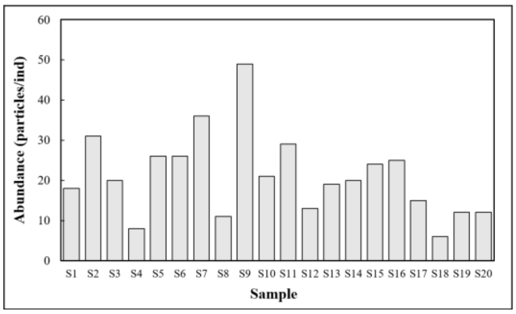

Figure 87. Microplastic abundance of *Anadara granosa* from the Musi Estuary

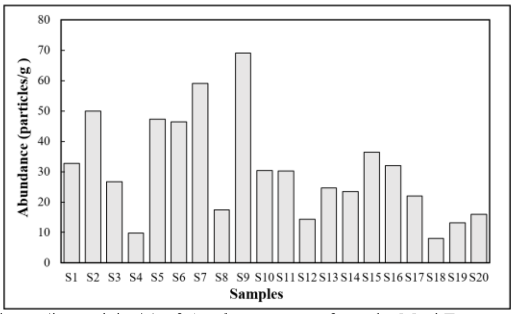

Figure 89. Microplastic abundance (in particles/g) of *Anadara granosa* from the Musi Estuary

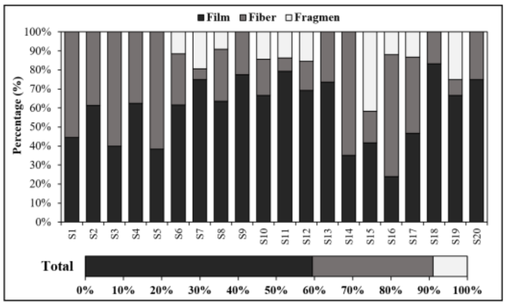

Figure 910. Shape of microplastics in *Anadara granosa* from the Musi Estuary

Risk assessment of microplastics in sediments and *Anadara granosa*

A risk assessment of microplastic contamination in the Musi River Estuary was carried out by calculating the Pollution Load Index (PLI), the Nemerow Pollution Index (NPI), and the Bioconcentration Factor (BCF). The PLI values across all sediment samples indicate that the estuarine sediment is subject to minor pollution, with values ranging between 1.00 and 1.64, as shown in Table 3. In the three zones of the estuary (inner, middle, and outer), the PLI values were 1.60, 1.49, and 1.20, respectively. We calculated the overall average PLI for the Musi Estuary to be 1.37. All zones reported PLI values below 3.00, which suggests that the area experiences only minor microplastic pollution. The analysis of microplastic presence in sediment samples revealed a significantly high concentration of microplastics, with an NPI value of 2.37. This suggests a substantial bioavailability of microplastics in the estuarine environment. This elevated NPI underscores the ecological risk posed by microplastic contamination, despite the relatively low PLI observed across the study area.

Table 3. The microplastic risk factor in sediments of Musi Estuary

Sediment Station	CF	PLI	PLI Zone	PLI Sediment	NPI
S1	2.70	1.64	Inner Zone 1.60	1.37	2.37
S2	2.55	1.60			
S3	2.44	1.56			
S4	2.21	1.49	Middle Zone 1.49		
S5	2.56	1.60			
S6	1.91	1.38			
S7	1.29	1.13	Outer Zone 1.20		
S8	1.00	1.00			
S9	1.20	1.09			
S10	1.97	1.40			

Anadara granosa analyzed in this study exhibited significant risk values associated with microplastic contamination. The PLI for these clams ranged from 1 to 2.86, with an overall mean PLI value of 1.77 for the entire sample, as shown in Table 4. This indicates that the pollution load in *A. granosa* falls within the minor category (PLI < 3). Furthermore, the bioavailability of microplastics in *A. granosa* was significantly higher, with an NPI value of 6.29, indicating a high bioavailability. The bioconcentration factor of microplastics from sediment to *A. granosa* was measured at 23.28, suggesting a significant potential for the transfer of microplastics from sediment to *A. granosa* in the Musi Estuary.

Our findings demonstrated that the bioavailability of microplastics in sediments and *A. granosa* was categorized as high (NPI = 2.37; NPI > 2). In comparison, the bioavailability of microplastics in *A. granosa* was even higher, with an NPI value of 9.89. The elevated bioavailability in sediments suggests a greater potential for absorption by aquatic organisms, particularly benthic animals. Furthermore, the bioconcentration factor (BCF) calculated for *A. granosa* in sediment was 23.28, indicating a significant transfer of microplastics from sediments to these organisms in the Musi Estuary. This high BCF value is attributed to the non-discriminatory feeding process of *A. granosa*, allowing them to ingest microplastics along with other particles. When compared to several benthic species from the Yangtze River Estuary, which exhibited a BCF of 29.48 ± 6.52 (Z. Li et al. 2022), the BCF of *A. granosa* in the Musi Estuary remains lower. Nonetheless, both sediments and *A. granosa* from the Musi Estuary are classified within the minor pollution risk index category (PLI < 10). The bioaccumulation of microplastics by benthic animals like *A. granosa* poses a significant risk to human health for those consuming these clams (Wang et al. 2023; Winiarska et al. 2024). Therefore, periodic assessments are crucial to evaluate the risk of microplastic contamination in sediments and *A. granosa*, providing essential information to understand the ecological and health implications in the Musi Estuary.

The impact of high bioaccumulation extends beyond the toxicity of microplastic materials; it also facilitates the accumulation of other pollutants. Previous research has detected heavy metals, such as lead (Pb) and copper (Cu), adhering to the surfaces of microplastics in the Musi Estuary (Purwiyanto et al. 2020). Additionally, various hazardous heavy metals, including iron (Fe), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn), were identified with high bioavailability in the aquatic environment of the Musi Estuary (Rahutami et al. 2022). This accumulation allows for the deposition of significant quantities of heavy metals on microplastic surfaces, thereby increasing the risk of microplastic toxicity for estuarine ecosystems. Moreover, the involvement of microorganism vectors, misidentification in aquatic organisms' diets, and their harmful toxicological effects on benthic animals heighten the risk associated with microplastics (Gong and Xie 2020). Consequently, the high output of microplastics from the Musi Estuary has the potential to jeopardize the condition of the surrounding aquatic environment, including fisheries and migratory birds, which are critical to the ecosystem (Rozirwan et al. 2019; Rozirwan et al. 2022).

Table 4. Risk factors for microplastics in *Anadara granosa* from the Musi Estuary

A. granosa sample	CF	PLI	PLI *A. granosa*	NPI	BCF
S1	3.00	1.73			
S2	5.17	2.27			
S3	3.33	1.83			
S4	1.33	1.15			
S5	4.33	2.08			
S6	4.33	2.08			
S7	6.00	2.45			
S8	1.83	1.35			
S9	8.17	2.86			
S10	3.50	1.87	1.77	6.29	23.28
S11	4.83	2.20			
S12	2.17	1.47			
S13	3.17	1.78			
S14	3.33	1.83			
S15	4.00	2.00			
S16	4.17	2.04			
S17	2.50	1.58			
S18	1.00	1.00			
S19	2.00	1.41			

S20	2.00	1.41

This study holds significant ecological implications for the Musi Estuary ecosystem, as the presence of microplastics poses a long-term threat to ecosystem stability. Previous studies have shown that microplastics can affect the physicochemical properties of sediments, such as electrical conductivity, organic matter content, and nutrients, and well as impact enzymatic activity in sediment bacteria (Rillig 2012; B. Yuan et al. 2022; W. Li et al. 2022). These changes can lead to structural and functional alterations in aquatic habitats (W. Li et al. 2022). Microplastics can also enter various levels of the food chain through bioaccumulation and biomagnification processes. For example, microplastics in plankton can cause a decline in zooplankton populations, which impacts food availability for small fish and predatory species at higher trophic levels (Malinowski et al. 2023). The accumulation of microplastics in *A. granosa* in this study indicates that the pressure of plastic waste in the Musi Estuary is already quite high. Microplastics can act as vectors for other pollutants, such as microorganisms, heavy metals, and other inorganic pollutants can increase the risk of toxicity for aquatic organisms, including *A. granosa* (Purwiyanto et al. 2020; Rafa et al. 2024). Research indicates that exposure to microplastics can lead to behavioral and physiological changes in aquatic organisms, including changes in diet and reproductive success (Guo et al. 2020; Liang et al. 2023). Moreover, microplastics disrupt endocrine functions and metabolic pathways, causing oxidative stress, cell necrosis, and apoptosis, which can ultimately lead to mortality (Pannetier et al. 2020; Jeyavani et al. 2021). Disruption of any component of the food chain can trigger a domino effect, threatening the balance of the Musi Estuary ecosystem. However, this study only examines microplastic pollution in sediment and *A. granosa* as environmental indicators. Additional research is needed to understand microplastic buildup in other species, such as fish, shrimp, and benthic organisms, for a more complete picture of microplastic pollution in the Musi Estuary and its impact on the global marine environment.

Microplastic contamination of *A. granosa* in the Musi Estuary poses a significant threat to local communities, particularly clam fishers. Microplastics that accumulate in *A. granosa* may pose health risks to community members who consume them regularly as a primary source of protein. Long-term exposure to microplastics can potentially disrupt various human body systems, including the digestive, respiratory, reproductive, nervous, and cardiovascular systems (Y. Li et al. 2024). Furthermore, microplastics may cause both acute and subchronic toxicity and are considered potentially carcinogenic and disruptive to human development (Z. Yuan et al. 2022). Once in the bloodstream, microplastics can be transported to the liver, the primary organ responsible for detoxification. Accumulation in the liver may trigger adverse physiological reactions, including increased oxidative stress, liver fibrosis, and impaired lipid metabolism. In addition to health risks, microplastic contamination in *A. granosa* in the Musi Estuary may reduce consumer confidence and decrease market demand due to food safety concerns (Unuofin and Igwaran 2023). The long-term effect could weaken local economic resilience as marine products in the region are perceived to be contaminated with microplastics (Barrientos et al. 2024). Therefore, it is crucial for governments and communities to recognize these risks and collaborate on mitigation efforts to protect ecosystems, public health, and local economies.

~~The presence of microplastics in sediments and *A. granosa* in the Musi Estuary poses a significant threat to the ecosystem's sustainability. To address microplastic pollution effectively, collaboration between governmental bodies and local communities is essential. Several strategies can be implemented to reduce microplastic pollution in aquatic environments, including the following measures:~~

1. ~~Educating the public on the importance of controlling plastic waste (Evode et al. 2021).~~
2. ~~Reducing single-use plastic consumption and encouraging the use of environmentally friendly alternatives.~~
3. ~~Banning plastic microbeads in personal care products and cosmetics (Zhang et al. 2022).~~
4. ~~Promoting sustainable plastic recycling at individual, community, national, and international levels (Babaremu et al. 2022; Thu Nguyen 2024).~~
5. ~~Strengthening waste management policies for product packaging and disposal practices within the industrial sector (Wu et al. 2023).~~
6. ~~Enforcing stricter regulations on wastewater treatment facilities and implementing comprehensive plastic waste management through mechanical, physical, chemical, and biological methods to reduce microplastics (Ragaert et al. 2017; Meiyerani et al. 2024).~~
7. ~~Prioritizing microplastic control by evaluating land-use contributions in urban areas, focusing on those with the highest pollution impact (Jin et al. 2022).~~

Furthermore, seafood hygiene practices in local communities and fishing industries can help reduce microplastic contamination (Lusher et al. 2017; Smith et al. 2018). For example, ~~*Anadara*~~ *A. granosa* and other seafood, when thoroughly cleaned by repeated washing and clam removal before cooking, may reduce microplastic intake (J. Li et al. 2022). The concentration of microplastics in shellfish is significantly lower after boiling and steaming compared to frying, suggesting that cooking methods affect microplastic retention in seafood (Evode et al. 2021). This method can also be applied to shrimp, fish, and other shellfish to lower the risk of microplastic exposure. Implementing these recommendations will help reduce microplastic pollution and provide long-term benefits for public health, ecosystem stability, and the economic resilience of local fisheries (Prata et al. 2019).

In conclusion, this study demonstrates the significant presence of microplastics in the sediment and *A. granosa* of the Musi Estuary, Indonesia. These findings indicate a serious threat to the aquatic ecosystem and to local public health, as microplastics can enter the food chain and potentially harm organisms across trophic levels, including humans (Ningrum and Patria 2022; Edwin et al. 2023; Patria et al. 2023). This pollution heightens environmental risks, particularly for species integral to both the community's diet and economy (Jeong et al. 2024). The microplastics likely originate from human activities, especially urban waste from upstream areas that flows downstream and accumulates in the estuary (Diansyah et al. 2024). These results highlight the urgent need for routine monitoring and stricter waste management practices, particularly for plastic disposal, to reduce further contamination (Barletta et al. 2019). A comprehensive strategy is essential to controlling plastic waste throughout the river system—from source to estuary. Effective measures should include coordinated waste management practices, public education on the impact of pollution, and cross-sector collaboration to preserve estuarine health (Wakwella et al. 2023; Ihenetu et al. 2024). Such initiatives are crucial to protecting ecosystem health and sustaining local fisheries, ensuring these resources continue to support community well-being.

ACKNOWLEDGEMENTS

The authors disclose receipt of the following financial support for the research, authorship, and publication of this article: Directorate of Research, Technology, and Community Service Directorate General of Higher Education, Research, and Technology under the Contract for Implementation of the State Higher Education Operational Assistance Program Research Program for Fiscal Year 2024 Number: 090/E5/PG.02.00.PL/2024.

REFERENCES

Abd Rahman NN, Mazlan N, Shukhairi SS, Nazahuddin MNA, Shawel AS, Harun H, Baktir A. 2024. Evaluation of the microplastics in bivalves and water column at Pantai Teluk Likas, North Borneo, Malaysia. *Environ. Sci. Pollut. Res.* 31(15): 23178–23192. https://doi.org/10.1007/s11356-024-32628-z

Abelouah MR, Ben-Haddad M, Hajji S, Nouj N, Ouheddou M, Mghili B, De-la-Torre GE, Costa LL, Banni M, Ait Alla A. 2024. Exploring marine biofouling on anthropogenic litter in the Atlantic coastline of Morocco. *Mar. Pollut. Bull.* 199(December 2023): 115938. https://doi.org/10.1016/j.marpolbul.2023.115938

Alam MJ, Shammi M, Tareq SM. 2023. Distribution of microplastics in shoreline water and sediment of the Ganges River Basin to Meghna Estuary in Bangladesh. *Ecotoxicol. Environ. Saf.* 266: 115537. https://doi.org/10.1016/j.ecoenv.2023.115537

Almiza G, Patria MP. 2021. Distribution and abundance of macroplastic at Musi estuary, South Sumatera, Indonesia. In: *J. Phys. Conf. Ser.* Vol. 1869. [place unknown]: IOP Publishing; p. 12178.

Aunurrahman A, Anggoro S, Muskananfola MR, Saputra SW. 2023. Detection and analysis of mangrove cover change in Kepalajerih Island, Batam, Indonesia using Landsat Imagery. *Biodiversitas J. Biol. Divers.* 24(11).

Barletta M, Lima ARA, Costa MF. 2019. Distribution, sources and consequences of nutrients, persistent organic pollutants, metals and microplastics in South American estuaries. *Sci. Total Environ.* 651: 1199–1218.

Barnes DKA, Galgani F, Thompson RC, Barlaz M. 2009. Accumulation and fragmentation of plastic debris in global environments. *Philos. Trans. R. Soc. B Biol. Sci.* 364(1526): 1985–1998. https://doi.org/10.1098/rstb.2008.0205

Barrientos M, Vásquez Lavín F, Ponce Oliva RD, Nayga RM, Gelcich S. 2024. Microplastics in seafood: Consumer preferences and valuation for mitigation technologies. *Food Res. Int.* 187: 114342. https://doi.org/10.1016/j.foodres.2024.114342

Bayo J, Rojo D, Olmos S. 2022. Weathering indices of microplastics along marine and coastal sediments from the harbor of Cartagena (Spain) and its adjoining urban beach. *Mar. Pollut. Bull.* 178(February): 113647. https://doi.org/10.1016/j.marpolbul.2022.113647

Belzagui F, Gutiérrez-Bouzán C. 2022. Review on alternatives for the reduction of textile microfibers emission to water. *J. Environ. Manage.* 317: 115347. https://doi.org/10.1016/j.jenvman.2022.115347

Boerema A, Meire P. 2017. Management for estuarine ecosystem services: A review. *Ecol. Eng.* 98: 172–182. https://doi.org/https://doi.org/10.1016/j.ecoleng.2016.10.051

Bonifacio PSP, Metillo EB, Romano EF. 2022. Microplastic in Sediments and Ingestion Rates in Three Edible Bivalve Mollusc Species in a Southern Philippine Estuary. *Water. Air. Soil Pollut.* 233(11). https://doi.org/10.1007/s11270-022-05926-w

Borrelle SB, Ringma J, Law KL, Monnahan CC, Lebreton L, McGivern A, Murphy E, Jambeck J, Leonard GH, Hilleary MA, et al. 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science (80-.).* 369(6510): 1515–1518. https://doi.org/10.1126/science.aba3656

Caruso G. 2019. Microplastics as vectors of contaminants. *Mar. Pollut. Bull.* 146: 921–924. https://doi.org/10.1016/j.marpolbul.2019.07.052

Castro-Jiménez J, Aminot Y, Bely N, Pollono C, Idjaton BIT, Bizzozero L, Pierre-Duplessix O, Phuong NN, Gasperi J. 2024. Organophosphate ester additives and microplastics in benthic compartments from the Loire estuary (French Atlantic coast). *Mar. Pollut. Bull.* 201(February). https://doi.org/10.1016/j.marpolbul.2024.116256

Cheng Z, Ma Y, Fan X, Wang Q, Liu Y, You Z. 2024. Historical behaviors of microplastic in estuarine and riverine reservoir sediment. *Mar. Pollut. Bull.* 202(September 2023). https://doi.org/10.1016/j.marpolbul.2024.116331

Costa MB da, Otegui MBP, Zamprogno GC, Caniçali FB, dos Reis Cozer C, Pelletier E, Graceli JB. 2023. Abundance, composition, and distribution of microplastics in intertidal sediment and soft tissues of four species of Bivalvia from Southeast Brazilian urban beaches. *Sci. Total Environ.* 857(October 2022): 159352. https://doi.org/10.1016/j.scitotenv.2022.159352

Dai L, Wang Z, Guo T, Hu L, Chen Y, Chen C, Yu G, Ma LQ, Chen J. 2022. Pollution characteristics and source analysis of microplastics in the Qiantang River in southeastern China. *Chemosphere*. 293: 133576. https://doi.org/10.1016/j.chemosphere.2022.133576

Diansyah G, Rozirwan, Rahman MA, Nugroho RY, Syakti AD. 2024. Dynamics of microplastic abundance under tidal fluctuation in Musi estuary, Indonesia. *Mar. Pollut. Bull.* 203: 116431. https://doi.org/doi.org/10.1016/j.marpolbul.2024.116431

Ding J-F, LI J-X, Sun C-J, He C-F, Jiang F-H, Gao F-L, Zheng L. 2018. Separation and Identification of Microplastics in Digestive System of Bivalves. *Chinese J. Anal. Chem.* 46(5): 690–697. https://doi.org/10.1016/S1872-2040(18)61086-2

Ding J, Sun C, He C, Li J, Ju P, Li F. 2021. Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. *Sci. Total Environ.* 782: 146830. https://doi.org/10.1016/j.scitotenv.2021.146830

Dwiyitno D, Schwanen C, Januar HI, Ariyani F, Irianto HE, Schwarzbauer J. 2024. Microplastic profile in the sediment of Jakarta Bay estuary,

Formatted: Indent: Before: 0 cm, Hanging: 1 cm

Indonesia: Characterization based on size fraction and the potential risk to the ecosystem. *Reg. Stud. Mar. Sci.* 73(November 2023): 103465. https://doi.org/10.1016/j.rsma.2024.103465

Edwin T, Primasari B, Annisa Purnama R. 2023. Characterization of microplastic in trawl fish caught in Padang City (Indonesia) coastal area. *Biodiversitas*. 24(1): 516–522. https://doi.org/10.13057/biodiv/d240160

Eo S, Hong SH, Cho Y, Song YK, Han GM, Shim WJ. 2023. Spatial distribution and historical trend of microplastic pollution in sediments from enclosed bays of South Korea. *Mar. Pollut. Bull.* 193(May): 115121. https://doi.org/10.1016/j.marpolbul.2023.115121

Evode N, Qamar SA, Bilal M, Barceló D, Iqbal HMN. 2021. Plastic waste and its management strategies for environmental sustainability. *Case Stud. Chem. Environ. Eng.* 4: 100142. https://doi.org/doi.org/10.1016/j.cscee.2021.100142

Fauziyah, Nurjuliasti Ningsih E, Arnando E, Fatimah, Agustriani F, Supriyadi F. 2023. Effect of hauling and soaking time of stationary lift nets on fish aggregation using a hydroacoustic monitoring approach. *Egypt. J. Aquat. Res.* 49(3): 339–346. https://doi.org/10.1016/j.ejar.2023.05.003

Fauziyah, Setiawan A, Agustriani F, Rozirwan, Melki, Nurjuliasti Ningsih E, Ulqodry TZ. 2022. Distribution pattern of potential fishing zones in the Bangka Strait waters: An application of the remote sensing technique. *Egypt. J. Remote Sens. Sp. Sci.* 25(1): 257–265. https://doi.org/https://doi.org/10.1016/j.ejrs.2021.12.003

Feng Q, An C, Chen Z, Lee K, Wang Z. 2023. Identification of the driving factors of microplastic load and morphology in estuaries for improving monitoring and management strategies: A global meta-analysis. *Environ. Pollut.* 333: 122014. https://doi.org/10.1016/j.envpol.2023.122014

Feng Q, Chen Z, An C, Yang X, Wang Z. 2023. Tide-induced infiltration and resuspension of microplastics in shorelines: Insights from tidal tank experiments. *Water Res.* 236: 119970. https://doi.org/10.1016/j.watres.2023.119970

Firdaus M, Trihadiningrum Y, Lestari P. 2020. Microplastic pollution in the sediment of Jagir estuary, Surabaya City, Indonesia. *Mar. Pollut. Bull.* 150: 110790.

Fitri S, Patria MP. 2019. Microplastic contamination on Anadara granosa Linnaeus 1758 in Pangkal Babu mangrove forest area, Tanjung Jabung Barat district, Jambi. *J. Phys. Conf. Ser.* 1282(1). https://doi.org/10.1088/1742-6596/1282/1/012109

Fitria Y, Rozirwan, Fitrani M, Nugroho RY, Fauziyah, Putri WAE. 2023. Gastropods as bioindicators of heavy metal pollution in the Banyuasin estuary shrimp pond area, South Sumatra, Indonesia. *Acta Ecol. Sin.* 43(6): 1129–1137. https://doi.org/https://doi.org/10.1016/j.chnaes.2023.05.009

Frias JPGL, Nash R. 2019. Microplastics: Finding a consensus on the definition. *Mar. Pollut. Bull.* 138(November 2018): 145–147. https://doi.org/10.1016/j.marpolbul.2018.11.022

Fu L, Li J, Wang G, Luan Y, Dai W. 2021. Adsorption behavior of organic pollutants on microplastics. *Ecotoxicol. Environ. Saf.* 217(November 2020): 112207. https://doi.org/10.1016/j.ecoenv.2021.112207

Gan Q, Cui J, Jin B. 2023. Environmental microplastics: Classification, sources, fates, and effects on plants. *Chemosphere*. 313: 137559. https://doi.org/10.1016/j.chemosphere.2022.137559

Gong J, Xie P. 2020. Research progress in sources, analytical methods, eco-environmental effects, and control measures of microplastics. *Chemosphere*. 254: 126790. https://doi.org/10.1016/j.chemosphere.2020.126790

Griffiths JR, Kadin M, Nascimento FJA, Tamelander T, Törnroos A, Bonaglia S, Bonsdorff E, Brüchert V, Gårdmark A, Järnström M. 2017. The importance of benthic–pelagic coupling for marine ecosystem functioning in a changing world. *Glob. Chang. Biol.* 23(6): 2179–2196.

Guo J-J, Huang X-P, Xiang L, Wang Y-Z, Li Y-W, Li H, Cai Q-Y, Mo C-H, Wong M-H. 2020. Source, migration and toxicology of microplastics in soil. *Environ. Int.* 137: 105263. https://doi.org/10.1016/j.envint.2019.105263

Han X, Wu H, Li Q, Cai W, Hu S. 2024. Assessment of heavy metal accumulation and potential risks in surface sediment of estuary area: A case study of Dagu river. *Mar. Environ. Res.* 196: 106416. https://doi.org/https://doi.org/10.1016/j.marenvres.2024.106416

Harris PT. 2020. The fate of microplastic in marine sedimentary environments: A review and synthesis. *Mar. Pollut. Bull.* 158(June): 111398. https://doi.org/10.1016/j.marpolbul.2020.111398

Hasan V, Andaini NE, Isroni W, Sari LA, Nafisyah AL, Dewi NN, Putri DNA, Prasati TAB, Ramadhani AA, Daniel K. 2023. Fish diversity of the bengawan solo river estuary, east java, Indonesia. *Biodiversitas J. Biol. Divers.* 24(4): 2207–2216.

Hasan V, South J, Katz AM, Ottoni FP. 2022. First record of the Smalleyed loter Prionobutis microps (Weber, 1907)(Teleostei: Eleotridae: Butinae) in Java, Indonesia. *Cybium*. 46(1): 49–51.

Hecker M, Peijnenburg W, Lam PKS, Brinkmann M. 2023. Emerging issues in aquatic toxicology – Plastic pollution. *Aquat. Toxicol.* 264. https://doi.org/10.1016/j.aquatox.2023.106729

Ihenetu SC, Enyoh CE, Wang C, Li G. 2024. Sustainable Urbanization and Microplastic Management: Implications for Human Health and the Environment. *Urban Sci.* 8(4): 252.

Islamy RA, Hasan V. 2020. Checklist of mangrove snails (Mollusca: Gastropoda) in south coast of pamekasan, Madura Island, East Java, Indonesia. *Biodiversitas J. Biol. Divers.* 21(7): 3127–3134.

Ismanto A, Hadibarata T, Kristanti RA, Sugianto DN, Widada S, Atmodjo W, Satriadi A, Anindita MA, Al-Mohaimeed AM, Abbasi AM. 2023. A novel report on the occurrence of microplastics in Pekalongan River Estuary, Java Island, Indonesia. *Mar. Pollut. Bull.* 196: 115563. https://doi.org/10.1016/j.marpolbul.2023.115563

Isroni W, Sari PDW, Sari LA, Daniel K, South J, Islamy RA, Wirabuana PYAP, Hasan V. 2023. Checklist of mangrove snails (Gastropoda: Mollusca) on the coast of Lamongan District, East Java, Indonesia. *Biodiversitas*. 24(3): 1676–1685.

Issac MN, Kandasubramanian B. 2021. Effect of microplastics in water and aquatic systems. *Environ. Sci. Pollut. Res.* 28(16): 19544–19562. https://doi.org/10.1007/s11356-021-13184-2

Jacq K, Debret M, Gardes T, Demarest M, Humbert K, Portet-Koltalo F. 2024. Spatial distribution of polycyclic aromatic hydrocarbons in sediment deposits in a Seine estuary tributary by hyperspectral imaging. *Sci. Total Environ.* 950: 175306. https://doi.org/https://doi.org/10.1016/j.scitotenv.2024.175306

Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL. 2015. Plastic waste inputs from land into the ocean. *Science (80-.).* 347(6223): 768–771.

Jeong E, Lee J-Y, Redwan M. 2024. Animal exposure to microplastics and health effects: A review. *Emerg. Contam.* 10(4): 100369. https://doi.org/doi.org/10.1016/j.emcon.2024.100369

Jeyavani J, Sibiya A, Shanthini S, Ravi C, Vijayakumar S, Rajan DK, Vaseeharan B. 2021. A Review on Aquatic Impacts of Microplastics and Its Bioremediation Aspects. *Curr. Pollut. Reports*. 7(3): 286–299. https://doi.org/10.1007/s40726-021-00188-2

Karami A, Golieskardi A, Choo CK, Romano N, Ho Y Bin, Salamatinia B. 2017. A high-performance protocol for extraction of microplastics in fish. *Sci. Total Environ.* 578: 485–494.

Kılıç S, Kılıç Ö, Belivermiş M, Ergül HA. 2023. Chronology of PAH and PCB pollution using sediment core in the Golden Horn estuary (Sea of Marmara). *Mar. Pollut. Bull.* 187: 114570. https://doi.org/https://doi.org/10.1016/j.marpolbul.2023.114570

Kunz A, Schneider F, Anthony N, Lin H-T. 2023. Microplastics in rivers along an urban-rural gradient in an urban agglomeration: Correlation with land use, potential sources and pathways. *Environ. Pollut.* 321: 121096. https://doi.org/10.1016/j.envpol.2023.121096

Lee H, Kim S, Sin A, Kim G, Khan S, Nadagouda MN, Sahle-Demessie E, Han C. 2023. Pretreatment methods for monitoring microplastics in soil and freshwater sediment samples: A comprehensive review. *Sci. Total Environ.* 871: 161718. https://doi.org/10.1016/j.scitotenv.2023.161718

Li G, Chen Z, Bowen M, Coco G. 2024. Transport and retention of sinking microplastics in a well-mixed estuary. *Mar. Pollut. Bull.* 203(May): 116417. https://doi.org/10.1016/j.marpolbul.2024.116417

Li J, Zhang L, Dang X, Su L, Jabeen K, Wang H, Wang Z. 2022. Effects of cooking methods on microplastics in dried shellfish. *Sci. Total Environ.* 837:

155787. https://doi.org/doi.org/10.1016/j.scitotenv.2022.155787

Li W, Wang Z, Li Weiping, Li Z. 2022. Impacts of microplastics addition on sediment environmental properties, enzymatic activities and bacterial diversity. *Chemosphere*. 307: 135836. https://doi.org/10.1016/j.chemosphere.2022.135836

Li Y, Chen L, Zhou N, Chen Y, Ling Z, Xiang P. 2024. Microplastics in the human body: A comprehensive review of exposure, distribution, migration mechanisms, and toxicity. *Sci. Total Environ.* 946: 174215. https://doi.org/10.1016/j.scitotenv.2024.174215

Li Z, Chao M, He X, Lan X, Tian C, Feng C, Shen Z. 2022. Microplastic bioaccumulation in estuary-caught fishery resource. *Environ. Pollut.* 306: 119392. https://doi.org/https://doi.org/10.1016/j.envpol.2022.119392

Liang W, Li B, Jong M-C, Ma C, Zuo C, Chen Q, Shi H. 2023. Process-oriented impacts of microplastic fibers on behavior and histology of fish. *J. Hazard. Mater.* 448: 130856. https://doi.org/10.1016/j.jhazmat.2023.130856

Liebezeit G, Dubaish F. 2012. Microplastics in beaches of the East Frisian islands Spiekeroog and Kachelotplate. *Bull. Environ. Contam. Toxicol.* 89: 213–217.

Lin L, Zhang X, Yuan B, Li H, Lu H, Liu J, Hong H, Yan C. 2023. Effects of Biofouling on the Properties and Sinking Behavior of Disposable Face Masks in Seawater: A Systematic Comparison with Microplastic Films and Particles. *Environ. Sci. Technol. Lett.* 10(9): 792–797. https://doi.org/10.1021/acs.estlett.3c00460

Lonsdale J-A, Leach C, Parsons D, Barkwith A, Manson S, Elliott M. 2022. Managing estuaries under a changing climate: A case study of the Humber Estuary, UK. *Environ. Sci. Policy*. 134: 75–84. https://doi.org/doi.org/10.1016/j.envsci.2022.04.001

Lusher A, Hollman P, Mendoza-Hill J. 2017. Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety. [place unknown]: FAO.

Mahary A, Effendi I, Hendrik H, Darwis D. 2023. Strategy for development of blood cockles (Anadara granosa) cultivation in Batubara Regency, North Sumatera, Indonesia. *AACL Bioflux*. 16(3): 1636–1647.

Maherlsa R, Purwiyanto AIS, Agustriani F, Putri WAE. 2019. Identification of surface macro debrisin river flow and estuary of Musi River, South Sumatera Province, Indonesia. In: *J. Phys. Conf. Ser.* Vol. 1282. [place unknown]: IOP Publishing; p. 12106.

Malinowski CR, Searle CL, Schaber J, Höök TO. 2023. Microplastics impact simple aquatic food web dynamics through reduced zooplankton feeding and potentially releasing algae from consumer control. *Sci. Total Environ.* 904: 166691. https://doi.org/10.1016/j.scitotenv.2023.166691

Malli A, Corella-Puertas E, Hajjar C, Boulay AM. 2022. Transport mechanisms and fate of microplastics in estuarine compartments: A review. *Mar. Pollut. Bull.* 177(September 2021): 113553. https://doi.org/10.1016/j.marpolbul.2022.113553

Mohan P, Shahul Hamid F, Furumai H, Nishikawa K. 2024. Beneath the surface: Exploring microplastic intricacies in Anadara granosa. *Mar. Environ. Res.* 199: 106581. https://doi.org/10.1016/j.marenvres.2024.106581

Namira N, Daud A, Mallongi A, Amqam H, Wahyu A, Irwandy I. 2023. Risk Analysis of Microplastic Exposure Through Consumption of Anadara Granosa at Coastal Area. *Pharmacogn. J.* 15(4): 558–562. https://doi.org/10.5530/pj.2023.15.119

Napper IE, Bakir A, Rowland SJ, Thompson RC. 2015. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. *Mar. Pollut. Bull.* 99(1–2): 178–185. https://doi.org/10.1016/j.marpolbul.2015.07.029

Narmatha Sathish M, Immaculate Jeyasanta K, Patterson J. 2020. Monitoring of microplastics in the clam Donax cuneatus and its habitat in Tuticorin coast of Gulf of Mannar (GoM), India. *Environ. Pollut.* 266: 115219. https://doi.org/10.1016/j.envpol.2020.115219

Natsir M, Ulya Z, Fitriani R. 2022. Mangrove forest utilization policies reconceptualized with a view to improving the regional economy in Aceh Tamiang District, Indonesia. *Biodiversitas J. Biol. Divers.* 23(12).

Ningrum EW, Patria MP. 2022. Microplastic contamination in Indonesian anchovies from fourteen locations. *Biodiversitas*. 23(1): 125–134. https://doi.org/10.13057/biodiv/d230116

Pannetier P, Morin B, Le Bihanic F, Dubreil L, Clérandeau C, Chouvellon F, Van Arkel K, Danion M, Cachot J. 2020. Environmental samples of microplastics induce significant toxic effects in fish larvae. *Environ. Int.* 134: 105047. https://doi.org/doi.org/10.1016/j.envint.2019.105047

Patria MP, Kholis N, Anggreini D, Buyong F. 2023. Abundance and distribution of microplastics in seawater, sediment, and macroalgae sea grapes Caulerpa racemosa from Semak Daun Island, Jakarta Bay, Indonesia. *Biodiversitas J. Biol. Divers.* 24(6). https://doi.org/10.13057/biodiv/d240638

Perumal K, Muthuramalingam S. 2022. Global sources, abundance, size, and distribution of microplastics in marine sediments - A critical review. *Estuar. Coast. Shelf Sci.* 264: 107702. https://doi.org/10.1016/j.ecss.2021.107702

Potipat J, Srimoon R, Mekprayoon S. 2024. Microplastic contamination in the Chanthaburi estuarine ecosystem, Eastern part of Thailand. *J. Environ. Biol.* 45(2): 152–160. https://doi.org/10.22438/jeb/45/2/MRN-5210

Prasetiyono E, Nirmala K, Supriyono E, Sukenda, Hastuti YP. 2022. Analysis of environmental quality, production performance and economic feasibility of Anadara granosa cultivation in Sukal, Bangka Belitung Province. *AACL Bioflux*. 15(6): 2881–2891.

Prata JC, Silva ALP, Da Costa JP, Mouneyrac C, Walker TR, Duarte AC, Rocha-Santos T. 2019. Solutions and integrated strategies for the control and mitigation of plastic and microplastic pollution. *Int. J. Environ. Res. Public Health*. 16(13): 2411.

Praveena SM, Shaifuddin SNM, Akizuki S. 2018. Exploration of microplastics from personal care and cosmetic products and its estimated emissions to marine environment: An evidence from Malaysia. *Mar. Pollut. Bull.* 136: 135–140. https://doi.org/10.1016/j.marpolbul.2018.09.012

Purwiyanto AIS, Prartono T, Riani E, Koropitan AF, Naulita Y, Takarina ND, Cordova MR. 2022. The contribution of estuaries to the abundance of microplastics in Jakarta Bay, Indonesia. *Mar. Pollut. Bull.* 184: 114117. https://doi.org/https://doi.org/10.1016/j.marpolbul.2022.114117

Purwiyanto AIS, Suteja Y, Ningrum PS, Putri WAE, Agustriani F, Cordova MR, Koropitan AF. 2020. Concentration and adsorption of Pb and Cu in microplastics: case study in aquatic environment. *Mar. Pollut. Bull.* 158: 111380.

Rafa N, Ahmed B, Zohora F, Bakya J, Ahmed S, Ahmed SF, Mofijur M, Chowdhury AA, Almomani F. 2024. Microplastics as carriers of toxic pollutants: Source, transport, and toxicological effects. *Environ. Pollut.* 343: 123190. https://doi.org/10.1016/j.envpol.2023.123190

Rahmatin NM, Soegianto A, Irawan B, Payus CM, Indriyasari KN, Marchellina A, Mukholladun W, Irnidayanti Y. 2024. The spatial distribution and physico-chemical characteristic of microplastics in the sediment and cockle (Anadara granosa) from the coastal waters of East Java, Indonesia, and the health hazards associated with cockle consumption. *Mar. Pollut. Bull.* 198(October 2023). https://doi.org/10.1016/j.marpolbul.2023.115906

Rahutami S, Said M, Ibrahim E. 2022. Actual status assessment and prediction of the Musi River water quality, Palembang, South Sumatra, Indonesia. *J. Ecol. Eng.* 23(10).

Retnaningdyah C, Febriansyah SC, Hakim L. 2022. Evaluation of the quality of mangrove ecosystems using macrozoobenthos as bioindicators in the Southern Coast of East Java, Indonesia. *Biodiversitas J. Biol. Divers.* 23(12).

Rillig MC. 2012. Microplastic in Terrestrial Ecosystems and the Soil? *Environ. Sci. Technol.* 46(12): 6453–6454. https://doi.org/10.1021/es302011r

Rozirwan, Az-Zahrah SAF, Khotimah NN, Nugroho RY, Putri WAE, Fauziyah, Melki, Agustriani F, Siregar YI. 2024. Ecological Risk Assessment of Heavy Metal Contamination in Water, Sediment, and Polychaeta (Neoleanira Tetragona) from Coastal Areas Affected by Aquaculture, Urban Rivers, and Ports in South Sumatra. *J. Ecol. Eng.* 25(1): 303–319.

Rozirwan, Fauziyah, Nugroho RY, Melki, Ulqodry TZ, Agustriani F, Ningsih EN, Putri WAE. 2022. An ecological assessment of crab's diversity among habitats of migratory birds at berbak-sembilang national park indonesia. *Int. J. Conserv. Sci.* 13(3): 961–972.

Rozirwan, Fauziyah, Wulandari PI, Nugroho RY, Agutriani F, Agussalim A, Supriyadi F, Iskandar I. 2022. Assessment distribution of the phytoplankton community structure at the fishing ground, Banyuasin estuary, Indonesia. *Acta Ecol. Sin.* 42: 670–678. https://doi.org/https://doi.org/10.1016/j.chnaes.2022.02.006

Rozirwan, Iskandar I, Hendri M, Apri R, Supardi, Azhar N, Mardiansyah W. 2019. Distribution of phytoplankton diversity and abundance in Maspari island waters, South Sumatera, Indonesia. In: *IOP Conf. Ser. J. Phys.* Vol. 1282. [place unknown]: IOP Publishing; p. 012105. https://doi.org/10.1088/1742-6596/1282/1/012105

Rozirwan, Melki, Apri R, Fauziyah, Agussalim A, Hartoni, Iskandar I. 2021. Assessment the macrobenthic diversity and community structure in the Musi Estuary, South Sumatra, Indonesia. *Acta Ecol. Sin.* 41(4): 346–350. https://doi.org/https://doi.org/10.1016/j.chnaes.2021.02.015

Rozirwan, Nanda, Nugroho RY, Diansyah G, Muhtadi, Fauziyah, Putri WAE, Agussalim A. 2023. Phytochemical composition, total phenolic content and antioxidant activity of Anadara granosa (Linnaeus, 1758) collected from the east coast of South Sumatra, Indonesia. *Baghdad Sci. J.* 20(4): 1258–1265. https://doi.org/dx.doi.org/10.21123/bsj.2023.6941

Rozirwan R, Khotimah NN, Putri WAE, Fauziyah F, Aryawati R, Damiri N, Isnaini I, Nugroho RY. 2023. Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment. *Biodiversitas J. Biol. Divers.* 24(12). https://doi.org/doi.org/10.13057/biodiv/d241236

Rozirwan, Ramadani S, Putri WAE, Fauziyah, Khotimah NN, Nugroho RY. 2023. Evaluation of Calcium and Phosphorus content in Scallop Shells (Placuna placenta) and Blood Cockle Shells (Anadara granosa) from Banyuasin Waters, South Sumatra. *Egypt. J. Aquat. Biol. Fish.* 27(3): 1053–1068.

Sahidin A, Zahidah Z, Herawati H, Wardianto Y, Setyobudiandi I, Partasasmita R. 2018. Macrozoobenthos as bioindicator of ecological status in Tanjung Pasir Coastal, Tangerang District, Banten Province, Indonesia. *Biodiversitas J. Biol. Divers.* 19(3): 1123–1129. https://doi.org/10.13057/biodiv/d190347

Saleh R, Daud A, Ishak H, Amqam H, Wahyu A, Stang, Birawida AB, Mallongi A. 2023. Spatial Distribution of Microplastic Contamination in Blood Clams (Anadara granosa) on the Jeneponto Coast, South Sulawesi. *Pharmacogn. J.* 15(4): 680–690. https://doi.org/10.5530/pj.2023.15.137

Samuels W, Awe A, Sparks C. 2024. Microplastic pollution and risk assessment in surface water and sediments of the Zandvlei Catchment and estuary, Cape Town, South Africa. *Environ. Pollut.* 342: 122987. https://doi.org/10.1016/j.envpol.2023.122987

Santucci L, Fernández-Severini MD, Rimondino GN, Colombo C V., Prieto G, Forero-López AD, Carol ES. 2024. Assessment of meso- and microplastics distribution in coastal sediments and waters at the middle estuary of the Rio De La Plata, Argentina (SW Atlantic Ocean). *Sci. Total Environ.* 914(January). https://doi.org/10.1016/j.scitotenv.2024.170026

Sari A, Tuwo A, Saru A. 2022. Diversity of fauna species in the mangrove ecosystem of Youtefa Bay Tourism Park, Papua, Indonesia. *Biodiversitas J. Biol. Divers.* 23(9): 4490–4500.

Smith M, Love DC, Rochman CM, Neff RA. 2018. Microplastics in seafood and the implications for human health. *Curr. Environ. Heal. reports*. 5: 375–386.

Surbakti H, Nurjaya IW, Bengen DG, Prartono T. 2023. Temporal variation of freshwater as control of mangrove in Banyuasin Estuary, South Sumatra, Indonesia. *Biodiversitas J. Biol. Divers.* 24(3): 1502–1510.

Suteja Y, Purwiyanto AIS, Purbonegoro T, Cordova MR. 2024. Spatial and temporal trends of microplastic contamination in surface sediment of Benoa Bay: An urban estuary in Bali-Indonesia. *Mar. Pollut. Bull.* 202(April): 116357. https://doi.org/10.1016/j.marpolbul.2024.116357

Ta AT, Babel S. 2023. Occurrence and spatial distribution of microplastic contaminated with heavy metals in a tropical river: Effect of land use and population density. *Mar. Pollut. Bull.* 191(April): 114919. https://doi.org/10.1016/j.marpolbul.2023.114919

Tang C, Li Y, He C, Acharya K. 2020. Dynamic behavior of sediment resuspension and nutrients release in the shallow and wind-exposed Meiliang Bay of Lake Taihu. *Sci. Total Environ.* 708: 135131. https://doi.org/10.1016/j.scitotenv.2019.135131

Thacharodi A, Meenatchi R, Hassan S, Hussain N, Bhat MA, Arockiaraj J, Ngo HH, Le QH, Pugazhendhi A. 2024. Microplastics in the environment: A critical overview on its fate, toxicity, implications, management, and bioremediation strategies. *J. Environ. Manage.* 349: 119433. https://doi.org/10.1016/j.jenvman.2023.119433

Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, McGonigle D, Russell AE. 2004. Lost at sea: where is all the plastic? *Science (80-.).* 304(5672): 838.

Tomlinson DL, Wilson JG, Harris CR, Jeffrey DW. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer meeresuntersuchungen*. 33: 566–575.

Truchet DM, López ADF, Ardusso MG, Rimondino GN, Buzzi NS, Malanca FE, Spetter CV, Severini MDF. 2021. Microplastics in bivalves, water and sediments from a touristic sandy beach of Argentina. *Mar. Pollut. Bull.* 173: 113023. https://doi.org/10.1016/j.marpolbul.2021.113023

Ukhrowi HR, Wardhana W, Patria MP. 2021. Microplastic abundance in blood cockle Anadara granosa (linnaeus, 1758) at Lada Bay, Pandeglang, Banten. *J. Phys. Conf. Ser.* 1725(1): 012053. https://doi.org/10.1088/1742-6596/1725/1/012053

Unuofin JO, Igwaran A. 2023. Microplastics in seafood: Implications for food security, safety, and human health. *J. Sea Res.* 194: 102410. https://doi.org/10.1016/j.seares.2023.102410

Vital SA, Cardoso C, Avio C, Pittura L, Regoli F, Bebianno MJ. 2021. Do microplastic contaminated seafood consumption pose a potential risk to human health? *Mar. Pollut. Bull.* 171: 112769. https://doi.org/10.1016/j.marpolbul.2021.112769

Wakwella A, Wenger A, Jenkins A, Lamb J, Kuempel CD, Claar D, Corbin C, Falinski K, Rivera A, Grantham HS. 2023. Integrated watershed management solutions for healthy coastal ecosystems and people. *Cambridge Prism. Coast. Futur.* 1: e27.

Walker TR, Fequet L. 2023. Current trends of unsustainable plastic production and micro(nano)plastic pollution. *TrAC - Trends Anal. Chem.* 160: 116984. https://doi.org/10.1016/j.trac.2023.116984

Wang G, Lu J, Li W, Ning J, Zhou L, Tong Y, Liu Z, Zhou H, Xiayihazi N. 2021. Seasonal variation and risk assessment of microplastics in surface water of the Manas River Basin, China. *Ecotoxicol. Environ. Saf.* 208: 111477. https://doi.org/https://doi.org/10.1016/j.ecoenv.2020.111477

Wang Y, Wu Y, Pu Q, Sun P, Zhao W, Liu M, Li Y. 2023. Aquatic toxicity of tire microplastics on marine and freshwater organisms: An in silico approach. *Chemosphere*. 313(October 2022). https://doi.org/10.1016/j.chemosphere.2022.137523

Ward JE, Zhao S, Holohan BA, Mladinich KM, Griffin TW, Wozniak J, Shumway SE. 2019. Selective Ingestion and Egestion of Plastic Particles by the Blue Mussel (Mytilus edulis) and Eastern Oyster (Crassostrea virginica): Implications for Using Bivalves as Bioindicators of Microplastic Pollution. *Environ. Sci. Technol.* 53(15): 8776–8784. https://doi.org/10.1021/acs.est.9b02073

Winiarska E, Jutel M, Zemelka-Wiacek M. 2024. The potential impact of nano- and microplastics on human health: Understanding human health risks. *Environ. Res.* 251(P2): 118535. https://doi.org/10.1016/j.envres.2024.118535

Xu K, Shahab A, Rinklebe J, Xiao H, Li J, Ye F, Li Y, Wang D, Bank MS, Wei G. 2024. Spatial distribution, morphology, and risk assessment of microplastics in sediment from the Pearl River Estuary, China. *Emerg. Contam.* 10(3): 100383. https://doi.org/10.1016/j.emcon.2024.100383

Xu P, Peng G, Su L, Gao Y, Gao L, Li D. 2018. Microplastic risk assessment in surface waters: A case study in the Changjiang Estuary, China. *Mar. Pollut. Bull.* 133: 647–654.

Xu Q, Xing R, Sun M, Gao Y, An L. 2020. Microplastics in sediments from an interconnected river-estuary region. *Sci. Total Environ.* 729: 139025. https://doi.org/10.1016/j.scitotenv.2020.139025

Yang X, An C, Feng Q, Boufadel M, Ji W. 2022. Aggregation of microplastics and clay particles in the nearshore environment: Characteristics, influencing factors, and implications. *Water Res.* 224: 119077. https://doi.org/10.1016/j.watres.2022.119077

Yuan B, Gan W, Sun J, Lin B, Chen Z. 2023. Depth profiles of microplastics in sediments from inland water to coast and their influential factors. *Sci. Total Environ.* 903: 166151. https://doi.org/10.1016/j.scitotenv.2023.166151

Yuan B, Gan W, Sun J, Lin B, Chen Z, Li WW, Wang Z, Li WW, Li Z, Rillig MC. 2022. Depth profiles of microplastics in sediments from inland water to coast and their influential factors. *Environ. Sci. Technol.* 903(12): 6453–6454. https://doi.org/10.1016/j.scitotenv.2023.166151

Yuan Z, Nag R, Cummins E. 2022. Human health concerns regarding microplastics in the aquatic environment - From marine to food systems. *Sci. Total Environ.* 823: 153730. https://doi.org/10.1016/j.scitotenv.2022.153730

Yulinda E, Saad M, Yusuf M. 2020. A study on the economic potential of blood cockles (Anadara granosa) in Rokan Hilir, Riau Province, Indonesia. *AACL Bioflux*. 13(3): 1504–1510.

Zhang K, Hamidian AH, Tubić A, Zhang Y, Fang JKH, Wu C, Lam PKS. 2021. Understanding plastic degradation and microplastic formation in the environment: A review. *Environ. Pollut.* 274. https://doi.org/10.1016/j.envpol.2021.116554

Zhao J, Feng X, Shi Xiaolai, Bai Y, Yu X, Shi Xuefa, Zhang W, Zhang R. 2015. Sedimentary organic and inorganic records of eutrophication and hypoxia in and off the Changjiang Estuary over the last century. *Mar. Pollut. Bull.* 99(1): 76–84. https://doi.org/doi.org/10.1016/j.marpolbul.2015.07.060

Zhao X, Chen H, Jia Q-L, Shen C-S, Zhu Y, Li L, Nie Y-H, Ye J-F. 2020. [Pollution Status and Pollution Behavior of Microplastic in Surface Water and Sediment of Urban Rivers]. *Huan jing ke xue= Huanjing kexue*. 41(8): 3612–3620. https://doi.org/10.13227/j.hjkx.201912236

Zheng Y, Li J, Cao W, Jiang F, Zhao C, Ding H, Wang M, Gao F, Sun C. 2020. Vertical distribution of microplastics in bay sediment reflecting effects of sedimentation dynamics and anthropogenic activities. *Mar. Pollut. Bull.* 152: 110885. https://doi.org/10.1016/j.marpolbul.2020.110885

Zhou Z, Zhang P, Zhang G, Wang S, Cai Y, Wang H. 2021. Vertical microplastic distribution in sediments of Fuhe River estuary to Baiyangdian Wetland in Northern China. *Chemosphere*. 280: 130800. https://doi.org/10.1016/j.chemosphere.2021.130800

Formatted: Indent: Hanging: 1 cm

Unsri Google Apps

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

1 pesan

Smujo Editors via SMUJO <support@smujo.com> 27 Maret 2025 pukul 16.55
Balas Ke: Smujo Editors <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

Rozirwan Rozirwan:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Implication of microplastics presence in sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia". **Complete your revision with a Table of Responses containing your answers to reviewer comments (for multiple comments) and/or enable Track Changes**. We are waiting for your revision in the system (https://smujo.id/biodiv), do not send it via email.

Our decision is: Revisions Required

Reviewer A:

Dear author

The author has corrected several reviewer suggestions. But this article still needs improvement. All comments are available in the text

Recommendation: Revisions Required

Biodiversitas Journal of Biological Diversity

A-19666-Article Text-1157421-1-4-20250324.doc
8494K

Author(s)` Response to Reviewer :

Dear Reviewer,

We sincerely appreciate your time and effort in reviewing our manuscript and providing valuable feedback. Your insightful comments have been instrumental in improving the quality of our work. In response, we have carefully revised the manuscript accordingly. Please find our detailed responses to each of your suggestions below.

With kind regards,
The Author (s)

Table of Author(s)` Response

No	**Comments**	**Response**
1.	Change “Blood clams” into the species name “*A. granosa*”	We have changd into the species name
2.	Are there water quality information in this research? Such as salinity, DO, turbidity, temperature, etc	Yes, we have measured the water quality such as temperature, pH, DO, salinity, water brightness, current speed. We have added the information in paragraph 1 in Study Area Section **(Line 87 – 89)**
3.	See guideline of references. Yellow color	we have made changes to this references section

COVERING LETTER

Dear **Editor-in-Chief,**

I herewith enclosed a research article,

- ☑ The submission has not been previously published, nor is it before another journal for consideration (or an explanation has been provided in Comments to the Editor).
- ☑ The submission file is in OpenOffice, Microsoft Word (DOC, not DOCX), or RTF document file format.
- ☑ The text is single-spaced; uses a 10-point font; employs italics, rather than underlining (except with URL addresses); and all illustrations, figures, and tables are placed within the text at the appropriate points, rather than at the end.
- ☑ The text adheres to the stylistic and bibliographic requirements outlined in the Author Guidelines.
- ☑ Most of the references come from current scientific journals (c. 80% published in the last 10 years), except for taxonomic papers.
- ☑ Where available, DOIs for the references have been provided.
- ☑ When available, a certificate for proofreading is included.

SUBMISSION CHECKLIST

Ensure that the following items are present:

The first corresponding author must be accompanied with contact details:

- ☑ E-mail address
- ☑ Full postal address (incl street name and number (location), city, postal code, state/province, country)
- ☑ Phone and facsimile numbers (incl country phone code)

All necessary files have been uploaded, and contain:

- ☑ Keywords
- ☑ Running titles
- ☑ All figure captions
- ☑ All tables (incl title and note/description)

Further considerations

- ☑ Manuscript has been "spell & grammar-checked" Better, if it is revised by a professional science editor or a native English speaker
- ☑ References are in the correct format for this journal
- ☑ All references mentioned in the Reference list are cited in the text, and vice versa
- ☑ Colored figures are only used if the information in the text may be losing without those images
- ☑ Charts (graphs and diagrams) are drawn in black and white images; use shading to differentiate

Title:

Implication of microplastic presence in sediment and blood clams (*Anadara granosa*, Linnaeus 1758) (Mollusca: Bivalvia) in the Musi Estuary, Indonesia

Author(s) name:

M. AKBAR RAHMAN[1], ROZIRWAN[2♥], WIKE EKA AYU PUTRI[2], GUSTI DIANSYAH[2], MELKI [2], ICA DELYA [2], REDHO YOGA NUGROHO[2]

Address

(Fill in your institution's name and address, your personal cellular phone and email)

[1]Environmental Management Study Program, Graduate Program, Universitas Sriwijaya, Palembang 30139, South Sumatra, Indonesia

[2]Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, Ogan Ilir 30662, South Sumatra, Indonesia. Tel./fax.: +62-813-7171-1885, ♥email: rozirwan@unsri.ac.id

For possibility publication on the journal:

(fill in *Biodiversitas* or *Nusantara Bioscience* or *mention the others*)

- [x] Biodiversitas Journal of Biological Diversity
- [ ] Nusantara Bioscience
- [ ] Prosiding Seminar Nasional Masyarakat Biodiversitas Indonesia
- [ ] Asian Journal of Agriculture
- [ ] Asian Journal of Ethnobiology
- [ ] Asian Journal of Forestry
- [ ] Asian Journal of Natural Product Biochemistry
- [ ] Asian Journal of Tropical Biotechnology
- [ ] International Journal of Bonorowo Wetlands
- [ ] Cell Biology and Development
- [ ] Indo Pacific Journal of Ocean Life
- [ ] International Journal of Tropical Drylands

Novelty:

(state your claimed novelty of the findings versus current knowledge)

This research is groundbreaking because there is currently no information available on the abundance of microplastics in sediments of the Musi Estuary, Indonesia. This article provides a comprehensive review of recent research on microplastics in the sediments of the Musi Estuary and their impact on benthic animals (*Anadara granosa*), one of the seafood from the Musi Estuary.

Statements:

This manuscript has not been published and is not under consideration for publication in any other journal or any other type of publication (including web hosting) either by me or any of my co-authors.

Author (s) has been read and agreed to the Ethical Guidelines.

List of five potential reviewers

(Fill in names of five potential reviewers **that agree to review your manuscpt** and their **email** addresses. He/she should have Scopus ID and come from different institution with the authors; and from at least three different countries)

1. Mohamad Fawzi Mahomoodally

Department of Health Sciences, Faculty of Science, University of Mauritius, 230 Réduit, Mauritius

Email f.mahomoodally@uom.ac.mu

Scopus ID: 9537009000

His skills and expertise in Phytochemicals, Natural Products, and Medicinal Plants are very benefical for reviewing our articles

2. Muthu Thiruvengadam, Ph.D

Department of Applied Bioscience, Konkuk University, Seoul

Email muthu@konkuk.ac.kr

Scopus ID: 13606231700

His skills and expertise in Natural Product, Medicinal and Pharmaceutical, Drug Discovery is very helpful for reviewing our articles

3. Benjamin Boucherle, Ph.D
Université Grenoble Alpes · Departement de Pharmacochimie Moléculaire
His skills and expertise in Natural Product, Medicinal and Pharmaceutical, Drug Discovery is very helpful for reviewing our articles
Benjamin.boucherle@univ-grenoble-alpes.fr
Scopus ID: 19638352500

4. Rodrigo Egydio Barreto, Ph.D
São Paulo State University, Departamento de Fisiologia, Centro De Aquicultura Da UNESP
His skills and expertise in marine biology are very helpful for reviewing our articles
rodrigo.egydio@unesp.br
Scopus ID: 7004866217

5. Prof. Dr. Bintal Amin
Marine Science Department, Faculty of fisheries and marine Science, University of Riau
bintal.amin@lecturer.unri.ac.id
Scopus ID: 23491429700

Place and date:

Palembang, September 30, 2024

Sincerely yours,
(fill in your name, no need scanned autograph)

Rozirwan

Implication of microplastic presence in sediment and blood clams *Anadara granosa* (Linnaeus 1758) (Mollusca: Bivalvia) in the Musi Estuary, Indonesia

M. AKBAR RAHMAN[1], ROZIRWAN[2♥], WIKE EKA AYU PUTRI[2], GUSTI DIANSYAH[2], MELKI[2], ICA DELYA[2], REDHO YOGA NUGROHO[2]

[1]Environmental Management Study Program, Graduate Program, Universitas Sriwijaya, Palembang 30139, South Sumatra, Indonesia
[2]Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, Ogan Ilir 30662, South Sumatra, Indonesia.
Tel./fax.: +62-813-7171-1885, ♥email: rozirwan@unsri.ac.id

Manuscript received: 30 September 2024. Revision accepted: .... 2024.

Abstract. Microplastic pollution poses a serious risk to estuarine ecosystems, affecting sediments and benthic species. Blood clams ~~(~~*Anadara granosa*, (Linnaeus 1758) represent a significant commercial seafood product in Indonesia, including those from the Musi Estuary. This study investigated the risks associated with microplastic contamination in sediments and *A. granosa* in the Musi Estuary, located in South Sumatra, Indonesia. Sediment samples were extracted using sodium chloride (NaCl, 1.2 g cm^{-3}) and hydrogen peroxide (30% H_2O_2). In contrast, *A. granosa* samples were digested with 10% KOH for microplastic extraction. The abundance and shape of microplastics were analyzed from both samples. Pollution risk assessment was conducted through the calculation of the Pollution Load Index (PLI), Nemerow Pollution Index (NPI), and Bioconcentration Factor (BCF). The results revelved the presence of microplastics in sediments, with a mean abundance of 1.31±0.41 particles/g dw, while in *A. granosa*, it was 21.05±10.31 particles/ind. Both samples exhibited high microplastic bioaccumulation (NPI > 2), although the pollution load remained relatively low (minor category, PLI < 10). The bioconcentration factor between *A. granosa* and sediment was determined to be 23.28, indicating that the *A. granosa* absorbed microplastics present in the sediment. These findings highlight the significant bioaccumulation potential of microplastics in *A. granosa* ~~blood clams~~ within the Musi Estuary. ~~It is important for~~ The local community and government need to establish mitigations for future microplastic management efforts.

Keywords: Bioaccumulation, blood clams, microplastics, Musi Estuary, sediment

Running title: Microplastics in sediment and blood clams

INTRODUCTION

River estuaries are intricate and dynamic ecosystems that play a vital role in ecological sustainability and support a variety of socio-economic activities (Boerema and Meire 2017; Hasan et al. 2022; Retnaningdyah et al. 2022; Hasan et al. 2023). These ecosystems provide essential habitats for diverse species and act as focal points for human activities, including urbanization, recreation, and commercial enterprises (Islamy and Hasan 2020; Lonsdale et al. 2022; Natsir et al. 2022; Aunurrahman et al. 2023). Among the major estuaries in Sumatra, the Musi Estuary holds significant ecological and economic importance (Surbakti et al. 2023). It serves as a critical habitat for various fish species and benthic organisms, which in turn sustain the livelihoods of local communities through the utilization of water resources (Rozirwan et al. 2021; Fauziyah et al. 2022; Rozirwan et al. 2022; Fauziyah et al. 2023). Nevertheless, the intensification of human activities within and surrounding the Musi Estuary has resulted in significant environmental deterioration (Maherlsa et al. 2019). Major contributors to this issue include heavy metal and microplastic contamination, which pose a substantial threat to ecosystem health (Purwiyanto et al. 2022; Rahutami et al. 2022; Fitria et al. 2023; ~~R.~~ Rozirwan et al. 2023; Diansyah et al. 2024; Rozirwan et al. 2024). These pollutants endanger the ecological equilibrium of the estuary, with the potential to affect its biodiversity and the livelihoods dependent upon it.

Macrozoobenthos are considered pivotal components in preserving the equilibrium of estuarine ecosystems (Sari et al. 2022; Isroni et al. 2023). These organisms play a crucial role in the food web and nutrient cycling, thereby supporting a variety of marine species (Griffiths et al. 2017). Moreover, macrozoobenthos are highly sensitive to environmental changes, making them reliable bioindicators of ecological degradation (Sahidin et al. 2018). Research worldwide highlights that macrozoobenthos, including bivalves such as ~~blood clams~~ *Anadara granosa* (Linnaeus 1758) are often used as bioindicators because they can take in and store pollutants from their environment through filter-feeding (Fitri and Patria 2019; Ward et al. 2019; Ding et al. 2021; Bonifacio et al. 2022; Saleh et al. 2023; Rahmatin et al. 2024). *Anadara granosa* is widely consumed by the general public as a nutrient-rich seafood, particularly among local communities

(Rozirwan, et al. 2023; Rozirwan, et al. 2023). Among these, *A. granosa* is a prominent bivalve species that plays a crucial role in maintaining ecosystem stability and generating substantial economic benefits for coastal communities (Yulinda et al. 2020; Prasetiyono et al. 2022; Mahary et al. 2023). Given its ecological importance and economic value within coastal and estuarine systems, it is imperative to investigate pollutant contamination in *A. granosa* to understand the broader impacts of environmental pollution comprehensively.

Various pollutants, including heavy metals, hydrocarbons, pesticides, and microplastics, have been identified as significant contaminants of estuarine ecosystems, with many of these pollutants accumulating in sediments (Zhao et al. 2015; Kılıç et al. 2023; Han et al. 2024; Jacq et al. 2024). Among these, plastic pollution has emerged as a critical concern due to its pervasive impact on aquatic environments (Borrelle et al. 2020; Hecker et al. 2023). Over the last five decades, the widespread reliance on single-use plastics has led to extensive accumulation and fragmentation of plastic materials across diverse ecosystems (Zhang et al. 2021; Walker and Fequet 2023). As plastics degrade, they break down into microplastics, defined as particles ranging in size from 1 µm to 5 mm (Frias and Nash 2019). These microplastics enter aquatic ecosystems through various pathways, such as the fragmentation of discarded plastic products, the release of synthetic fibers during washing, and the intentional addition of microbeads in personal care products (Napper et al. 2015; Praveena et al. 2018; Belzagui and Gutiérrez-Bouzán 2022; Gan et al. 2023). Microplastics pose multiple threats by releasing toxic additives and acting as carriers of hazardous organic pollutants and heavy metals (Caruso 2019; Fu et al. 2021; Issac and Kandasubramanian 2021; Ta and Babel 2023). These impacts are multifaceted, disrupting food webs, altering nutrient cycles, modifying habitats, and potentially inducing genetic changes in aquatic organisms (Thacharodi et al. 2024).

Prior research has quantified microplastic concentrations in the waters of the Musi Estuary, with reported levels of 467.67 ± 127.84 particles/m³ during flood tide and 723.67 ± 112.05 particles/m³ at ebb tide (Diansyah et al. 2024). These microplastics are frequently associated with toxic heavy metals, such as lead (Pb) and copper (Cu), which exacerbate their harmful environmental effects (Purwiyanto et al. 2022). In the water column, microplastics tend to settle into estuarine sediments, which have been identified as the second-largest global reservoir for microplastics after fjords (Harris 2020). The accumulation of microplastics in estuarine sediments poses significant ecological challenges, particularly due to their ingestion by benthic organisms, including *A. granosa* (Fitri and Patria 2019; Saleh et al. 2023; Rahmatin et al. 2024; Mohan et al. 2024). While numerous studies have examined microplastic concentrations in the water column, research on their distribution in sediments and bioaccumulation in benthic species, particularly *A. granosa*, remains limited.

This study aims to investigate the bioaccumulation and risks of microplastic pollution in sediments and *A. granosa* in the Musi Estuary, Indonesia. The findings are expected to enhance understanding of benthic organisms, especially *A. granosa*, and its potential health risks for local seafood consumers.

MATERIALS AND METHODS

Study Area and Sample Collection

The Musi Estuary, located on the east coast of South Sumatra, is where seawater from the Bangka Strait mixes with freshwater from the Musi River. The Musi Esturay is an important area for fisheries and benthic habitats in South Sumatra, Indonesia (Rozirwan et al. 2021; Rozirwan et al. 2022). Sampling locations were selected based on hydrodynamic conditions influencing microplastic transport and deposition, considering salinity variations and water mass interactions (Cheng et al. 2024; Diansyah et al. 2024). Locations of the sampling sites are shown in Figure 1 and Table 1. Based on in situ measurements, water parameters include temperature (27.31 – 31.6 °C), pH (6.95 – 8), dissolved oxygen (3.62 – 5.21 mg/L), salinity (6 – 30 ‰), water brightness (0.1 – 0.9 m), water current speed (0.1 – 1.8 m/s). Sediment and *A. granosa* were collected during low tide from the Musi Estuary, South Sumatra, Indonesia. Sediment samples were collected from ten sampling points using a Peterson Grab at each station (Dwiyitno et al. 2024). Samples were placed in glass jars that had been rinsed with pure distilled water and covered using aluminum foil to avoid contamination. Samples were placed in a cool box (±4 °C) for further analysis in the laboratory.

Anadara granosa samples were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). Twenty adult *A. granosa* (7.48–11.44 cm) were collected from fishermen's catch in the Musi Estuary. *Anadara granosa* samples were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). The mussels were rinsed with pure distilled water to remove any dirt. *Anadara granosa* were wrapped in aluminum foil and stored in a cooler at approximately 4 °C to preserve their freshness. After that, they were transported to the laboratory and frozen at -20°C before further analysis (Ding et al. 2021).

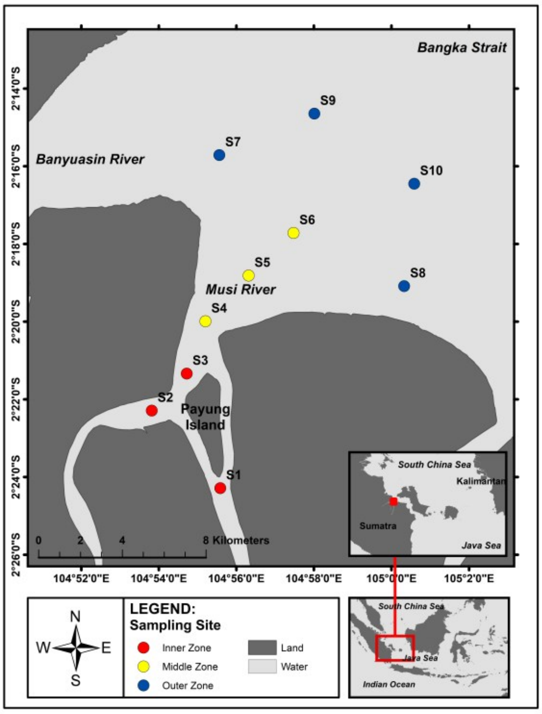

Figure 1. Study site at the Musi Estuary, Indonesia.

Table 1. Coordinates of the sampling location.

Estuary Zone	Description	Station	Latitude (ºS)	Longitude (ºE)
Inner Zone	closest to the river body and dominated by freshwater	S1	2.40470	104.92643
	mangrove vegetation and muddy substrate	S2	2.37144	104.89695
	near densely populated coastal village activities, shipping and fishing activities	S3	2.35558	104.91200
Middle Zone	between the inner zone and the outer zone	S4	2.33316	104.92003
	mangrove vegetation and muddy substrate	S5	2.31353	104.93862
	shipping and fishing activities	S6	2.29524	104.95794
Outer Zone	closest to the ocean (at the sea), dominated by seawater, no vegetation, muddy substrate shipping and fishing activities	S7	2.26183	104.92603
		S8	2.31807	105.00547
		S9	2.24403	104.96686
		S10	2.27413	105.00978

Formatted Table

Formatted Table

Microplastic extraction from sediment

Microplastics in sediments were extracted using the standard method of density separation and organic matter removal with minor modifications (Thompson et al. 2004; Liebezeit and Dubaish 2012). A total of 500 g of wet sediment samples were placed in a beaker glass covered with aluminum foil. The samples were dried in an oven at 60 °C for 48 hours, or until they reached a constant mass (Patria et al. 2023). The sediment samples were pulverized and sieved through a 5 mm steel sieve. A portion of 100 g of dried sediment was taken from the sieve, placed into a beaker glass, and covered with aluminum foil to prevent external contamination. The sample was suspended in 400 mL of saturated NaCl solution (1.2 g cm^{-3}), which is four times the sample weight, using a magnetic stirrer. This NaCl solution was prepared by dissolving pure

NaCl crystals (Merck Millipore EMSURE®) in filtered distilled water that was free from contaminants. The selection of a NaCl solution for the separation of microplastics from sediments was based on the premise that this method is cost-effective and environmentally friendly (Perumal and Muthuramalingam 2022). Stirring was carried out for 5 minutes until completely dissolved, and the mixture was allowed to stand for 1 hour. After one hour, 10 mL of 30% H_2O_2 was added to assist in the breakdown of organic matter, followed by stirring for an additional five minutes. Hydrogen peroxide (H_2O_2) is commonly used in similar studies and is regarded as highly effective for organic matter removal (Lee et al. 2023). The sample was allowed to stand for 24 hours, covered with aluminum foil. The samples were then filtered using the Whatman No. 42 filter paper (mesh size 0.45 µm, Φ = 90 mm), assisted by a vacuum pump at 17 kPa to isolate the microplastics. The collected samples were deposited into petri dishes for identification.

Microplastic extraction from *Anadara granosa*

The previously frozen *A. granosa* samples were defrosted under controlled conditions at room temperature (± 25°C) for 1 hour. After the ice melted, the *A. granosa* were washed with pure distilled water to eliminate contamination from other objects, such as sediment. The length and wet weight of the *A. granosa* were measured using an analytical balance (0.01 g). The digestive tract was carefully removed from the *A. granosa* using sterile stainless steel utensils that had been rinsed with distilled water. The extraction of microplastics from the digestive tract of the *A. granosa* was adapted from previous studies with minor modifications (Ding et al. 2018; Ding et al. 2021). The digestive tract was transferred into an Erlenmeyer flask, and 100 mL of KOH solution (10%) was added. The use of KOH is regarded as a more efficacious method for the digestion of biological material, and it has no impact on the integrity of the plastic polymer (Karami et al. 2017). The sample was covered with aluminum foil and stirred for 5 minutes using a 150 rpm magnetic stirrer. The supernatant was incubated at room temperature (±25ºC) until complete digestion of organic matter occurred. The sample was then filtered through Whatman 42 filter paper (mesh size 0.45 µm, Φ = 90 mm) to isolate microplastic. The filter paper was dried in an oven at 40°C for 5 hours and stored in petri dishes for subsequent identification of microplastic content.

Microplastic identification and quantification

Identification and quantification of microplastics from sediments and *A. granosa* were performed using the same method. Microplastic identification was performed using an Olympus CX23 microscope with 10 x 10 or 4 x 10 magnification to visually detect microplastics (Diansyah et al. 2024). The filter paper was observed closely and carefully to avoid contaminants that could enter the filter paper. Microplastics were identified based on the number and form of microplastics (fragment, film, fiber, and foam). The data obtained were recorded by sample type and station/individual for statistical purposes. To prevent contamination, personnel wear cotton lab coats, latex gloves, and cotton masks. Furthermore, access to the detection room is restricted to prevent outside contact during observations.

Procedures for quality assurance and contamination prevention

The quality and contamination control measures were implemented to prevent any alterations to the microplastics in the samples. Before sampling, glass jars and aluminum foil were rinsed with filtered distilled water. Although the samples were in a cool box, they were stored in a place that was not exposed to direct sunlight to keep the samples in good condition. Personnel are also required to wear latex gloves during sampling. During the study, from sampling to laboratory analysis, the use of plastic equipment was minimized to avoid unintentional fragmentation of the microplastics. The distilled water used was filtered with filter paper (0.45 µm,) to prevent microplastics from entering our materials. All equipment was washed with filtered distilled water to remove potential contamination from external particles (Ding et al. 2021). We prepared two controls by filtering each solution we used to avoid contaminants from materials, equipment, and air. No microplastics were found contaminating the instrument. The sterilized equipment was wrapped in aluminum foil to prevent any input of contaminants from outside. Laboratory personnel were required to wear latex gloves, lab coats, and masks throughout the analysis. Access to the laboratory was restricted during the analysis to minimize external interference that could lead to protocol errors.

Data analysis

Pollution Load Index (PLI)

PLI was calculated using a pollutant load approach, which assesses the total concentration of contaminants relative to a baseline level, to evaluate its significance. Equations were utilized to quantify the level of microplastic pollution in both sediments and *A. granosa* in the Musi Estuary, with the method adapted accordingly (Tomlinson et al. 1980; Xu et al. 2018; Wang et al. 2021)

$$CF_i = \frac{C_i}{C_{0i}}$$

This equation shows that the concentration factor (CF_i) at a particular sample is obtained by dividing the current concentration (C_i) by the initial concentration (C_{0i}). Ci indicates the quantified presence of microplastics at each sampling location or within each clam (ind), while C_{0i} denotes the background concentration, defined as the lowest value recorded across all sampling locations. Given the lack of previously published research on microplastics in sediments or *A. granosa* in the Musi River Estuary, we determined C_{0i} values from minimum concentrations across sampling stations.

$$PLI = \sqrt{CF_i}$$

This equation shows that the Pollution Load Index (PLI) is generated by calculating the square root of the Concentration Factor (CF). The PLI value of microplastics is derived from the contaminant factor (CF_i) calculated for each station/individual.

$$PLI_{zone} = \sqrt[n]{PLI_1 \times PLI_2 \times \ldots\ PLI_n}$$

Pollution Load Index of Zone (PLI_{zone}) is determined by taking the square root of the product of individual PLI values from multiple sites within the zone. This method integrates data from several measurement points, providing a more comprehensive assessment of microplastic contamination within the analyzed. A PLI_{zone} is used to assess pollution based on specific estuary zones as well as the overall estuary area. PLI values are categorized into four predefined categories of pollution load, as shown in Table 2.

Table 2. Microplastic pollution load categories

Definition	Value			
Value of the pollution load index (PLI)	<10	10-20	20-30	>30
Risk category	I	II	III	IV
Keterangan	Minor	Middle	High	Extreme

Nemerow Pollution Index (NPI)

NPI is designed to assess the bioavailability of microplastics in sediments and *A. granosa*. This index was adapted from equations used in prior studies evaluating heavy metal contamination (Alam et al. 2023).

$$NPI = \sqrt{\frac{\left(\frac{C_i}{S_i}\right)max^2 + \left(\frac{C_i}{S_i}\right)ave^2}{2}}$$

The NPI value is calculated using the square root of the mean squared deviation, incorporating both the maximum and average concentration ratios relative to the background concentration (S_i). The formula includes the sum of the squares of the maximum concentration ratio ($C_{i\ max}/S_i$) and the average concentration ratio ($C_{i\ ave}$). The Ci value represents the concentration of microplastics found in the sediment or clams at a specific station or individual, while the Si value denotes the background level of microplastics, determined as the lowest concentration recorded across all sample types. The NPI provides a measure of microplastic bioavailability in sediments and *A. granosa*, with values below 2 indicating low bioavailability and values above 2 indicating high bioavailability.

Bioconcentration Factor (BCF)

The Bioconcentration Factor (BCF) quantifies the extent to which microplastics accumulate in biota relative to their environmental concentration and is calculated using the following equation (Li et al. 2022).

$$BCF = \frac{C\ biota_{\ ave}}{C\ sediment_{\ ave}}$$

In this equation, BCF represents the bioconcentration factor, which is derived from the calculation of the average concentration of microplastic in biota (*A. granosa*) divided by the average concentration of microplastic in its environment (sediment). This value is intended to assess how much microplastic is concentrated in the biota.

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics 27. Descriptive statistics, including total, mean, standard deviation, percentage, minimum, and maximum, were utilized to assess data variation. A one-way ANOVA was applied to analyze differences in microplastic abundance between estuarine zones when the data met normality assumptions. For non-normal data, the Kruskal-Wallis test was employed to assess the significance of differences between zones. All tests were carried out with a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Microplastic presence in sediment from Musi Estuary

The Musi Estuary in South Sumatra, Indonesia, is a dynamic brackish water environment where freshwater from the Musi River meets the saltwater of the Bangka Strait. Characterized by turbid waters and muddy sediments rich in organic matter, the estuary is fringed by mangrove forests that provide habitat for aquatic species, including the ~~blood clam (~~~~*Anadara*~~ A. *granosa*~~)~~, a key species in local aquaculture (Rozirwan et al. 2023). Surrounded by urban and industrial areas, including Palembang, the estuary faces pollution from domestic, agricultural, and industrial waste, making it susceptible to microplastic accumulation in sediments and ingestion by benthic organisms like *A. granosa* ~~blood clams~~ (Almiza and Patria 2021; Diansyah et al. 2024).

Figure 2. General conditions in the Musi estuary**.** A. Coastal Settlements; B. Shipping Activities; C. Fisheries; D. Mangrove Ecosystem

The results of this study indicate that microplastics were detected at all sampling stations, as shown in Figure 4. A total of 1,308 microplastic particles were identified, with concentrations ranging from 66 to 178 particles per 100 g of dry sediment (dry weight, dw). The average abundance of microplastics was 1.31 ± 0.41 particles/g dw, with the highest concentration found at station S1 (1.78 particles/g dw) and the lowest at station S8 (0.66 particles/g dw). High levels of human activity in the upstream area of Musi Estuary, which flows downstream to the estuary and ultimately into the ocean, are responsible for the presence of microplastics (Rozirwan et al. 2021; Diansyah et al. 2024). Urban activities in close proximity to the Musi River Watershed, particularly in Palembang City, significantly contribute to the generation of plastic waste. Increased population density near riverbanks enhances the potential for plastic pollution. Furthermore, population density is a crucial factor in the entry of microplastics into rivers (Eo et al. 2023; Dwiyitno et al. 2024). As a result, plastic pollutants from domestic activities, such as the disposal of food packaging and plastic bags, can be transported through stormwater drains and eventually end up in rivers (Kunz et al. 2023). Fishing activities around Musi Estuary can contribute to microplastic pollution, primarily through fibers released from fishing nets (Li et al. 2022; Fauziyah et al. 2023). This increases anthropogenic pressure at river mouths, which can lead to greater accumulation of microplastics (Castro-Jiménez et al. 2024). Additionally, tidal fluctuation influences water flow, which facilitates the deposition of microplastics in sediment at these locations (Harris 2020). The findings of this study indicate that anthropogenic activities are responsible for high levels of microplastic deposition in the sediments of Musi Estuary. Microplastic particles that accumulate in sediments serve as a habitat for benthic organisms, which can have long-term implications for ecosystem health and balance (Rahmatin et al. 2024). As vectors for pollutants, microplastics can exacerbate toxicity, potentially endangering various populations (Caruso 2019; Fu et al. 2021; Issac and Kandasubramanian 2021; Ta and Babel 2023). Furthermore, the processes of bioaccumulation and biomagnification in benthic organisms present heightened risks to these animals, potentially leading to human consumption (Unuofin and Igwaran 2023). Therefore, it is crucial for local governments to address the handling and prevention of further microplastic accumulation.

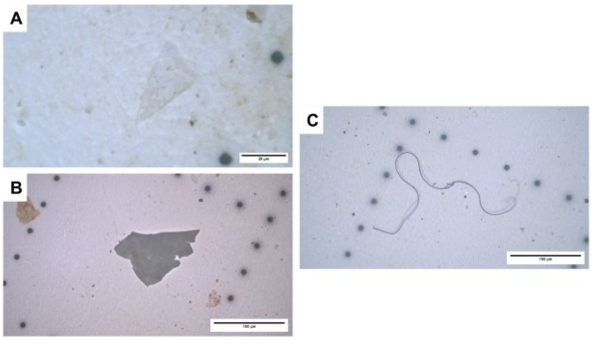

Figure 3. Various forms of microplastics, A. Film; B. Fragment; C. Fiber

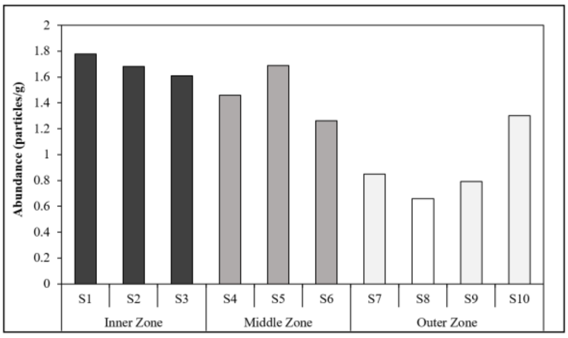

Figure 4. Distribution of microplastics from sediments in Musi Estuary, Indonesia.

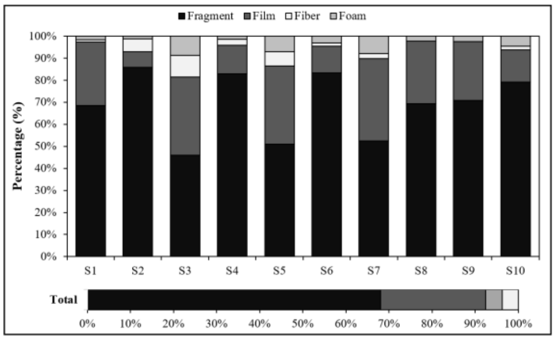

Figure 5. Percentage abundance of microplastic shapes form sediments in Musi Estuary, Indonesia

The microplastics identified in the sediments were predominantly fragments (68.92%), followed by films (23.86%), fibers (4.05%), and foams (3.17%) (Figure 3 and Figure 5). The dominance of fragments, which are a common form of secondary microplastics, occurs as a result of macroplastic degradation (Barnes et al. 2009). Fragments represented the most common type across all sediment samples analyzed. This dominance of fragments in estuarine sediments aligns with findings from various studies conducted in other estuarine environments. Research indicates that estuarine sediments globally tend to accumulate diverse microplastic forms, particularly fibers (Firdaus et al. 2020; Alam et al. 2023; Samuels et al. 2024; Santucci et al. 2024), with many studies also reporting a predominance of fragment types (Zhou et al. 2021; Suteja et al. 2024). These observations corroborate the literature, which consistently shows that fibers and fragments constitute the majority of microplastic pollution in estuarine ecosystems (Feng, An, et al. 2023).

This study reveals notable variations in microplastic concentrations compared to similar research in estuaries globally. Our findings indicate that the Musi Estuary has lower microplastic concentrations than those reported in several other Indonesian and international estuaries. For example, the Jakarta Bay Estuary exhibits concentrations nearly ten times higher, ranging from 1,184 to 1,337 particles per 100 grams of river sediment and 804 to 1,055 particles per 100 grams of beach sediment (Dwiyitno et al. 2024). Such elevated levels are likely due to increased anthropogenic activities along Jakarta's rivers, which substantially contribute to plastic waste flow. In another comparison, the Pearl River Estuary in China also shows higher microplastic densities, with concentrations between 2.05×10^3 and 7.75×10^3 particles per kilogram of dry weight sediment (Xu et al. 2024). This estuary's coastal regions experience high human activity, enhancing the potential for microplastic deposition. Similarly, the Meghna Estuary in Bangladesh, which receives sediment from the Ganges River Basin, reports even higher microplastic levels at 4,014.66 ± 1,717.59 particles per kilogram dry weight (Alam et al. 2023). These findings underscore the significant role of anthropogenic influences on microplastic accumulation in global estuarine sediments, including the Musi Estuary. Other environmental factors, like location, sampling period, sediment depth, sediment composition, and local hydrodynamic conditions, may also affect these changes in the amount of microplastics found (Zheng et al. 2020; Feng, Chen, et al. 2023; Yuan et al. 2023).

In contrast, the abundance of microplastics in the sediments of the Musi Estuary surpasses levels reported in other regions, both within Indonesia and globally. Concentrations in the Musi Estuary are notably higher than those in the Zandvlei River Watershed and estuarine areas of South Africa (70.23 ± 7.36 particles/kg dw) (Samuels et al. 2024), the Claromecó Estuary in Argentina (299 ± 114 particles/kg dw) (Truchet et al. 2021), and the upper sediment layer (0-5 cm) of the Fuhe River Estuary in Northern China (1049 ± 462 particles/kg dw) (Zhou et al. 2021). These numbers are also higher than those found in coastal Río de la Plata (547.83 ± 620.06 particles/kg dw) (Santucci et al. 2024), Benoa Bay, Bali (31.08 ± 21.53 particles/kg dw) (Suteja et al. 2024), the Jagir Estuary in Surabaya (up to 590 particles/kg dw) (Firdaus et al. 2020), and the Pekalongan River Estuary in Java (0.77 to 1.01 particles/g dw) (Ismanto et al. 2023). The high microplastic concentration in the Musi Estuary is likely due to extensive plastic waste disposal in the river basin by the surrounding community. Research supports that plastic debris forms a substantial part of the macro-waste in the Musi River (Maherlsa et al. 2019). Additionally, local communities frequently establish settlements along the river, relying on it for water access and transportation. Consequently, domestic waste, including plastic, often enters the river directly. This local waste management issue reflects a broader trend, with Indonesia identified as the world's second-largest contributor to oceanic plastic pollution, following China (Jambeck et al. 2015).

Spatial distribution microplastic in Sediments

The study revealed that the abundance of microplastics was significantly higher in the inner and middle zones when compared to the outer zone. The mean abundances were 1.69±0.08 particles/g dw in the inner zone, 1.47±0.22 particles/g dw in the middle zone, and 0.9±0.28 particles/g dw in the outer zone. Significant differences in mean microplastic abundance between zones were revealed by the one-way ANOVA ($p < 0.05$), as illustrated in Figure 6. The Tukey HSD test revealed no significant difference in mean microplastic abundance between the inner and middle zones However, we observed a significant difference in the outer zone compared to both the middle and outer zones. Our results indicate that the inner and middle estuary regions exhibit greater mean concentrations of microplastics compared to the outer estuary. Natural factors, particularly the effects of currents and wave action in coastal and estuarine environments, significantly influence this phenomenon by altering microplastic distribution. The influx of freshwater promotes the sedimentation and prolonged retention of high-density microplastics within the system (G. Li et al. 2024). Furthermore, the sedimentation process is affected by the density and buoyancy of microplastics, with increased salinity in estuarine waters enhancing buoyancy forces and influencing distribution patterns (Cheng et al. 2024). Our findings align with research from the Liaohe Estuary in China, revealing a higher accumulation of microplastics in inner river sediments compared to the outer estuary (Xu et al. 2020). Additionally, sampling depth plays a critical role in accurately measuring microplastics in surface waters, bottom layers, and sediments (Feng, An, et al. 2023).

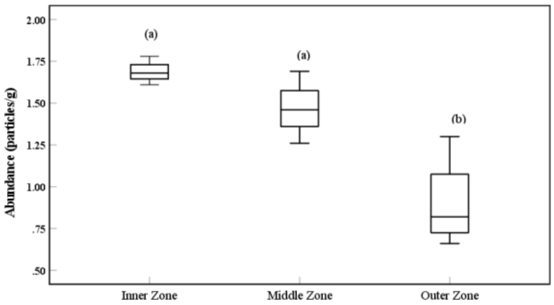

Figure 6. The difference in microplastic abundance between zones in the sediments

The spatial analysis revealed distinct patterns of microplastic accumulation between the two sides of the coast adjacent to the estuary. Notably, Site S7 exhibited higher concentrations compared to Site S8, likely due to its proximity to other pollution sources. Specifically, S7 is located near the Banyuasin Estuary, which is believed to significantly contribute to the deposition of microplastics in the surrounding sediments. Based on Costa et al. (2023), confirmed that nearby sources of pollution heavily influence microplastic deposition in coastal regions. The accumulation of microplastics at the mouth of the adjacent river further exacerbates this phenomenon, facilitating the settlement of microplastics within the sediment. Additionally, studies suggest that the depth of the sampling locations significantly influences microplastic deposition, revealing a greater abundance of microplastics at deeper water levels (Bayo et al. 2022). The substantial accumulation of microplastics in sediments is attributed to their persistent characteristics as well as the protective conditions offered by deeper environments, which are shielded from UV light, maintain lower temperatures, and exhibit lower oxygen levels, thus slowing biodegradation processes (Zhang et al. 2021).

Our findings confirm the presence of microplastics in the sediments of the Musi Estuary, likely originating from suspended microplastics that eventually settle from the water's surface. Previous research has found that there are 467.67 ± 127.84 particles/m³ and 723.67 ± 112.05 particles/m³ of microplastic in surface waters during ebb and flow conditions, respectively (Diansyah et al. 2024). Hydrodynamic conditions in the estuary and processes like aggregation and biofouling, which increase microplastic density, influence the deposition of these particles (Malli et al. 2022). The specific properties of the microplastics and the water dynamics of the estuary strongly influence microplastic deposition. For instance, biofouling can make microplastics denser, accelerating their descent into sediments (Lin et al. 2023). Since microplastics often have higher densities than water, they can remain suspended in the water column before eventually settling (Dai et al. 2022). High Total Suspended Solids (TSS) in the Musi Estuary have the potential to cause aggregation of microplastics (Rahutami et al. 2022). High TSS levels make it easier for sediments and other suspended particles to stick together on microplastic surfaces, which speeds up their deposition (Yang et al. 2022). However, microplastics can also become resuspended in the water column (Tang et al. 2020). Stirring forces in estuarine environments can lift microplastics back into the water, where turbulence and bioturbation may redistribute them (Malli et al. 2022). Therefore, additional studies are required to fully characterize the mechanisms of microplastic deposition in the Musi Estuary. Climate factors also influence microplastic distribution in Musi Estuary sediments. In Indonesia, where regions such as the Musi Estuary experience distinct rainy and dry seasons, seasonal changes affect water dynamics and microplastic transport. During the rainy season, increased river velocity may carry microplastics upward from sediments, while in the dry season, slower flows facilitate microplastic accumulation at the water's surface (Zhao et al. 2020). Currently, there are no studies specifically examining the seasonal impact on microplastic presence in the Musi Estuary, underscoring the need for further research to address this gap.

Bioaccumulation of microplastics in *Anadara granosa*

We extracted 133 microplastic particles from the digestive tracts of twenty samples of *A. granosa* species presented in Figure 7. Each sample from the Musi Estuary had accumulated microplastics, ranging from 6 to 49 particles/ind or 8 to 69.01 particles/g ww, as shown in Figure 8 and Figure 9. The mean abundance of microplastics found in the digestive tracts was 21.05±10.31 particles/ind or 30.46±16.7 particles/g ww. Several factors contribute to the increased microplastic inputs in bivalve species, including human activities, tourism, fishing equipment, freshwater runoff, and wastewater discharge, combined with the area's hydrodynamic conditions (Vital et al. 2021). The elevated levels of microplastics found in *A. granosa* from the Musi River Estuary suggest a significant degree of contamination in their habitat, including both water and sediment, which may adversely affect the health of these organisms and disrupt local ecological balances. This observation aligns with existing literature, which indicates a strong correlation between the abundance of microplastics in bivalves, such as mussels, and their sediment environments (Narmatha Sathish et al. 2020), reinforcing the need for monitoring these pollutants in aquatic ecosystems.

Figure 7. Specimens of *Anadara granosa* from Musi Estuary, Indonesia.

Microplastics were observed in three morphological forms: film, fiber, and fragment. Film accounted for the majority of microplastics (59.38%), followed by fiber (31.59%) and fragments (9.03%), as shown in Figure 10. The digestive tracts of the *A. granosa* studied did not contain any pellets or foam. Statistical analysis using the Kruskal-Wallis test revealed significant differences in the abundance of the three microplastic forms ($p < 0.05$). This predominance of film microplastics in *A. granosa* is likely attributable to the extensive use of disposable plastic packaging within the community, which subsequently degrades into microplastics. Although fragments dominate the sediment substrate, *A. granosa* predominantly absorb film microplastics. The lower density of film microplastics may facilitate their accumulation in the upper sediment layer, making them susceptible to resuspension in the overlying water column. This phenomenon is consistent with the feeding behavior of *A. granosa*, which frequently filter water from the sediment surface, resulting in the accumulation of film microplastics within their digestive tracts.

Our findings indicate a higher abundance of microplastics in *A. granosa* from the Musi Estuary compared to certain other regions globally. For instance, *A. granosa* from the Chanthaburi estuarine ecosystem in eastern Thailand contained 0.40±0.16 particles/g ww (Potipat et al. 2024), while samples from Peninsular Malaysia showed concentrations of 0.20 ± 0.08 particles/g ww and 1.54 ± 0.30 particles/ind ww (Mohan et al. 2024). Additionally, microplastic levels in *A. granosa* from Pao Village, Tarowang District, Jeneponto Regency, Indonesia, were measured at 0.0144 particles/g ww (Namira et al. 2023), and those from Likas Bay Beach in North Borneo, Malaysia, at 24.4 ± 0.6 particles/g ww (Abd Rahman et al. 2024). In contrast, the *A. granosa* analyzed in this study accumulated lower microplastic concentrations than those reported in several other studies. For instance, *A. granosa* from the Pangkal Babu mangrove forest area in Tanjung Jabung Barat district, Jambi, exhibited 434 ± 97.05 particles/ind (Fitri and Patria 2019), while those from Lada Bay in Pandeglang, Banten, had concentrations of 618.8 ± 121.4 particles/ind (Ukhrowi et al. 2021). Overall, this study shows that microplastics have contaminated the sediment environment of the Musi Estuary, South Sumatra, indicating that *A. granosa* can serve as effective bioindicators of this pollution.

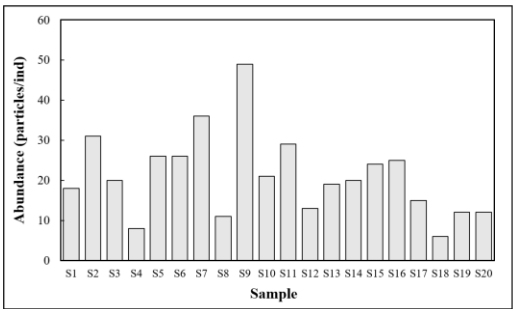

Figure 8. Microplastic abundance of *Anadara granosa* from the Musi Estuary

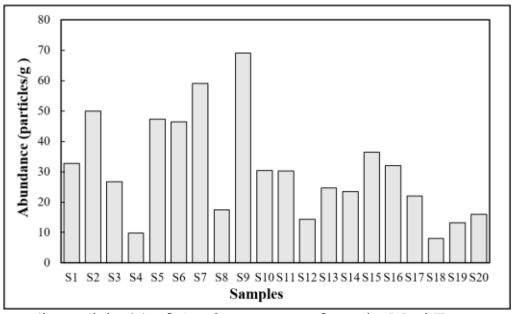

Figure 9. Microplastic abundance (in particles/g) of *Anadara granosa* from the Musi Estuary

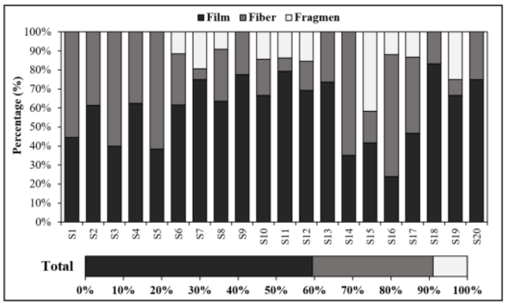

Figure 10. Shape of microplastics in *Anadara granosa* from the Musi Estuary

Risk assessment of microplastics in sediments and *Anadara granosa*

A risk assessment of microplastic contamination in the Musi River Estuary was carried out by calculating the Pollution Load Index (PLI), the Nemerow Pollution Index (NPI), and the Bioconcentration Factor (BCF). The PLI values across all sediment samples indicate that the estuarine sediment is subject to minor pollution, with values ranging between 1.00 and 1.64, as shown in Table 3. In the three zones of the estuary (inner, middle, and outer), the PLI values were 1.60, 1.49, and 1.20, respectively. We calculated the overall average PLI for the Musi Estuary to be 1.37. All zones reported PLI values below 3.00, which suggests that the area experiences only minor microplastic pollution. The analysis of microplastic presence in sediment samples revealed a significantly high concentration of microplastics, with an NPI value of 2.37. This suggests a substantial bioavailability of microplastics in the estuarine environment. This elevated NPI underscores the ecological risk posed by microplastic contamination, despite the relatively low PLI observed across the study area.

Table 3. The microplastic risk factor in sediments of Musi Estuary

Sediment Station	CF	PLI	PLI Zone	PLI Sediment	NPI
S1	2.70	1.64	Inner Zone 1.60	1.37	2.37
S2	2.55	1.60			
S3	2.44	1.56			
S4	2.21	1.49	Middle Zone 1.49		
S5	2.56	1.60			
S6	1.91	1.38			
S7	1.29	1.13	Outer Zone 1.20		
S8	1.00	1.00			
S9	1.20	1.09			
S10	1.97	1.40			

Anadara granosa analyzed in this study exhibited significant risk values associated with microplastic contamination. The PLI for these clams ranged from 1 to 2.86, with an overall mean PLI value of 1.77 for the entire sample, as shown in Table 4. This indicates that the pollution load in *A. granosa* falls within the minor category (PLI < 3). Furthermore, the bioavailability of microplastics in *A. granosa* was significantly higher, with an NPI value of 6.29, indicating a high bioavailability. The bioconcentration factor of microplastics from sediment to *A. granosa* was measured at 23.28, suggesting a significant potential for the transfer of microplastics from sediment to *A. granosa* in the Musi Estuary.

Our findings demonstrated that the bioavailability of microplastics in sediments and *A. granosa* was categorized as high (NPI = 2.37; NPI > 2). In comparison, the bioavailability of microplastics in *A. granosa* was even higher, with an NPI value of 9.89. The elevated bioavailability in sediments suggests a greater potential for absorption by aquatic organisms, particularly benthic animals. Furthermore, the bioconcentration factor (BCF) calculated for *A. granosa* in sediment was 23.28, indicating a significant transfer of microplastics from sediments to these organisms in the Musi Estuary. This high BCF value is attributed to the non-discriminatory feeding process of *A. granosa*, allowing them to ingest microplastics along with other particles. When compared to several benthic species from the Yangtze River Estuary, which exhibited a BCF of 29.48 ± 6.52 (Z. Li et al. 2022), the BCF of *A. granosa* in the Musi Estuary remains lower. Nonetheless, both sediments and *A. granosa* from the Musi Estuary are classified within the minor pollution risk index category (PLI < 10). The bioaccumulation of microplastics by benthic animals like *A. granosa* poses a significant risk to human health for those consuming these clams (Wang et al. 2023; Winiarska et al. 2024). Therefore, periodic assessments are crucial to evaluate the risk of microplastic contamination in sediments and *A. granosa*, providing essential information to understand the ecological and health implications in the Musi Estuary.

The impact of high bioaccumulation extends beyond the toxicity of microplastic materials; it also facilitates the accumulation of other pollutants. Previous research has detected heavy metals, such as lead (Pb) and copper (Cu), adhering to the surfaces of microplastics in the Musi Estuary (Purwiyanto et al. 2020). Additionally, various hazardous heavy metals, including iron (Fe), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn), were identified with high bioavailability in the aquatic environment of the Musi Estuary (Rahutami et al. 2022). This accumulation allows for the deposition of significant quantities of heavy metals on microplastic surfaces, thereby increasing the risk of microplastic toxicity for estuarine ecosystems. Moreover, the involvement of microorganism vectors, misidentification in aquatic organisms' diets, and their harmful toxicological effects on benthic animals heighten the risk associated with microplastics (Gong and Xie 2020). Consequently, the high output of microplastics from the Musi Estuary has the potential to jeopardize the condition of the surrounding aquatic environment, including fisheries and migratory birds, which are critical to the ecosystem (Rozirwan et al. 2019; Rozirwan et al. 2022).

Table 4. Risk factors for microplastics in *Anadara granosa* from the Musi Estuary

A. granosa sample	CF	PLI	PLI *A. granosa*	NPI	BCF
S1	3.00	1.73			
S2	5.17	2.27			
S3	3.33	1.83			
S4	1.33	1.15			
S5	4.33	2.08			
S6	4.33	2.08			
S7	6.00	2.45			
S8	1.83	1.35			
S9	8.17	2.86			
S10	3.50	1.87	1.77	6.29	23.28
S11	4.83	2.20			
S12	2.17	1.47			
S13	3.17	1.78			
S14	3.33	1.83			
S15	4.00	2.00			
S16	4.17	2.04			
S17	2.50	1.58			
S18	1.00	1.00			
S19	2.00	1.41			

S20	2.00	1.41

This study holds significant ecological implications for the Musi Estuary ecosystem, as the presence of microplastics poses a long-term threat to ecosystem stability. Previous studies have shown that microplastics can affect the physicochemical properties of sediments, such as electrical conductivity, organic matter content, and nutrients, and well as impact enzymatic activity in sediment bacteria (Rillig 2012; B. Yuan et al. 2022; W. Li et al. 2022). These changes can lead to structural and functional alterations in aquatic habitats (W. Li et al. 2022). Microplastics can also enter various levels of the food chain through bioaccumulation and biomagnification processes. For example, microplastics in plankton can cause a decline in zooplankton populations, which impacts food availability for small fish and predatory species at higher trophic levels (Malinowski et al. 2023). The accumulation of microplastics in *A. granosa* in this study indicates that the pressure of plastic waste in the Musi Estuary is already quite high. Microplastics can act as vectors for other pollutants, such as microorganisms, heavy metals, and other inorganic pollutants can increase the risk of toxicity for aquatic organisms, including *A. granosa* (Purwiyanto et al. 2020; Rafa et al. 2024). Research indicates that exposure to microplastics can lead to behavioral and physiological changes in aquatic organisms, including changes in diet and reproductive success (Guo et al. 2020; Liang et al. 2023). Moreover, microplastics disrupt endocrine functions and metabolic pathways, causing oxidative stress, cell necrosis, and apoptosis, which can ultimately lead to mortality (Pannetier et al. 2020; Jeyavani et al. 2021). Disruption of any component of the food chain can trigger a domino effect, threatening the balance of the Musi Estuary ecosystem. However, this study only examines microplastic pollution in sediment and *A. granosa* as environmental indicators. Additional research is needed to understand microplastic buildup in other species, such as fish, shrimp, and benthic organisms, for a more complete picture of microplastic pollution in the Musi Estuary and its impact on the global marine environment.

Microplastic contamination of *A. granosa* in the Musi Estuary poses a significant threat to local communities, particularly clam fishers. Microplastics that accumulate in *A. granosa* may pose health risks to community members who consume them regularly as a primary source of protein. Long-term exposure to microplastics can potentially disrupt various human body systems, including the digestive, respiratory, reproductive, nervous, and cardiovascular systems (Y. Li et al. 2024). Furthermore, microplastics may cause both acute and subchronic toxicity and are considered potentially carcinogenic and disruptive to human development (Z. Yuan et al. 2022). Once in the bloodstream, microplastics can be transported to the liver, the primary organ responsible for detoxification. Accumulation in the liver may trigger adverse physiological reactions, including increased oxidative stress, liver fibrosis, and impaired lipid metabolism. In addition to health risks, microplastic contamination in *A. granosa* in the Musi Estuary may reduce consumer confidence and decrease market demand due to food safety concerns (Unuofin and Igwaran 2023). The long-term effect could weaken local economic resilience as marine products in the region are perceived to be contaminated with microplastics (Barrientos et al. 2024). Therefore, it is crucial for governments and communities to recognize these risks and collaborate on mitigation efforts to protect ecosystems, public health, and local economies.

Furthermore, seafood hygiene practices in local communities and fishing industries can help reduce microplastic contamination (Lusher et al. 2017; Smith et al. 2018). For example, *A. granosa* and other seafood, when thoroughly cleaned by repeated washing and clam removal before cooking, may reduce microplastic intake (J. Li et al. 2022). The concentration of microplastics in shellfish is significantly lower after boiling and steaming compared to frying, suggesting that cooking methods affect microplastic retention in seafood (Evode et al. 2021). This method can also be applied to shrimp, fish, and other shellfish to lower the risk of microplastic exposure. Implementing these recommendations will help reduce microplastic pollution and provide long-term benefits for public health, ecosystem stability, and the economic resilience of local fisheries (Prata et al. 2019).

In conclusion, this study demonstrates the significant presence of microplastics in the sediment and *A. granosa* of the Musi Estuary, Indonesia. These findings indicate a serious threat to the aquatic ecosystem and to local public health, as microplastics can enter the food chain and potentially harm organisms across trophic levels, including humans (Ningrum and Patria 2022; Edwin et al. 2023; Patria et al. 2023). This pollution heightens environmental risks, particularly for species integral to both the community's diet and economy (Jeong et al. 2024). The microplastics likely originate from human activities, especially urban waste from upstream areas that flows downstream and accumulates in the estuary (Diansyah et al. 2024). These results highlight the urgent need for routine monitoring and stricter waste management practices, particularly for plastic disposal, to reduce further contamination (Barletta et al. 2019). A comprehensive strategy is essential to controlling plastic waste throughout the river system—from source to estuary. Effective measures should include coordinated waste management practices, public education on the impact of pollution, and cross-sector collaboration to preserve estuarine health (Wakwella et al. 2023; Ihenetu et al. 2024). Such initiatives are crucial to protecting ecosystem health and sustaining local fisheries, ensuring these resources continue to support community well-being.

ACKNOWLEDGEMENTS

The authors disclose receipt of the following financial support for the research, authorship, and publication of this article: Directorate of Research, Technology, and Community Service Directorate General of Higher Education, Research, and Technology under the Contract for Implementation of the State Higher Education Operational Assistance Program Research Program for Fiscal Year 2024 Number: 090/E5/PG.02.00.PL/2024.

REFERENCES

Abd Rahman NN, Mazlan N, Shukhairi SS, Nazahuddin MNA, Shawel AS, Harun H, Baktir A. 2024. Evaluation of the microplastics in bivalves and water column at Pantai Teluk Likas, North Borneo, Malaysia. Environmental Science and Pollution Research 31(15): 23178–23192. DOI:10.1007/s11356-024-32628-z

Abelouah MR, Ben-Haddad M, Hajji S, Nouj N, Ouheddou M, Mghili B, De-la-Torre GE, Costa LL, Banni M, Ait Alla A. 2024. Exploring marine biofouling on anthropogenic litter in the Atlantic coastline of Morocco. Marine Pollution Bulletin 199(12): 115938. DOI:10.1016/j.marpolbul.2023.115938

Alam MJ, Shammi M, Tareq SM. 2023. Distribution of microplastics in shoreline water and sediment of the Ganges River Basin to Meghna Estuary in Bangladesh. Ecotoxicology and Environmental Safety 266: 115537. DOI:10.1016/j.ecoenv.2023.115537

Almiza G, Patria MP. 2021. Distribution and abundance of macroplastic at Musi estuary, South Sumatera, Indonesia. In: Journal of Physics: Conference SeriesVol. 1869Malang: IOP Publishing; p. 12178.

Aunurrahman A, Anggoro S, Muskananfola MR, Saputra SW. 2023. Detection and analysis of mangrove cover change in Kepalajerih Island, Batam, Indonesia using Landsat Imagery. Biodiversitas Journal of Biological Diversity 24(11): 6126–6133.

Barletta M, Lima ARA, Costa MF. 2019. Distribution, sources and consequences of nutrients, persistent organic pollutants, metals and microplastics in South American estuaries. Science of the Total environment 651: 1199–1218.

Barnes DKA, Galgani F, Thompson RC, Barlaz M. 2009. Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences 364(1526): 1985–1998. DOI:10.1098/rstb.2008.0205

Barrientos M, Vásquez Lavín F, Ponce Oliva RD, Nayga RM, Gelcich S. 2024. Microplastics in seafood: Consumer preferences and valuation for mitigation technologies. Food Research International 187: 114342. DOI:10.1016/j.foodres.2024.114342

Bayo J, Rojo D, Olmos S. 2022. Weathering indices of microplastics along marine and coastal sediments from the harbor of Cartagena (Spain) and its adjoining urban beach. Marine Pollution Bulletin 178(2): 113647. DOI:10.1016/j.marpolbul.2022.113647

Belzagui F, Gutiérrez-Bouzán C. 2022. Review on alternatives for the reduction of textile microfibers emission to water. Journal of Environmental Management 317: 115347. DOI:10.1016/j.jenvman.2022.115347

Boerema A, Meire P. 2017. Management for estuarine ecosystem services: A review. Ecological Engineering 98: 172–182. DOI:https://doi.org/10.1016/j.ecoleng.2016.10.051

Bonifacio PSP, Metillo EB, Romano EF. 2022. Microplastic in Sediments and Ingestion Rates in Three Edible Bivalve Mollusc Species in a Southern Philippine Estuary. Water, Air, and Soil Pollution 233(11). DOI:10.1007/s11270-022-05926-w

Borrelle SB, Ringma J, Law KL, Monnahan CC, Lebreton L, McGivern A, Murphy E, Jambeck J, Leonard GH, Hilleary MA, et al. 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science 369(6510): 1515–1518. DOI:10.1126/science.aba3656

Caruso G. 2019. Microplastics as vectors of contaminants. Marine Pollution Bulletin 146: 921–924. DOI:10.1016/j.marpolbul.2019.07.052

Castro-Jiménez J, Aminot Y, Bely N, Pollono C, Idjaton BIT, Bizzozero L, Pierre-Duplessix O, Phuong NN, Gasperi J. 2024. Organophosphate ester additives and microplastics in benthic compartments from the Loire estuary (French Atlantic coast). Marine Pollution Bulletin 201(2): 116256. DOI:10.1016/j.marpolbul.2024.116256

Cheng Z, Ma Y, Fan X, Wang Q, Liu Y, You Z. 2024. Historical behaviors of microplastic in estuarine and riverine reservoir sediment. Marine Pollution Bulletin 202(9): 116331. DOI:10.1016/j.marpolbul.2024.116331

Costa MB da, Otegui MBP, Zamprogno GC, Caniçali FB, dos Reis Cozer C, Pelletier E, Graceli JB. 2023. Abundance, composition, and distribution of microplastics in intertidal sediment and soft tissues of four species of Bivalvia from Southeast Brazilian urban beaches. Science of the Total Environment 857(10): 159352. DOI:10.1016/j.scitotenv.2022.159352

Dai L, Wang Z, Guo T, Hu L, Chen Y, Chen C, Yu G, Ma LQ, Chen J. 2022. Pollution characteristics and source analysis of microplastics in the Qiantang River in southeastern China. Chemosphere 293: 133576. DOI:10.1016/j.chemosphere.2022.133576

Diansyah G, Rozirwan, Rahman MA, Nugroho RY, Syakti AD. 2024. Dynamics of microplastic abundance under tidal fluctuation in Musi estuary, Indonesia. Marine Pollution Bulletin 203: 116431. DOI:doi.org/10.1016/j.marpolbul.2024.116431

Ding J-F, LI J-X, Sun C-J, He C-F, Jiang F-H, Gao F-L, Zheng L. 2018. Separation and Identification of Microplastics in Digestive System of Bivalves. Chinese Journal of Analytical Chemistry 46(5): 690–697. DOI:10.1016/S1872-2040(18)61086-2

Ding J, Sun C, He C, Li J, Ju P, Li F. 2021. Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. Science of the Total Environment 782: 146830. DOI:10.1016/j.scitotenv.2021.146830

Dwiyitno D, Schwanen C, Januar HI, Ariyani F, Irianto HE, Schwarzbauer J. 2024. Microplastic profile in the sediment of Jakarta Bay estuary, Indonesia: Characterization based on size fraction and the potential risk to the ecosystem. Regional Studies in Marine Science 73(11): 103465. DOI:10.1016/j.rsma.2024.103465

Edwin T, Primasari B, Annisa Purnama R. 2023. Characterization of microplastic in trawl fish caught in Padang City (Indonesia) coastal area. Biodiversitas 24(1): 516–522. DOI:10.13057/biodiv/d240160

Eo S, Hong SH, Cho Y, Song YK, Han GM, Shim WJ. 2023. Spatial distribution and historical trend of microplastic pollution in sediments from enclosed bays of South Korea. Marine Pollution Bulletin 193(5): 115121. DOI:10.1016/j.marpolbul.2023.115121

Evode N, Qamar SA, Bilal M, Barceló D, Iqbal HMN. 2021. Plastic waste and its management strategies for environmental sustainability. Case Studies in Chemical and Environmental Engineering 4: 100142. DOI:doi.org/10.1016/j.cscee.2021.100142

Fauziyah, Nurjuliasti Ningsih E, Arnando E, Fatimah, Agustriani F, Supriyadi F. 2023. Effect of hauling and soaking time of stationary lift nets on fish aggregation using a hydroacoustic monitoring approach. Egyptian Journal of Aquatic Research 49(3): 339–346. DOI:10.1016/j.ejar.2023.05.003

Fauziyah, Setiawan A, Agustriani F, Rozirwan, Melki, Nurjuliasti Ningsih E, Ulqodry TZ. 2022. Distribution pattern of potential fishing zones in the Bangka Strait waters: An application of the remote sensing technique. The Egyptian Journal of Remote Sensing and Space Science 25(1): 257–265. DOI:https://doi.org/10.1016/j.ejrs.2021.12.003

Feng Q, An C, Chen Z, Lee K, Wang Z. 2023. Identification of the driving factors of microplastic load and morphology in estuaries for improving monitoring and management strategies: A global meta-analysis. Environmental Pollution 333: 122014. DOI:10.1016/j.envpol.2023.122014

Feng Q, Chen Z, An C, Yang X, Wang Z. 2023. Tide-induced infiltration and resuspension of microplastics in shorelines: Insights from tidal tank experiments. Water Research 236: 119970. DOI:10.1016/j.watres.2023.119970

Firdaus M, Trihadiningrum Y, Lestari P. 2020. Microplastic pollution in the sediment of Jagir estuary, Surabaya City, Indonesia. Marine Pollution Bulletin 150: 110790.

Fitri S, Patria MP. 2019. Microplastic contamination on Anadara granosa Linnaeus 1758 in Pangkal Babu mangrove forest area, Tanjung Jabung Barat district, Jambi. Journal of Physics: Conference Series 1282(1). DOI:10.1088/1742-6596/1282/1/012109

Fitria Y, Rozirwan, Fitrani M, Nugroho RY, Fauziyah, Putri WAE. 2023. Gastropods as bioindicators of heavy metal pollution in the Banyuasin estuary shrimp pond area, South Sumatra, Indonesia. Acta Ecologica Sinica 43(6): 1129–1137. DOI:https://doi.org/10.1016/j.chnaes.2023.05.009

Frias JPGL, Nash R. 2019. Microplastics: Finding a consensus on the definition. Marine Pollution Bulletin 138(11): 145–147. DOI:10.1016/j.marpolbul.2018.11.022

Fu L, Li J, Wang G, Luan Y, Dai W. 2021. Adsorption behavior of organic pollutants on microplastics. Ecotoxicology and Environmental Safety 217(11): 112207. DOI:10.1016/j.ecoenv.2021.112207

Gan Q, Cui J, Jin B. 2023. Environmental microplastics: Classification, sources, fates, and effects on plants. Chemosphere 313: 137559. DOI:10.1016/j.chemosphere.2022.137559

Gong J, Xie P. 2020. Research progress in sources, analytical methods, eco-environmental effects, and control measures of microplastics. Chemosphere 254: 126790. DOI:10.1016/j.chemosphere.2020.126790

Griffiths JR, Kadin M, Nascimento FJA, Tamelander T, Törnroos A, Bonaglia S, Bonsdorff E, Brüchert V, Gårdmark A, Järnström M. 2017. The importance of benthic–pelagic coupling for marine ecosystem functioning in a changing world. Global change biology 23(6): 2179–2196.

Guo J-J, Huang X-P, Xiang L, Wang Y-Z, Li Y-W, Li H, Cai Q-Y, Mo C-H, Wong M-H. 2020. Source, migration and toxicology of microplastics in soil. Environment International 137: 105263. DOI:10.1016/j.envint.2019.105263

Han X, Wu H, Li Q, Cai W, Hu S. 2024. Assessment of heavy metal accumulation and potential risks in surface sediment of estuary area: A case study of Dagu river. Marine Environmental Research 196: 106416. DOI:https://doi.org/10.1016/j.marenvres.2024.106416

Harris PT. 2020. The fate of microplastic in marine sedimentary environments: A review and synthesis. Marine Pollution Bulletin 158(6): 111398. DOI:10.1016/j.marpolbul.2020.111398

Hasan V, Andaini NE, Isroni W, Sari LA, Nafisyah AL, Dewi NN, Putri DNA, Prasati TAB, Ramadhani AA, Daniel K. 2023. Fish diversity of the bengawan solo river estuary, east java, Indonesia. Biodiversitas Journal of Biological Diversity 24(4): 2207–2216.

Hasan V, South J, Katz AM, Ottoni FP. 2022. First record of the Smalleyed loter Prionobutis microps (Weber, 1907)(Teleostei: Eleotridae: Butinae) in Java, Indonesia. Cybium 46(1): 49–51.

Hecker M, Peijnenburg W, Lam PKS, Brinkmann M. 2023. Emerging issues in aquatic toxicology – Plastic pollution. Aquatic Toxicology 264(11): 106729. DOI:10.1016/j.aquatox.2023.106729

Ihenetu SC, Enyoh CE, Wang C, Li G. 2024. Sustainable Urbanization and Microplastic Management: Implications for Human Health and the Environment. Urban Science 8(4): 252.

Islamy RA, Hasan V. 2020. Checklist of mangrove snails (Mollusca: Gastropoda) in south coast of pamekasan, Madura Island, East Java, Indonesia. Biodiversitas Journal of Biological Diversity 21(7): 3127–3134.

Ismanto A, Hadibarata T, Kristanti RA, Sugianto DN, Widada S, Atmodjo W, Satriadi A, Anindita MA, Al-Mohaimeed AM, Abbasi AM. 2023. A novel report on the occurrence of microplastics in Pekalongan River Estuary, Java Island, Indonesia. Marine Pollution Bulletin 196: 115563. DOI:10.1016/j.marpolbul.2023.115563

Isroni W, Sari PDW, Sari LA, Daniel K, South J, Islamy RA, Wirabuana PYAP, Hasan V. 2023. Checklist of mangrove snails (Gastropoda: Mollusca) on the coast of Lamongan District, East Java, Indonesia. Biodiversitas 24(3): 1676–1685.

Issac MN, Kandasubramanian B. 2021. Effect of microplastics in water and aquatic systems. Environmental Science and Pollution Research 28(16): 19544–19562. DOI:10.1007/s11356-021-13184-2

Jacq K, Debret M, Gardes T, Demarest M, Humbert K, Portet-Koltalo F. 2024. Spatial distribution of polycyclic aromatic hydrocarbons in sediment deposits in a Seine estuary tributary by hyperspectral imaging. Science of The Total Environment 950: 175306. DOI:https://doi.org/10.1016/j.scitotenv.2024.175306

Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL. 2015. Plastic waste inputs from land into the ocean. Science 347(6223): 768–771.

Jeong E, Lee J-Y, Redwan M. 2024. Animal exposure to microplastics and health effects: A review. Emerging Contaminants 10(4): 100369. DOI:doi.org/10.1016/j.emcon.2024.100369

Jeyavani J, Sibiya A, Shanthini S, Ravi C, Vijayakumar S, Rajan DK, Vaseeharan B. 2021. A Review on Aquatic Impacts of Microplastics and Its Bioremediation Aspects. Current Pollution Reports 7(3): 286–299. DOI:10.1007/s40726-021-00188-2

Karami A, Golieskardi A, Choo CK, Romano N, Ho Y Bin, Salamatinia B. 2017. A high-performance protocol for extraction of microplastics in fish. Science of the total environment 578: 485–494.

Kılıç S, Kılıç Ö, Belivermiş M, Ergül HA. 2023. Chronology of PAH and PCB pollution using sediment core in the Golden Horn estuary (Sea of Marmara). Marine Pollution Bulletin 187: 114570. DOI:https://doi.org/10.1016/j.marpolbul.2023.114570

Kunz A, Schneider F, Anthony N, Lin H-T. 2023. Microplastics in rivers along an urban-rural gradient in an urban agglomeration: Correlation with land use, potential sources and pathways. Environmental Pollution 321: 121096. DOI:10.1016/j.envpol.2023.121096

Lee H, Kim S, Sin A, Kim G, Khan S, Nadagouda MN, Sahle-Demessie E, Han C. 2023. Pretreatment methods for monitoring microplastics in soil and freshwater sediment samples: A comprehensive review. Science of The Total Environment 871: 161718. DOI:10.1016/j.scitotenv.2023.161718

Li G, Chen Z, Bowen M, Coco G. 2024. Transport and retention of sinking microplastics in a well-mixed estuary. Marine Pollution Bulletin 203(5): 116417. DOI:10.1016/j.marpolbul.2024.116417

Li J, Zhang L, Dang X, Su L, Jabeen K, Wang H, Wang Z. 2022. Effects of cooking methods on microplastics in dried shellfish. Science of The Total Environment 837: 155787. DOI:doi.org/10.1016/j.scitotenv.2022.155787

Li W, Wang Z, Li Weiping, Li Z. 2022. Impacts of microplastics addition on sediment environmental properties, enzymatic activities and bacterial diversity. Chemosphere 307: 135836. DOI:10.1016/j.chemosphere.2022.135836

Li Y, Chen L, Zhou N, Chen Y, Ling Z, Xiang P. 2024. Microplastics in the human body: A comprehensive review of exposure, distribution, migration mechanisms, and toxicity. Science of The Total Environment 946: 174215. DOI:10.1016/j.scitotenv.2024.174215

Li Z, Chao M, He X, Lan X, Tian C, Feng C, Shen Z. 2022. Microplastic bioaccumulation in estuary-caught fishery resource. Environmental Pollution 306: 119392. DOI:https://doi.org/10.1016/j.envpol.2022.119392

Liang W, Li B, Jong M-C, Ma C, Zuo C, Chen Q, Shi H. 2023. Process-oriented impacts of microplastic fibers on behavior and histology of fish. Journal of Hazardous Materials 448: 130856. DOI:10.1016/j.jhazmat.2023.130856

Liebezeit G, Dubaish F. 2012. Microplastics in beaches of the East Frisian islands Spiekeroog and Kachelotplate. Bulletin of environmental contamination and toxicology 89: 213–217.

Lin L, Zhang X, Yuan B, Li H, Lu H, Liu J, Hong H, Yan C. 2023. Effects of Biofouling on the Properties and Sinking Behavior of Disposable Face Masks in Seawater: A Systematic Comparison with Microplastic Films and Particles. Environmental Science & Technology Letters 10(9): 792–797. DOI:10.1021/acs.estlett.3c00460

Lonsdale J-A, Leach C, Parsons D, Barkwith A, Manson S, Elliott M. 2022. Managing estuaries under a changing climate: A case study of the Humber Estuary, UK. Environmental Science & Policy 134: 75–84. DOI:doi.org/10.1016/j.envsci.2022.04.001

Lusher A, Hollman P, Mendoza-Hill J. 2017. Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety. Roma: FAO.

Mahary A, Effendi I, Hendrik H, Darwis D. 2023. Strategy for development of blood cockles (Anadara granosa) cultivation in Batubara Regency, North Sumatera, Indonesia. AACL Bioflux 16(3): 1636–1647.

Maherlsa R, Purwiyanto AIS, Agustriani F, Putri WAE. 2019. Identification of surface macro debrisin river flow and estuary of Musi River, South

Sumatera Province, Indonesia. In: Journal of Physics: Conference SeriesVol. 1282Palembang: IOP Publishing; p. 12106.
Malinowski CR, Searle CL, Schaber J, Höök TO. 2023. Microplastics impact simple aquatic food web dynamics through reduced zooplankton feeding and potentially releasing algae from consumer control. Science of The Total Environment 904: 166691. DOI:10.1016/j.scitotenv.2023.166691
Malli A, Corella-Puertas E, Hajjar C, Boulay AM. 2022. Transport mechanisms and fate of microplastics in estuarine compartments: A review. Marine Pollution Bulletin 177(9): 113553. DOI:10.1016/j.marpolbul.2022.113553
Mohan P, Shahul Hamid F, Furumai H, Nishikawa K. 2024. Beneath the surface: Exploring microplastic intricacies in Anadara granosa. Marine Environmental Research 199: 106581. DOI:10.1016/j.marenvres.2024.106581
Namira N, Daud A, Mallongi A, Amqam H, Wahyu A, Irwandy I. 2023. Risk Analysis of Microplastic Exposure Through Consumption of Anadara Granosa at Coastal Area. Pharmacognosy Journal 15(4): 558–562. DOI:10.5530/pj.2023.15.119
Napper IE, Bakir A, Rowland SJ, Thompson RC. 2015. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. Marine Pollution Bulletin 99(1–2): 178–185. DOI:10.1016/j.marpolbul.2015.07.029
Narmatha Sathish M, Immaculate Jeyasanta K, Patterson J. 2020. Monitoring of microplastics in the clam Donax cuneatus and its habitat in Tuticorin coast of Gulf of Mannar (GoM), India. Environmental Pollution 266: 115219. DOI:10.1016/j.envpol.2020.115219
Natsir M, Ulya Z, Fitriani R. 2022. Mangrove forest utilization policies reconceptualized with a view to improving the regional economy in Aceh Tamiang District, Indonesia. Biodiversitas Journal of Biological Diversity 23(12): 6570–6578.
Ningrum EW, Patria MP. 2022. Microplastic contamination in Indonesian anchovies from fourteen locations. Biodiversitas 23(1): 125–134. DOI:10.13057/biodiv/d230116
Pannetier P, Morin B, Le Bihanic F, Dubreil L, Clérandeau C, Chouvellon F, Van Arkel K, Danion M, Cachot J. 2020. Environmental samples of microplastics induce significant toxic effects in fish larvae. Environment International 134: 105047. DOI:doi.org/10.1016/j.envint.2019.105047
Patria MP, Kholis N, Anggreini D, Buyong F. 2023. Abundance and distribution of microplastics in seawater, sediment, and macroalgae sea grapes Caulerpa racemosa from Semak Daun Island, Jakarta Bay, Indonesia. Biodiversitas Journal of Biological Diversity 24(6). DOI:10.13057/biodiv/d240638
Perumal K, Muthuramalingam S. 2022. Global sources, abundance, size, and distribution of microplastics in marine sediments - A critical review. Estuarine, Coastal and Shelf Science 264: 107702. DOI:10.1016/j.ecss.2021.107702
Potipat J, Srimoon R, Mekprayoon S. 2024. Microplastic contamination in the Chanthaburi estuarine ecosystem, Eastern part of Thailand. Journal of Environmental Biology 45(2): 152–160. DOI:10.22438/jeb/45/2/MRN-5210
Prasetiyono E, Nirmala K, Supriyono E, Sukenda, Hastuti YP. 2022. Analysis of environmental quality, production performance and economic feasibility of Anadara granosa cultivation in Sukal, Bangka Belitung Province. AACL Bioflux 15(6): 2881–2891.
Prata JC, Silva ALP, Da Costa JP, Mouneyrac C, Walker TR, Duarte AC, Rocha-Santos T. 2019. Solutions and integrated strategies for the control and mitigation of plastic and microplastic pollution. International journal of environmental research and public health 16(13): 2411.
Praveena SM, Shaifuddin SNM, Akizuki S. 2018. Exploration of microplastics from personal care and cosmetic products and its estimated emissions to marine environment: An evidence from Malaysia. Marine Pollution Bulletin 136: 135–140. DOI:10.1016/j.marpolbul.2018.09.012
Purwiyanto AIS, Prartono T, Riani E, Koropitan AF, Naulita Y, Takarina ND, Cordova MR. 2022. The contribution of estuaries to the abundance of microplastics in Jakarta Bay, Indonesia. Marine Pollution Bulletin 184: 114117. DOI:https://doi.org/10.1016/j.marpolbul.2022.114117
Purwiyanto AIS, Suteja Y, Ningrum PS, Putri WAE, Agustriani F, Cordova MR, Koropitan AF. 2020. Concentration and adsorption of Pb and Cu in microplastics: case study in aquatic environment. Marine pollution bulletin 158: 111380.
Rafa N, Ahmed B, Zohora F, Bakya J, Ahmed S, Ahmed SF, Mofijur M, Chowdhury AA, Almomani F. 2024. Microplastics as carriers of toxic pollutants: Source, transport, and toxicological effects. Environmental Pollution 343: 123190. DOI:10.1016/j.envpol.2023.123190
Rahmatin NM, Soegianto A, Irawan B, Payus CM, Indriyasari KN, Marchellina A, Mukholladun W, Irnidayanti Y. 2024. The spatial distribution and physico-chemical characteristic of microplastics in the sediment and cockle (Anadara granosa) from the coastal waters of East Java, Indonesia, and the health hazards associated with cockle consumption. Marine Pollution Bulletin 198(10): 115906. DOI:10.1016/j.marpolbul.2023.115906
Rahutami S, Said M, Ibrahim E. 2022. Actual status assessment and prediction of the Musi River water quality, Palembang, South Sumatra, Indonesia. Journal of Ecological Engineering 23(10): 68–79.
Retnaningdyah C, Febriansyah SC, Hakim L. 2022. Evaluation of the quality of mangrove ecosystems using macrozoobenthos as bioindicators in the Southern Coast of East Java, Indonesia. Biodiversitas Journal of Biological Diversity 23(12): 6480–6491.
Rillig MC. 2012. Microplastic in Terrestrial Ecosystems and the Soil? Environmental Science & Technology 46(12): 6453–6454. DOI:10.1021/es302011r
Rozirwan, Az-Zahrah SAF, Khotimah NN, Nugroho RY, Putri WAE, Fauziyah, Melki, Agustriani F, Siregar YI. 2024. Ecological Risk Assessment of Heavy Metal Contamination in Water, Sediment, and Polychaeta (Neoleanira Tetragona) from Coastal Areas Affected by Aquaculture, Urban Rivers, and Ports in South Sumatra. Journal of Ecological Engineering 25(1): 303–319.
Rozirwan, Fauziyah, Nugroho RY, Melki, Ulqodry TZ, Agustriani F, Ningsih EN, Putri WAE. 2022. An ecological assessment of crab's diversity among habitats of migratory birds at berbak-sembilang national park indonesia. International Journal of Conservation Science 13(3): 961–972.
Rozirwan, Fauziyah, Wulandari PI, Nugroho RY, Agutriani F, Agussalim A, Supriyadi F, Iskandar I. 2022. Assessment distribution of the phytoplankton community structure at the fishing ground, Banyuasin estuary, Indonesia. Acta Ecologica Sinica 42: 670–678. DOI:https://doi.org/10.1016/j.chnaes.2022.02.006
Rozirwan, Iskandar I, Hendri M, Apri R, Supardi, Azhar N, Mardiansyah W. 2019. Distribution of phytoplankton diversity and abundance in Maspari island waters, South Sumatera, Indonesia. In: IOP Conference Series: Journal of PhysicsVol. 1282[place unknown]: IOP Publishing; p. 012105. DOI:10.1088/1742-6596/1282/1/012105
Rozirwan, Khotimah NN, Putri WAE, Fauziyah, Aryawati R, Damiri N, Isnaini, Nugroho RY. 2023. Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment. Biodiversitas 24(12): 6733–6742. DOI:doi.org/10.13057/biodiv/d241236
Rozirwan, Melki, Apri R, Fauziyah, Agussalim A, Hartoni, Iskandar I. 2021. Assessment the macrobenthic diversity and community structure in the Musi Estuary, South Sumatra, Indonesia. Acta Ecologica Sinica 41(4): 346–350. DOI:https://doi.org/10.1016/j.chnaes.2021.02.015
Rozirwan, Nanda, Nugroho RY, Diansyah G, Muhtadi, Fauziyah, Putri WAE, Agussalim A. 2023. Phytochemical composition, total phenolic content and antioxidant activity of Anadara granosa (Linnaeus, 1758) collected from the east coast of South Sumatra, Indonesia. Baghdad Science Journal 20(4): 1258–1265. DOI:dx.doi.org/10.21123/bsj.2023.6941
Rozirwan, Ramadani S, Putri WAE, Fauziyah, Khotimah NN, Nugroho RY. 2023. Evaluation of Calcium and Phosphorus content in Scallop Shells (Placuna placenta) and Blood Cockle Shells (Anadara granosa) from Banyuasin Waters, South Sumatra. Egyptian Journal of Aquatic Biology and Fisheries 27(3): 1053–1068.
Sahidin A, Zahidah Z, Herawati H, Wardianto Y, Setyobudiandi I, Partasasmita R. 2018. Macrozoobenthos as bioindicator of ecological status in Tanjung Pasir Coastal, Tangerang District, Banten Province, Indonesia. Biodiversitas Journal of Biological Diversity 19(3): 1123–1129. DOI:10.13057/biodiv/d190347
Saleh R, Daud A, Ishak H, Amqam H, Wahyu A, Stang, Birawida AB, Mallongi A. 2023. Spatial Distribution of Microplastic Contamination in Blood Clams (Anadara granosa) on the Jeneponto Coast, South Sulawesi. Pharmacognosy Journal 15(4): 680–690. DOI:10.5530/pj.2023.15.137
Samuels W, Awe A, Sparks C. 2024. Microplastic pollution and risk assessment in surface water and sediments of the Zandvlei Catchment and estuary, Cape Town, South Africa. Environmental Pollution 342: 122987. DOI:10.1016/j.envpol.2023.122987

Santucci L, Fernández-Severini MD, Rimondino GN, Colombo C V., Prieto G, Forero-López AD, Carol ES. 2024. Assessment of meso- and microplastics distribution in coastal sediments and waters at the middle estuary of the Rio De La Plata, Argentina (SW Atlantic Ocean). Science of the Total Environment 914(January). DOI:10.1016/j.scitotenv.2024.170026

Sari A, Tuwo A, Saru A. 2022. Diversity of fauna species in the mangrove ecosystem of Youtefa Bay Tourism Park, Papua, Indonesia. Biodiversitas Journal of Biological Diversity 23(9): 4490–4500.

Smith M, Love DC, Rochman CM, Neff RA. 2018. Microplastics in seafood and the implications for human health. Current environmental health reports 5: 375–386.

Surbakti H, Nurjaya IW, Bengen DG, Prartono T. 2023. Temporal variation of freshwater as control of mangrove in Banyuasin Estuary, South Sumatra, Indonesia. Biodiversitas: Journal of Biological Diversity 24(3): 1502–1510.

Suteja Y, Purwiyanto AIS, Purbonegoro T, Cordova MR. 2024. Spatial and temporal trends of microplastic contamination in surface sediment of Benoa Bay: An urban estuary in Bali-Indonesia. Marine Pollution Bulletin 202(4): 116357. DOI:10.1016/j.marpolbul.2024.116357

Ta AT, Babel S. 2023. Occurrence and spatial distribution of microplastic contaminated with heavy metals in a tropical river: Effect of land use and population density. Marine Pollution Bulletin 191(4): 114919. DOI:10.1016/j.marpolbul.2023.114919

Tang C, Li Y, He C, Acharya K. 2020. Dynamic behavior of sediment resuspension and nutrients release in the shallow and wind-exposed Meiliang Bay of Lake Taihu. Science of The Total Environment 708: 135131. DOI:10.1016/j.scitotenv.2019.135131

Thacharodi A, Meenatchi R, Hassan S, Hussain N, Bhat MA, Arockiaraj J, Ngo HH, Le QH, Pugazhendhi A. 2024. Microplastics in the environment: A critical overview on its fate, toxicity, implications, management, and bioremediation strategies. Journal of Environmental Management 349: 119433. DOI:10.1016/j.jenvman.2023.119433

Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, McGonigle D, Russell AE. 2004. Lost at sea: where is all the plastic? Science 304(5672): 838.

Tomlinson DL, Wilson JG, Harris CR, Jeffrey DW. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgoländer meeresuntersuchungen 33: 566–575.

Truchet DM, López ADF, Ardusso MG, Rimondino GN, Buzzi NS, Malanca FE, Spetter CV, Severini MDF. 2021. Microplastics in bivalves, water and sediments from a touristic sandy beach of Argentina. Marine Pollution Bulletin 173: 113023. DOI:10.1016/j.marpolbul.2021.113023

Ukhrowi HR, Wardhana W, Patria MP. 2021. Microplastic abundance in blood cockle Anadara granosa (linnaeus, 1758) at Lada Bay, Pandeglang, Banten. Journal of Physics: Conference Series 1725(1): 012053. DOI:10.1088/1742-6596/1725/1/012053

Unuofin JO, Igwaran A. 2023. Microplastics in seafood: Implications for food security, safety, and human health. Journal of Sea Research 194: 102410. DOI:10.1016/j.seares.2023.102410

Vital SA, Cardoso C, Avio C, Pittura L, Regoli F, Bebianno MJ. 2021. Do microplastic contaminated seafood consumption pose a potential risk to human health? Marine Pollution Bulletin 171: 112769. DOI:10.1016/j.marpolbul.2021.112769

Wakwella A, Wenger A, Jenkins A, Lamb J, Kuempel CD, Claar D, Corbin C, Falinski K, Rivera A, Grantham HS. 2023. Integrated watershed management solutions for healthy coastal ecosystems and people. Cambridge Prisms: Coastal Futures 1: e27.

Walker TR, Fequet L. 2023. Current trends of unsustainable plastic production and micro(nano)plastic pollution. TrAC - Trends in Analytical Chemistry 160: 116984. DOI:10.1016/j.trac.2023.116984

Wang G, Lu J, Li W, Ning J, Zhou L, Tong Y, Liu Z, Zhou H, Xiayihazi N. 2021. Seasonal variation and risk assessment of microplastics in surface water of the Manas River Basin, China. Ecotoxicology and Environmental Safety 208: 111477. DOI:https://doi.org/10.1016/j.ecoenv.2020.111477

Wang Y, Wu Y, Pu Q, Sun P, Zhao W, Liu M, Li Y. 2023. Aquatic toxicity of tire microplastics on marine and freshwater organisms: An in silico approach. Chemosphere 313(October 2022). DOI:10.1016/j.chemosphere.2022.137523

Ward JE, Zhao S, Holohan BA, Mladinich KM, Griffin TW, Wozniak J, Shumway SE. 2019. Selective Ingestion and Egestion of Plastic Particles by the Blue Mussel (Mytilus edulis) and Eastern Oyster (Crassostrea virginica): Implications for Using Bivalves as Bioindicators of Microplastic Pollution. Environmental Science & Technology 53(15): 8776–8784. DOI:10.1021/acs.est.9b02073

Winiarska E, Jutel M, Zemelka-Wiacek M. 2024. The potential impact of nano- and microplastics on human health: Understanding human health risks. Environmental Research 251(P2): 118535. DOI:10.1016/j.envres.2024.118535

Xu K, Shahab A, Rinklebe J, Xiao H, Li J, Ye F, Li Y, Wang D, Bank MS, Wei G. 2024. Spatial distribution, morphology, and risk assessment of microplastics in sediment from the Pearl River Estuary, China. Emerging Contaminants 10(3): 100383. DOI:10.1016/j.emcon.2024.100383

Xu P, Peng G, Su L, Gao Y, Gao L, Li D. 2018. Microplastic risk assessment in surface waters: A case study in the Changjiang Estuary, China. Marine pollution bulletin 133: 647–654.

Xu Q, Xing R, Sun M, Gao Y, An L. 2020. Microplastics in sediments from an interconnected river-estuary region. Science of The Total Environment 729: 139025. DOI:10.1016/j.scitotenv.2020.139025

Yang X, An C, Feng Q, Boufadel M, Ji W. 2022. Aggregation of microplastics and clay particles in the nearshore environment: Characteristics, influencing factors, and implications. Water Research 224: 119077. DOI:10.1016/j.watres.2022.119077

Yuan B, Gan W, Sun J, Lin B, Chen Z. 2023. Depth profiles of microplastics in sediments from inland water to coast and their influential factors. Science of The Total Environment 903: 166151. DOI:10.1016/j.scitotenv.2023.166151

Yuan B, Gan W, Sun J, Lin B, Chen Z, Li WW, Wang Z, Li WW, Li Z, Rillig MC. 2022. Depth profiles of microplastics in sediments from inland water to coast and their influential factors. Environmental Science & Technology 903(12): 6453–6454. DOI:10.1016/j.scitotenv.2023.166151

Yuan Z, Nag R, Cummins E. 2022. Human health concerns regarding microplastics in the aquatic environment - From marine to food systems. Science of The Total Environment 823: 153730. DOI:10.1016/j.scitotenv.2022.153730

Yulinda E, Saad M, Yusuf M. 2020. A study on the economic potential of blood cockles (Anadara granosa) in Rokan Hilir, Riau Province, Indonesia. AACL Bioflux 13(3): 1504–1510.

Zhang K, Hamidian AH, Tubić A, Zhang Y, Fang JKH, Wu C, Lam PKS. 2021. Understanding plastic degradation and microplastic formation in the environment: A review. Environmental Pollution 274. DOI:10.1016/j.envpol.2021.116554

Zhao J, Feng X, Shi Xiaolai, Bai Y, Yu X, Shi Xuefa, Zhang W, Zhang R. 2015. Sedimentary organic and inorganic records of eutrophication and hypoxia in and off the Changjiang Estuary over the last century. Marine Pollution Bulletin 99(1): 76–84. DOI:doi.org/10.1016/j.marpolbul.2015.07.060

Zhao X, Chen H, Jia Q-L, Shen C-S, Zhu Y, Li L, Nie Y-H, Ye J-F. 2020. [Pollution Status and Pollution Behavior of Microplastic in Surface Water and Sediment of Urban Rivers]. Huan jing ke xue= Huanjing kexue 41(8): 3612–3620. DOI:10.13227/j.hjkx.201912236

Zheng Y, Li J, Cao W, Jiang F, Zhao C, Ding H, Wang M, Gao F, Sun C. 2020. Vertical distribution of microplastics in bay sediment reflecting effects of sedimentation dynamics and anthropogenic activities. Marine Pollution Bulletin 152: 110885. DOI:10.1016/j.marpolbul.2020.110885

Zhou Z, Zhang P, Zhang G, Wang S, Cai Y, Wang H. 2021. Vertical microplastic distribution in sediments of Fuhe River estuary to Baiyangdian Wetland in Northern China. Chemosphere 280: 130800. DOI:10.1016/j.chemosphere.2021.130800

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

[biodiv] New notification from Biodiversitas Journal of Biological Diversity

4 pesan

Aditya Triyanto via SMUJO <support@smujo.com> 7 April 2025 pukul 14.17
Balas Ke: Aditya Triyanto <aditya@smujo.id>, Ahmad Dwi Setyawan <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

You have a new notification from Biodiversitas Journal of Biological Diversity:

You have been added to a discussion titled "Uncorrected proof" regarding the submission "Implication of microplastics presence in sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia".

Link: https://smujo.id/biodiv/authorDashboard/submission/19666

Ahmad Dwi Setyawan

Biodiversitas Journal of Biological Diversity

Aditya Triyanto via SMUJO <support@smujo.com> 7 April 2025 pukul 18.15
Balas Ke: Aditya Triyanto <aditya@smujo.id>, Ahmad Dwi Setyawan <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

You have a new notification from Biodiversitas Journal of Biological Diversity:

There is new activity in the discussion titled "Uncorrected proof" regarding the submission "Implication of microplastics presence in sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia".

Link: https://smujo.id/biodiv/authorDashboard/submission/19666

Ahmad Dwi Setyawan

[Kutipan teks disembunyikan]

DEWI NUR PRATIWI via SMUJO <support@smujo.com> 7 April 2025 pukul 19.59
Balas Ke: DEWI NUR PRATIWI <biodiv07@gmail.com>, Ahmad Dwi Setyawan <editors@smujo.id>
Kepada: Rozirwan Rozirwan <rozirwan@unsri.ac.id>

You have a new notification from Biodiversitas Journal of Biological Diversity:

You have been added to a discussion titled "BILLING" regarding the submission "Implication of microplastics presence in sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia".

Link: https://smujo.id/biodiv/authorDashboard/submission/19666

Ahmad Dwi Setyawan

[Kutipan teks disembunyikan]

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id> 8 April 2025 pukul 20.12
Kepada: DEWI NUR PRATIWI <biodiv07@gmail.com>, Ahmad Dwi Setyawan <editors@smujo.id>

Dear Editor,

Thank you for your notification regarding the billing for our submission titled *"Implication of microplastics presence in sediment and Blood Clams (Anadara granosa) in the Musi Estuary Indonesia"* (Submission ID: 19666).

We would like to inform you that the payment has been successfully completed. Please find the proof of payment attached to this email for your reference.

Kindly confirm the receipt of this document and let us know if there are any further steps required from our side.

[Kutipan teks disembunyikan]

--

Prof. Dr. Rozirwan
Head of Marine Bioecology Laboratory
Department of Marine Science
Faculty of Mathematics and Natural Sciences
Sriwijaya University
Jalan Raya Palembang-Prabumulih KM 32, Indralaya
Ogan Ilir, Sumatera Selatan, Indonesia, Pos Code: 30862
Email: rozirwan@unsri.ac.id, rozirwan@gmail.com

WhatsApp Image 2025-04-08 at 09.49.11_aa4206f4.jpg
70K

Biodiversitas & Nusantara Biosci.

INVOICE
for AUTHOR

Society for Indonesian Biodiversity
Jl. Ir. Sutami 36 A Surakarta 57126
Tel./Fax. 0271-663375, email: unsjournals@gmail.com
http://biodiversitas.mipa.uns.ac.id/
http://biosains.mipa.uns.ac.id/nusbioscience.htm

DATE	07/04/2025
	195
CUSTOMER ID	195
DUE DATE	14/05/2025

BILL TO

ROZIRWAN
Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya
Jl. Raya Palembang-Prabumulih Km. 32, Ogan Ilir 30862, South Sumatra, Indonesia.
Tel.:+62-711-580056, Fax.:+62-711-580268
email: rozirwan@unsri.ac.id

Title:

Implication of microplastic presence in sediment and blood clams Anadara granosa (Linnaeus 1758) (Mollusca: Bivalvia) in the Musi Estuary, Indonesia

DESCRIPTION	TAXED	AMOUNT (IDR)
Payment for manuscript publication		6.000.000,00
Payment for English improvement		-
Cost reduction for manuscript presented in the SIB Meeting		-

Subtotal	6.000.000,00
Taxable	-
Tax rate	0,000%
Tax due	-
Other	-
TOTAL IDR	**6.000.000,00**

OTHER COMMENTS

1. Currency exchange: USD 1 = IDR 16,000
2. **Total bill: IDR 6,000,000,-**
3. Transfer to
   Acc. No: 9191919987
   Bank name : Bank Syariah Indonesia (BSI), Karanganyar Palur 1 Branch Office
   Beneficiary name : CV SMUJO INTERNATIONAL
   Swift code : BSMDIDJA
4. Send the proof of payment via OJS
   and a carbon copy (CC) to unsjournals@gmail.com

wondr by BNI

Transfer berhasil

Rp6.000.000

08 Apr 2025 • 09:02:25 WIB •
Ref ID: 20250408090212299154

Penerima

CV SMUJO INTERNATIONAL

BANK BSI • 9191919987

Sumber dana

ROZIRWAN

TAPLUS • ******534

Detail transfer

Nominal	Rp6.000.000
Biaya transaksi	Rp2.500
Metode transfer	BI-FAST
BIZ ID	20250408BNINIDJA0100 0240172765
Tujuan transaksi	Lainnya
Catatan	Publication fee Rozirwan El AI Implication of micr

Total	**Rp6.002.500**

RECEIPT

Date 08/04/2025 No. 195

Received From ROZIRWAN **Amount IDR** Rp 6.000.000,00

Amount ENAM JUTA RUPIAH

For Payment of Biaya publikasi naskah dengan judul:
Implication of microplastic presence in sediment and blood clams Anadara granosa (Linnaeus 1758) (Mollusca: Bivalvia) in the Musi Estuary, Indonesia

Paid by [ ] Cash
[√] BNI transfer 356986994
[ ] Money Order

Received By Dewi Nur Pratiwi
Bendahara

SMUJO INTERNATIONAL

Account Amt	Rp	6.000.000,00
This Payment	Rp	6.000.000,00
Balance Due	Rp	-

Rozirwan ROZIRWAN <rozirwan@unsri.ac.id>

[biodiv] Editor Decision

2 pesan

Team Support Smujo via SMUJO <support@smujo.com> 16 April 2025 pukul 10.13
Balas Ke: Team Support Smujo <support@smujo.id>
Kepada: "M. AKBAR RAHMAN" <author@smujo.id>, ROZIRWAN <rozirwan@unsri.ac.id>

M. AKBAR RAHMAN, ROZIRWAN, WIKE EKA AYU PUTRI, GUSTI DIANSYAH, MELKI, ICA DELYA, REDHO YOGA NUGROHO:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "Implication of microplastic presence in sediment and blood clams *Anadara granosa* (Mollusca: Bivalvia) in the Musi Estuary, Indonesia".

Our decision is to: Accept Submission

Letter of Acceptance:
https://smujo.id/loa/19666

Best Regards,
Team Support Smujo.id

____
Biodiversitas Journal of Biological Diversity

Team Support Smujo via SMUJO <support@smujo.com> 16 April 2025 pukul 10.13
Balas Ke: Team Support Smujo <support@smujo.id>
Kepada: "M. AKBAR RAHMAN" <author@smujo.id>, ROZIRWAN <rozirwan@unsri.ac.id>

M. AKBAR RAHMAN, ROZIRWAN, WIKE EKA AYU PUTRI, GUSTI DIANSYAH, MELKI, ICA DELYA, REDHO YOGA NUGROHO:

The editing of your submission, "Implication of microplastic presence in sediment and blood clams *Anadara granosa* (Mollusca: Bivalvia) in the Musi Estuary, Indonesia," is complete. We are now sending it to production.

Submission URL: https://smujo.id/biodiv/authorDashboard/submission/19666

[Kutipan teks disembunyikan]

BIODIVERSITAS
Volume 26, Number 4, April 2025
Pages: 1720-1733

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260422

Implication of microplastic presence in sediment and blood clams *Anadara granosa* (Mollusca: Bivalvia) in the Musi Estuary, Indonesia

M. AKBAR RAHMAN[1], ROZIRWAN[2,♥], WIKE EKA AYU PUTRI[2], GUSTI DIANSYAH[2], MELKI[2], ICA DELYA[2], REDHO YOGA NUGROHO[2]

[1]Department of Environment Management, Graduate School of Environmental Sciences, Universitas Sriwijaya. Jl. Padang Selasa No.524, Palembang 30129, South Sumatra, Indonesia

[2]Department of Marine Science, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya. Jl. Raya Palembang-Prabumulih Km. 32, Ogan Ilir 30862, South Sumatra, Indonesia. Tel.:+62-711-580056, Fax.:+62-711-580268, ♥email: rozirwan@unsri.ac.id

Manuscript received: 30 September 2024. Revision accepted: 4 April 2025.

Abstract. *Rahman MA, Rozirwan, Putri WEA, Diansyah G, Melki, Delya I, Nugroho RY. 2025. Implication of microplastic presence in sediment and blood clams* Anadara granosa *(Mollusca: Bivalvia) in the Musi Estuary, Indonesia. Biodiversitas 26: 1720-1733.* Microplastic pollution poses a serious risk to estuarine ecosystems, affecting sediments and benthic species. Blood clams *Anadara granosa* represent a significant commercial seafood product in Indonesia, including those from the Musi Estuary. This study investigated the risks associated with microplastic contamination in sediments and *A. granosa* in the Musi Estuary, located in South Sumatra, Indonesia. Sediment samples were extracted using sodium chloride (NaCl, 1.2 g cm^{-3}) and hydrogen peroxide (30% H_2O_2). In contrast, *A. granosa* samples were digested with 10% KOH for microplastic extraction. The abundance and shape of microplastics were analyzed from both samples. Pollution risk assessment was conducted through the calculation of the Pollution Load Index (PLI), Nemerow Pollution Index (NPI), and Bioconcentration Factor (BCF). The results revealed the presence of microplastics in sediments, with a mean abundance of 1.31±0.41 particles/g dw, while in *A. granosa*, it was 21.05±10.31 particles/ind. Both samples exhibited high microplastic bioaccumulation (NPI>2), although the pollution load remained relatively low (minor category, PLI<10). The bioconcentration factor between *A. granosa* and sediment was determined to be 23.28, indicating that the *A. granosa* absorbed microplastics present in the sediment. These findings highlight the significant bioaccumulation potential of microplastics in *A. granosa* within the Musi Estuary. The local community and government need to establish mitigations for future microplastic management efforts.

Keywords: Bioaccumulation, blood clams, microplastics, Musi Estuary, sediment

INTRODUCTION

River estuaries are dynamic ecosystems crucial for ecological balance and socio-economic functions (Boerema and Meire 2017; Hasan et al. 2022, et al. 2023; Retnaningdyah et al. 2022). They support diverse species and serve as hubs for urban, recreational, and commercial use (Islamy and Hasan 2020; Lonsdale et al. 2022; Natsir et al. 2022; Aunurrahman et al. 2023). Among the major estuaries in Sumatra, Indonesia, the Musi Estuary holds significant ecological and economic importance (Surbakti et al. 2023). It provides essential habitat for fish and benthic species that support local livelihoods (Rozirwan et al. 2021, et al. 2022a; Fauziyah et al. 2022, 2023). However, Intensified human activity around the Musi River has caused severe environmental degradation, mainly due to heavy metal and microplastic pollution (Maherlsa et al. 2019; Purwiyanto et al. 2022; Rahutami et al. 2022; Fitria et al. 2023; Rozirwan et al. 2023a, et al. 2024; Diansyah et al. 2024). These pollutants may compromise estuarine stability, with potential impacts on biodiversity and dependent communities.

Macrozoobenthos are considered pivotal components in preserving the equilibrium of estuarine ecosystems (Sari et al. 2022; Isroni et al. 2023). These organisms play a crucial role in the food web and nutrient cycling (Griffiths et al. 2017). Moreover, macrozoobenthos are highly sensitive to environmental changes, making them reliable bioindicators of ecological degradation (Sahidin et al. 2018). Bivalves such as *Anadara granosa* (Linnaeus, 1758) are commonly used as bioindicators due to their ability to accumulate pollutants through filter-feeding (Fitri and Patria 2019; Ward et al. 2019; Ding et al. 2021; Bonifacio et al. 2022; Saleh et al. 2023; Rahmatin et al. 2024). *Anadara granosa* is widely consumed by the general public as a nutrient-rich seafood, particularly among local communities (Rozirwan et al. 2023b, c). Among these, *A. granosa* is an important bivalve that helps maintain ecosystem balance and supports the livelihoods of coastal communities (Yulinda et al. 2020; Prasetiyono et al. 2022; Mahary et al. 2023). *Anadara granosa*'s ecological and economic roles make assessing its pollutant contamination essential to understanding environmental pollution impacts.

Pollutants such as heavy metals, hydrocarbons, pesticides, and microplastics frequently accumulate in estuarine sediments (Zhao et al. 2015; Kılıç et al. 2023; Han et al. 2024; Jacq et al. 2024). Among these, plastic pollution has emerged as a critical concern due to its pervasive impact on aquatic environments (Borrelle et al. 2020; Hecker et al. 2023). Over the last five decades, single-use plastics have accumulated and fragmented widely across ecosystems (Zhang et al. 2021; Walker and

Fequet 2023). As plastics degrade, they break down into microplastics, defined as particles ranging in size from 1 μm to 5 mm (Frias and Nash 2019). Microplastics in aquatic ecosystems originate from plastic fragmentation, synthetic fiber release during washing, and microbeads in personal care products (Napper et al. 2015; Praveena et al. 2018; Belzagui and Gutiérrez-Bouzán 2022; Gan et al. 2023). Microplastics threaten aquatic ecosystems by releasing toxic additives and transporting organic pollutants and heavy metals (Caruso 2019; Fu et al. 2021; Issac and Kandasubramanian 2021; Ta and Babel 2023). These impacts may disrupt food webs, alter nutrient cycles, modify habitats, and potentially cause genetic changes in aquatic organisms (Thacharodi et al. 2024).

Previous studies reported surface water microplastic concentrations in the Musi Estuary at 467.67±127.84 particles/m³ during flood tide and 723.67±112.05 particles/m³ at ebb tide (Diansyah et al. 2024). These microplastics often bind with toxic heavy metals, such as lead (Pb) and copper (Cu), amplifying their environmental harm (Purwiyanto et al. 2022). Microplastics in the water column tend to settle in estuarine sediments, the second-largest global reservoir after fjords (Harris 2020). Microplastic accumulation in estuarine sediments raises ecological concerns, especially due to ingestion by benthic organisms like *A. granosa* (Fitri and Patria 2019; Saleh et al. 2023; Mohan et al. 2024; Rahmatin et al. 2024). While numerous studies have examined microplastic concentrations in the water column, research on their distribution in sediments and bioaccumulation in benthic species, particularly *A. granosa*, remains limited.

This study aims to investigate the bioaccumulation and risks of microplastic pollution in sediments and *A. granosa* in the Musi Estuary, Indonesia. The findings are expected to enhance understanding of benthic organisms, especially *A. granosa*, and its potential health risks for local seafood consumers.

MATERIALS AND METHODS

Study area and sample collection

The Musi Estuary, located on the east coast of South Sumatra, Indonesia is where seawater from the Bangka Strait mixes with freshwater from the Musi River. The Musi Esturay is an important area for fisheries and benthic habitats in South Sumatra, Indonesia (Rozirwan et al. 2021, et al. 2022b). Sampling locations were selected based on hydrodynamic conditions influencing microplastic transport and deposition, considering salinity variations and water mass interactions (Cheng et al. 2024; Diansyah et al. 2024). Locations of the sampling sites are shown in Figure 1 and Table 1. Based on in situ measurements, water parameters include temperature (27.31-31.6°C), pH (6.95-8), dissolved oxygen (3.62-5.21 mg/L), salinity (6-30‰), water brightness (0.1-0.9 m), water current speed (0.1-1.8 m/s). Sediment and *A. granosa* were collected during low tide from the Musi Estuary, South Sumatra, Indonesia. Sediment samples were collected from ten sampling points using a Peterson Grab at each station (Dwiyitno et al. 2024). Samples were placed in glass jars that had been rinsed with pure distilled water and covered using aluminum foil to avoid contamination. Samples were placed in a cool box (±4°C) for further analysis in the laboratory.

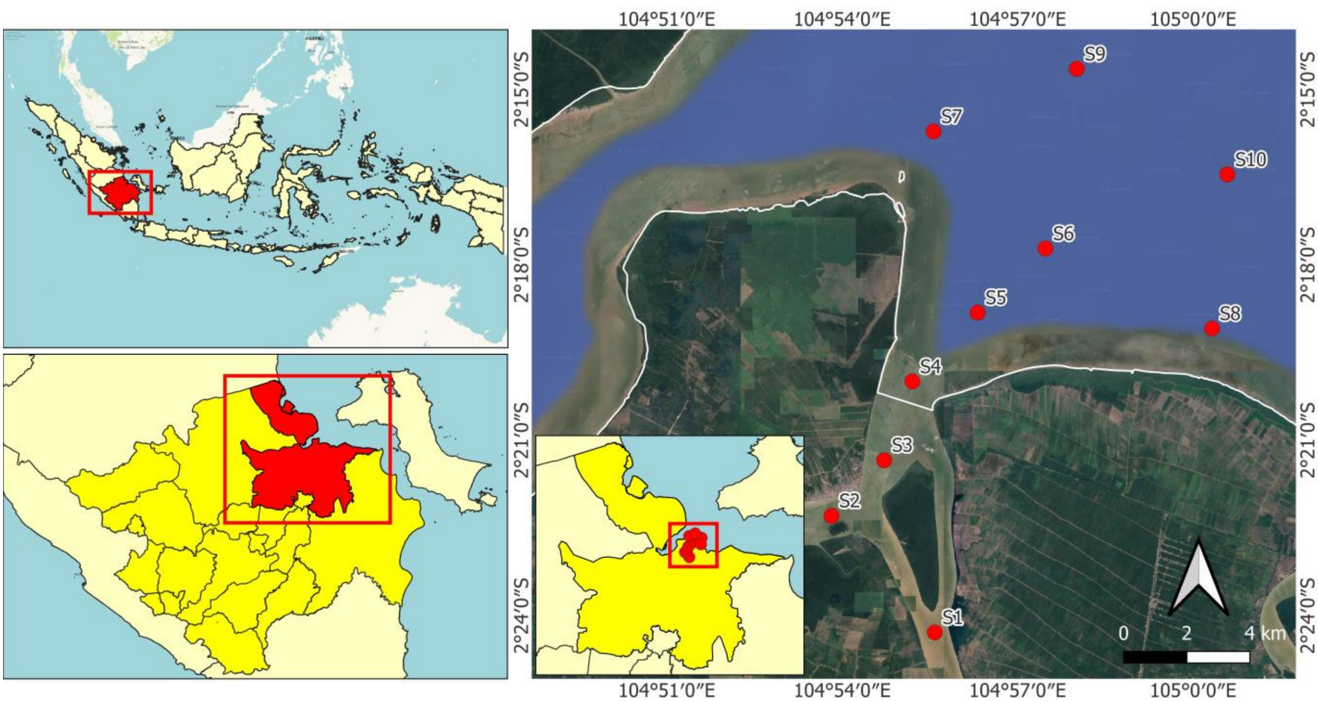

Figure 1. Study site at the Musi Estuary, South Sumatra, Indonesia

Table 1. Coordinates of the sampling location

Estuary zone	Description	Station	Latitude (°S)	Longitude (°E)
Inner zone	closest to the river body and dominated by freshwater	S1	2.40470°S	104.92643°E
	mangrove vegetation and muddy substrate	S2	2.37144°S	104.89695°E
	near densely populated coastal village activities, shipping and fishing activities	S3	2.35558°S	104.91200°E
Middle zone	between the inner zone and the outer zone	S4	2.33316°S	104.92003°E
	mangrove vegetation and muddy substrate	S5	2.31353°S	104.93862°E
	shipping and fishing activities	S6	2.29524°S	104.95794°E
Outer zone	closest to the ocean (at the sea), dominated by seawater,	S7	2.26183°S	104.92603°E
	no vegetation, muddy substrate	S8	2.31807°S	105.00547°E
	shipping and fishing activities	S9	2.24403°S	104.96686°E
		S10	2.27413°S	105.00978°E

Anadara granosa samples were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). Twenty adult *A. granosa* (7.48-11.44 cm) were collected from fishermen's catch in the Musi Estuary. *Anadara granosa* samples were identified based on their morphological traits according to the World Register of Marine Species (WoRMS) (Abelouah et al. 2024). The mussels were rinsed with pure distilled water to remove any dirt. *Anadara granosa* were wrapped in aluminum foil and stored in a cooler at approximately 4°C to preserve their freshness. After that, they were transported to the laboratory and frozen at -20°C before further analysis (Ding et al. 2021).

Microplastic extraction from sediment

Microplastics in sediments were extracted using the standard method of density separation and organic matter removal with minor modifications (Thompson et al. 2004; Liebezeit and Dubaish 2012). A total of 500 g of wet sediment samples were placed in a beaker glass covered with aluminum foil. The samples were dried in an oven at 60℃ for 48 hours, or until they reached a constant mass (Patria et al. 2023). The sediment samples were pulverized and sieved through a 5 mm steel sieve. A portion of 100 g of dried sediment was taken from the sieve, placed into a beaker glass, and covered with aluminum foil to prevent external contamination.

The sample was suspended in 400 mL of saturated NaCl solution (1.2 g cm^{-3}), which is four times the sample weight, using a magnetic stirrer. This NaCl solution was prepared by dissolving pure NaCl crystals (Merck Millipore EMSURE®) in filtered distilled water that was free from contaminants. The selection of a NaCl solution for the separation of microplastics from sediments was based on the premise that this method is cost-effective and environmentally friendly (Perumal and Muthuramalingam 2022).

Stirring was carried out for 5 minutes until completely dissolved, and the mixture was allowed to stand for 1 hour. After one hour, 10 mL of 30% H_2O_2 was added to assist in the breakdown of organic matter, followed by stirring for an additional five minutes. Hydrogen peroxide (H_2O_2) is commonly used in similar studies and is regarded as highly effective for organic matter removal (Lee et al. 2023). The sample was allowed to stand for 24 hours, covered with aluminum foil. The samples were then filtered using the Whatman No. 42 filter paper (mesh size 0.45 µm, Φ = 90 mm), assisted by a vacuum pump at 17 kPa to isolate the microplastics. The collected samples were deposited into petri dishes for identification.

Microplastic extraction from *Anadara granosa*

The previously frozen *A. granosa* samples were defrosted under controlled conditions at room temperature (±25℃) for 1 hour. After the ice melted, the *A. granosa* were washed with pure distilled water to eliminate contamination from other objects, such as sediment. The length and wet weight of the *A. granosa* were measured using an analytical balance (0.01 g). The digestive tract was carefully removed from the *A. granosa* using sterile stainless steel utensils that had been rinsed with distilled water. The extraction of microplastics from the digestive tract of the *A. granosa* was adapted from previous studies with minor modifications (Ding et al. 2018, et al. 2021). The digestive tract was transferred into an Erlenmeyer flask, and 100 mL of KOH solution (10%) was added. The use of KOH is regarded as a more efficacious method for the digestion of biological material, and it has no impact on the integrity of the plastic polymer (Karami et al. 2017). The sample was covered with aluminum foil and stirred for 5 minutes using a 150 rpm magnetic stirrer. The supernatant was incubated at room temperature (±25°C) until complete digestion of organic matter occurred. The sample was then filtered through Whatman 42 filter paper (mesh size 0.45 µm, Φ = 90 mm) to isolate microplastic. The filter paper was dried in an oven at 40°C for 5 hours and stored in petri dishes for subsequent identification of microplastic content.

Microplastic identification and quantification

Identification and quantification of microplastics from sediments and *A. granosa* were performed using the same method. Microplastic identification was performed using an Olympus CX23 microscope with 10 × 10 or 4 × 10 magnification to visually detect microplastics (Diansyah et al. 2024). The filter paper was observed closely and carefully to avoid contaminants that could enter the filter paper. Microplastics were identified based on the number and form of microplastics (fragment, film, fiber, and foam).

The data obtained were recorded by sample type and station/individual for statistical purposes. To prevent contamination, personnel wear cotton lab coats, latex gloves, and cotton masks. Furthermore, access to the detection room is restricted to prevent outside contact during observations.

Procedures for quality assurance and contamination prevention

The quality and contamination control measures were implemented to prevent any alterations to the microplastics in the samples. Before sampling, glass jars and aluminum foil were rinsed with filtered distilled water. Although the samples were in a cool box, they were stored in a place that was not exposed to direct sunlight to keep the samples in good condition. Personnel are also required to wear latex gloves during sampling. During the study, from sampling to laboratory analysis, the use of plastic equipment was minimized to avoid unintentional fragmentation of the microplastics. The distilled water used was filtered with filter paper (0.45 µm,) to prevent microplastics from entering our materials. All equipment was washed with filtered distilled water to remove potential contamination from external particles (Ding et al. 2021). We prepared two controls by filtering each solution we used to avoid contaminants from materials, equipment, and air. No microplastics were found contaminating the instrument. The sterilized equipment was wrapped in aluminum foil to prevent any input of contaminants from outside. Laboratory personnel were required to wear latex gloves, lab coats, and masks throughout the analysis. Access to the laboratory was restricted during the analysis to minimize external interference that could lead to protocol errors.

Data analysis

Pollution Load Index (PLI)

PLI was calculated using a pollutant load approach, which assesses the total concentration of contaminants relative to a baseline level, to evaluate its significance. Equations were utilized to quantify the level of microplastic pollution in both sediments and *A. granosa* in the Musi Estuary, with the method adapted accordingly (Tomlinson et al. 1980; Xu et al. 2018; Wang et al. 2021):

$$CF_i = \frac{C_i}{C_{0i}}$$

This equation shows that the Concentration Factor (CF_i) at a particular sample is obtained by dividing the current Concentration (C_i) by the Initial Concentration (C_{0i}). Ci indicates the quantified presence of microplastics at each sampling location or within each clam (ind), while C_{0i} denotes the background concentration, defined as the lowest value recorded across all sampling locations. Given the lack of previously published research on microplastics in sediments or *A. granosa* in the Musi River Estuary, we determined C_{0i} values from minimum concentrations across sampling stations.

$$PLI = \sqrt{CF_i}$$

This equation shows that the Pollution Load Index (PLI) is generated by calculating the square root of the Concentration Factor (CF). The PLI value of microplastics is derived from the Contaminant Factor (CF_i) calculated for each station/individual.

$$PLI_{zone} = \sqrt[n]{PLI_1 \times PLI_2 \times \ldots\ PLI_n}$$

Pollution Load Index of Zone (PLI_{zone}) is determined by taking the square root of the product of individual PLI values from multiple sites within the zone. This method integrates data from several measurement points, providing a more comprehensive assessment of microplastic contamination within the analyzed. A PLI_{zone} is used to assess pollution based on specific estuary zones as well as the overall estuary area. PLI values are categorized into four predefined categories of pollution load, as shown in Table 2.

Nemerow Pollution Index (NPI)

NPI is designed to assess the bioavailability of microplastics in sediments and *A. granosa*. This index was adapted from equations used in prior studies evaluating heavy metal contamination (Alam et al. 2023).

$$NPI = \sqrt{\frac{\left(\frac{C_i}{S_i}\right) max^2 + \left(\frac{C_i}{S_i}\right) ave^2}{2}}$$

The NPI value is calculated using the square root of the mean squared deviation, incorporating both the maximum and average concentration ratios relative to the background concentration (S_i). The formula includes the sum of the squares of the maximum concentration ratio ($C_{i\ max}/S_i$) and the average concentration ratio ($C_{i\ ave}$). The Ci value represents the concentration of microplastics found in the sediment or clams at a specific station or individual, while the Si value denotes the background level of microplastics, determined as the lowest concentration recorded across all sample types. The NPI provides a measure of microplastic bioavailability in sediments and *A. granosa*, with values below 2 indicating low bioavailability and values above 2 indicating high bioavailability.

Bioconcentration Factor (BCF)

The Bioconcentration Factor (BCF) quantifies the extent to which microplastics accumulate in biota relative to their environmental concentration and is calculated using the following equation (Li et al. 2022a).

Table 2. Microplastic pollution load categories

Definition	Value			
Value of the Pollution Load Index (PLI)	<10	10-20	20-30	>30
Risk category	I	II	III	IV
Information	Minor	Middle	High	Extreme

$$BCF = \frac{C\ biota_{\ ave}}{C\ sediment_{\ ave}}$$

In this equation, BCF represents the bioconcentration factor, which is derived from the calculation of the average concentration of microplastic in biota (*A. granosa*) divided by the average concentration of microplastic in its environment (sediment). This value is intended to assess how much microplastic is concentrated in the biota.

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics 27. Descriptive statistics, including total, mean, standard deviation, percentage, minimum, and maximum, were utilized to assess data variation. A One-Way ANOVA was applied to analyze differences in microplastic abundance between estuarine zones when the data met normality assumptions. For non-normal data, the Kruskal-Wallis test was employed to assess the significance of differences between zones. All tests were carried out with a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Microplastic presence in sediment from Musi Estuary

The Musi Estuary in South Sumatra, Indonesia, is a dynamic brackish water environment where freshwater from the Musi River meets the saltwater of the Bangka Strait (Figure 2). Characterized by turbid waters and muddy sediments rich in organic matter, the estuary is fringed by mangrove forests that provide habitat for aquatic species, including the *A. granosa*, a key species in local aquaculture (Rozirwan et al. 2023c). Surrounded by urban and industrial areas, including Palembang, the estuary faces pollution from domestic, agricultural, and industrial waste, making it susceptible to microplastic accumulation in sediments and ingestion by benthic organisms like *A. granosa* (Almiza and Patria 2021; Diansyah et al. 2024).

The results of this study indicate that microplastics were detected at all sampling stations, as shown in Figure 4. A total of 1,308 microplastic particles were identified, with concentrations ranging from 66 to 178 particles per 100 g of dry sediment (dry weight, dw). The average abundance of microplastics was 1.31±0.41 particles/g dw, with the highest concentration found at station S1 (1.78 particles/g dw) and the lowest at station S8 (0.66 particles/g dw). High levels of human activity in the upstream area of Musi Estuary, which flows downstream to the estuary and ultimately into the ocean, are responsible for the presence of microplastics (Rozirwan et al. 2021; Diansyah et al. 2024). Urban activities in close proximity to the Musi River Watershed, particularly in Palembang City, significantly contribute to the generation of plastic waste. Increased population density near riverbanks enhances the potential for plastic pollution. Furthermore, population density is a crucial factor in the entry of microplastics into rivers (Eo et al. 2023; Dwiyitno et al. 2024). As a result, plastic pollutants from domestic activities, such as the disposal of food packaging and plastic bags, can be transported through stormwater drains and eventually end up in rivers (Kunz et al. 2023). Fishing activities around Musi Estuary can contribute to microplastic pollution, primarily through fibers released from fishing nets (Li et al. 2022a Fauziyah et al. 2023). This increases anthropogenic pressure at river mouths, which can lead to a greater accumulation of microplastics (Castro-Jiménez et al. 2024). Additionally, tidal fluctuation influences water flow, which facilitates the deposition of microplastics in sediment at these locations (Harris 2020). The findings of this study indicate that anthropogenic activities are responsible for high levels of microplastic deposition in the sediments of Musi Estuary. Microplastic particles that accumulate in sediments serve as a habitat for benthic organisms, which can have long-term implications for ecosystem health and balance (Rahmatin et al. 2024). As vectors for pollutants, microplastics can exacerbate toxicity, potentially endangering various populations (Caruso 2019; Fu et al. 2021; Issac and Kandasubramanian 2021; Ta and Babel 2023). Furthermore, the processes of bioaccumulation and biomagnification in benthic organisms present heightened risks to these animals, potentially leading to human consumption (Unuofin and Igwaran 2023). Therefore, it is crucial for local governments to address the handling and prevention of further microplastic accumulation.

Figure 2. General conditions in the Musi Estuary, South Sumatra, Indonesia: A. Coastal settlements; B. Shipping activities; C. Fisheries; D. Mangrove ecosystem

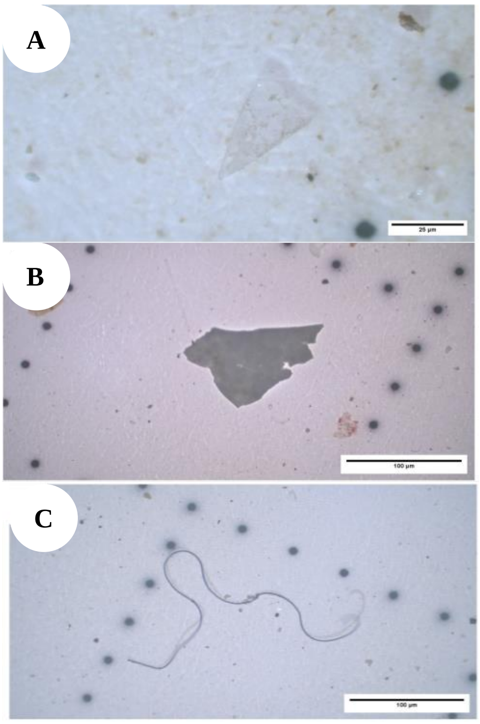

Figure 3. Various forms of microplastics from Musi Estuary, South Sumatra, Indonesia: A. Film; B. Fragment; C. Fiber

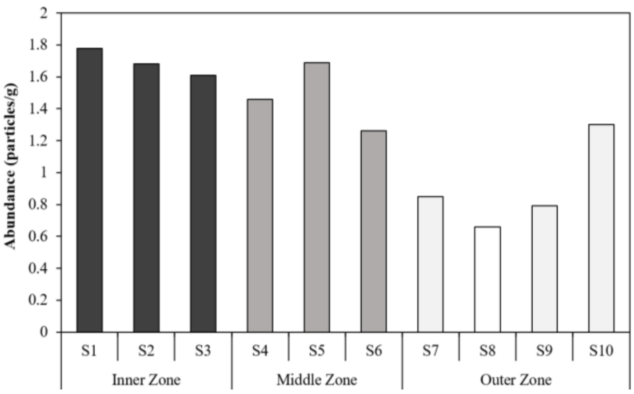

Figure 4. Distribution of microplastics from sediments in Musi Estuary, South Sumatra, Indonesia

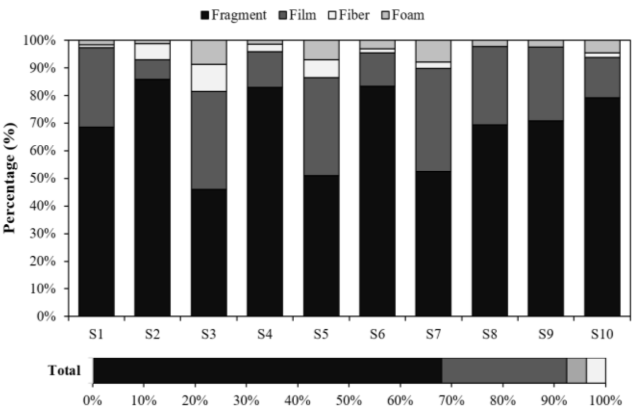

Figure 5. Percentage abundance of microplastic shapes form sediments in Musi Estuary, South Sumatra, Indonesia

The microplastics identified in the sediments were predominantly fragments (68.92%), followed by films (23.86%), fibers (4.05%), and foams (3.17%) (Figure 3 and Figure 5). The dominance of fragments, which are a common form of secondary microplastics, occurs as a result of macroplastic degradation (Barnes et al. 2009). Fragments represented the most common type across all sediment samples analyzed. This dominance of fragments in estuarine sediments aligns with findings from various studies conducted in other estuarine environments. Research indicates that estuarine sediments globally tend to accumulate diverse microplastic forms, particularly fibers (Firdaus et al. 2020; Alam et al. 2023; Samuels et al. 2024; Santucci et al. 2024), with many studies also reporting a predominance of fragment types (Zhou et al. 2021; Suteja et al. 2024). These observations corroborate the literature, which consistently shows that fibers and fragments constitute the majority of microplastic pollution in estuarine ecosystems (Feng et al. 2023a).

This study reveals notable variations in microplastic concentrations compared to similar research in estuaries globally. Our findings indicate that the Musi Estuary has lower microplastic concentrations than those reported in several other Indonesian and international estuaries. For example, the Jakarta Bay Estuary exhibits concentrations nearly ten times higher, ranging from 1,184 to 1,337 particles per 100 grams of river sediment and 804 to 1,055 particles per 100 grams of beach sediment (Dwiyitno et al. 2024). Such elevated levels are likely due to increased anthropogenic activities along Jakarta's rivers, which substantially contribute to plastic waste flow. In another comparison, the Pearl River Estuary in China also shows higher microplastic densities, with concentrations between 2.05×10^3 and 7.75×10^3 particles per kilogram of dry weight sediment (Xu et al. 2024). This estuary's coastal regions experience high human activity, enhancing the potential for microplastic deposition. Similarly, the Meghna Estuary in Bangladesh, which receives sediment from the Ganges River Basin, reports even higher microplastic levels at 4,014.66±1,717.59 particles per kilogram dry weight (Alam et al. 2023). These findings underscore the significant role of anthropogenic influences on microplastic accumulation in global estuarine sediments, including the Musi Estuary. Other environmental factors, like location, sampling period, sediment depth, sediment composition, and local hydrodynamic conditions, may also affect these changes in the amount of microplastics found (Zheng et al. 2020; Feng et al. 2023b; Yuan et al. 2023).

In contrast, the abundance of microplastics in the sediments of the Musi Estuary surpasses levels reported in other regions, both within Indonesia and globally. Concentrations in the Musi Estuary are notably higher than those in the Zandvlei River Watershed and estuarine areas of South Africa (70.23±7.36 particles/kg dw) (Samuels et al. 2024), the Claromecó Estuary in Argentina (299±114 particles/kg dw) (Truchet et al. 2021), and the upper sediment layer (0-5 cm) of the Fuhe River Estuary in Northern China (1049±462 particles/kg dw) (Zhou et al. 2021). These numbers are also higher than those found in coastal Río de la Plata (547.83±620.06 particles/kg dw) (Santucci et al. 2024), Benoa Bay, Bali (31.08±21.53 particles/kg dw) (Suteja et al. 2024), the Jagir Estuary in Surabaya (up to 590 particles/kg dw) (Firdaus et al. 2020), and the Pekalongan River Estuary in Java (0.77 to 1.01 particles/g dw) (Ismanto et al. 2023). The high microplastic concentration in the Musi Estuary is likely due to extensive plastic waste disposal in the river basin by the surrounding community. Research supports that plastic debris forms a substantial part of the macro-waste in the Musi River (Maherlsa et al. 2019). Additionally, local communities frequently establish settlements along the river, relying on it for water access and transportation. Consequently, domestic waste, including plastic, often enters the river directly. This local waste management issue reflects a broader trend, with Indonesia identified as the world's second-largest contributor to oceanic plastic pollution, following China (Jambeck et al. 2015).

Spatial distribution microplastic in sediments

The study revealed that the abundance of microplastics was significantly higher in the inner and middle zones when compared to the outer zone. The mean abundances were 1.69±0.08 particles/g dw in the inner zone, 1.47±0.22 particles/g dw in the middle zone, and 0.9±0.28 particles/g dw in the outer zone. Significant differences in mean microplastic abundance between zones were revealed by the one-way ANOVA ($p<0.05$), as illustrated in Figure 6. The Tukey HSD test revealed no significant difference in mean microplastic abundance between the inner and middle zones However, we observed a significant difference in the outer zone compared to both the middle and outer zones. Our results indicate that the inner and middle estuary regions exhibit greater mean concentrations of microplastics compared to the outer estuary. Natural factors, particularly the effects of currents and wave action in coastal and estuarine environments, significantly influence this phenomenon by altering microplastic distribution. The influx of freshwater promotes the sedimentation and prolonged retention of high-density microplastics within the system (Li et al. 2024a). Furthermore, the sedimentation process is affected by the density and buoyancy of microplastics, with increased salinity in estuarine waters enhancing buoyancy forces and influencing distribution patterns (Cheng et al. 2024). Our findings align with research from the Liaohe Estuary in China, revealing a higher accumulation of microplastics in inner river sediments compared to the outer estuary (Xu et al. 2020). Additionally, sampling depth plays a critical role in accurately measuring microplastics in surface waters, bottom layers, and sediments (Feng et al. 2023a).

The spatial analysis revealed distinct patterns of microplastic accumulation between the two sides of the coast adjacent to the estuary. Notably, Site S7 exhibited higher concentrations compared to Site S8, likely due to its proximity to other pollution sources. Specifically, S7 is located near the Banyuasin Estuary, which is believed to significantly contribute to the deposition of microplastics in the surrounding sediments. Based on da Costa et al. (2023), confirmed that nearby sources of pollution heavily influence microplastic deposition in coastal regions. The accumulation of microplastics at the mouth of the adjacent river further exacerbates this phenomenon, facilitating the settlement of microplastics within the sediment. Additionally, studies suggest that the depth of the sampling locations significantly influences microplastic deposition, revealing a greater abundance of microplastics at deeper water levels (Bayo et al. 2022). The substantial accumulation of microplastics in sediments is attributed to their persistent characteristics as well as the protective conditions offered by deeper environments, which are shielded from UV light, maintain lower temperatures, and exhibit lower oxygen levels, thus slowing biodegradation processes (Zhang et al. 2021).

Our findings confirm the presence of microplastics in the sediments of the Musi Estuary, likely originating from suspended microplastics that eventually settle from the water's surface. Previous research has found that there are 467.67±127.84 particles/m³ and 723.67±112.05 particles/m³ of microplastic in surface waters during ebb and flow conditions, respectively (Diansyah et al. 2024). Hydrodynamic conditions in the estuary and processes like aggregation and biofouling, which increase microplastic density, influence the deposition of these particles (Malli et al. 2022). The specific properties of the microplastics and the water dynamics of the estuary strongly influence microplastic deposition. For instance, biofouling can make microplastics denser, accelerating their descent into sediments (Lin et al. 2023). Since microplastics often have higher densities than water, they can remain suspended in the water column before eventually settling (Dai et al. 2022). High Total Suspended Solids (TSS) in the Musi Estuary have the potential to cause aggregation of microplastics (Rahutami et al. 2022). High TSS levels make it easier for sediments and other suspended particles to stick together on microplastic surfaces, which speeds up their deposition (Yang et al. 2022). However, microplastics can also become resuspended in the water column (Tang et al. 2020). Stirring forces in estuarine environments can lift microplastics back into the water, where turbulence and bioturbation may redistribute them (Malli et al. 2022). Therefore, additional studies are required to fully characterize the mechanisms of microplastic deposition in the Musi Estuary. Climate factors also influence microplastic distribution in Musi Estuary sediments. In Indonesia, where regions such as the Musi Estuary experience distinct rainy and dry seasons, seasonal changes affect water dynamics and microplastic transport. During the rainy season, increased river velocity may carry microplastics upward from sediments, while in the dry season, slower flows facilitate microplastic accumulation at the water's surface (Zhao et al. 2020). Currently, there are no studies specifically examining the seasonal impact on microplastic presence in the Musi Estuary, underscoring the need for further research to address this gap.

Bioaccumulation of microplastics in *Anadara granosa*

We extracted 133 microplastic particles from the digestive tracts of twenty samples of *A. granosa* species presented in Figure 7. Each sample from the Musi Estuary had accumulated microplastics, ranging from 6 to 49 particles/ind or 8 to 69.01 particles/g ww, as shown in Figures 8 and 9. The mean abundance of microplastics found in the digestive tracts was 21.05±10.31 particles/ind or 30.46±16.7 particles/g ww. Several factors contribute to the increased microplastic inputs in bivalve species, including human activities, tourism, fishing equipment, freshwater runoff, and wastewater discharge, combined with the area's hydrodynamic conditions (Vital et al. 2021). The elevated levels of microplastics found in *A. granosa* from the Musi River Estuary suggest a significant degree of contamination in their habitat, including both water and sediment, which may adversely affect the health of these organisms and disrupt local ecological balances. This observation aligns with existing literature, which indicates a strong correlation between the abundance of microplastics in bivalves, such as mussels, and their sediment environments (Sathish et al. 2020), reinforcing the need for monitoring these pollutants in aquatic ecosystems.

Microplastics were observed in three morphological forms: film, fiber, and fragment. Film accounted for the majority of microplastics (59.38%), followed by fiber (31.59%) and fragments (9.03%), as shown in Figure 10. The digestive tracts of the *A. granosa* studied did not contain any pellets or foam. Statistical analysis using the Kruskal-Wallis test revealed significant differences in the abundance of the three microplastic forms ($p<0.05$). This predominance of film microplastics in *A. granosa* is likely attributable to the extensive use of disposable plastic packaging within the community, which subsequently degrades into microplastics. Although fragments dominate the sediment substrate, *A. granosa* predominantly absorbs film microplastics. The lower density of film microplastics may facilitate their accumulation in the upper sediment layer, making them susceptible to resuspension in the overlying water column. This phenomenon is consistent with the feeding behavior of *A. granosa*, which frequently filters water from the sediment surface, resulting in the accumulation of film microplastics within their digestive tracts.

Our findings indicate a higher abundance of microplastics in *A. granosa* from the Musi Estuary compared to certain other regions globally. For instance, *A. granosa* from the Chanthaburi estuarine ecosystem in eastern Thailand contained 0.40±0.16 particles/g ww (Potipat et al. 2024), while samples from Peninsular Malaysia showed concentrations of 0.20±0.08 particles/g ww and 1.54±0.30 particles/ind ww (Mohan et al. 2024). Additionally, microplastic levels in *A. granosa* from Pao Village, Tarowang Sub-district, Jeneponto District, Indonesia, were measured at 0.0144 particles/g ww (Namira et al. 2023), and those from Likas Bay Beach in North Borneo, Malaysia, at 24.4±0.6 particles/g ww (Abd Rahman et al. 2024). In contrast, the *A. granosa* analyzed in this study accumulated lower microplastic concentrations than those reported in several other studies. For instance, *A. granosa* from the Pangkal Babu mangrove forest area in Tanjung Jabung Barat District, Jambi, exhibited 434±97.05 particles/ind (Fitri and Patria 2019), while those from Lada Bay in Pandeglang, Banten, had concentrations of 618.8±121.4 particles/ind (Ukhrowi et al. 2021). Overall, this study shows that microplastics have contaminated the sediment environment of the Musi Estuary, South Sumatra, indicating that *A. granosa* can serve as effective bioindicators of this pollution.

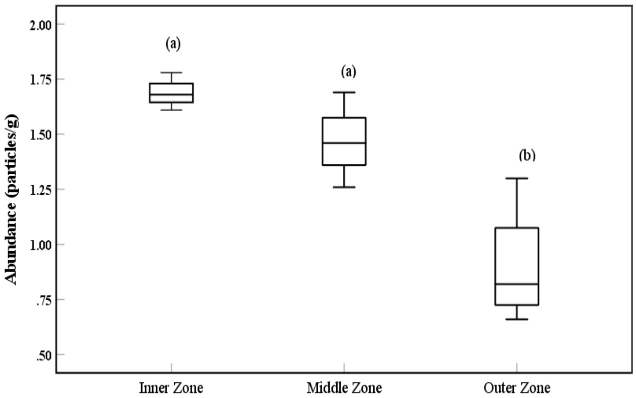

Figure 6. The difference in microplastic abundance between zones in the sediments from Musi Estuary, South Sumatra, Indonesia

Figure 7. Specimens of *Anadara granosa* from Musi Estuary, South Sumatra, Indonesia

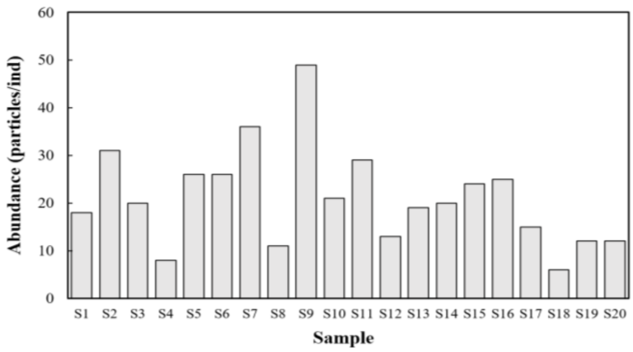

Figure 8. Microplastic abundance of *Anadara granosa* from the Musi Estuary, South Sumatra, Indonesia

Table 3. The microplastic risk factor in sediments of Musi Estuary, South Sumatra, Indonesia

Sediment Station	CF	PLI	PLI zone	PLI sediment	NPI
S1	2.70	1.64	Inner zone	1.37	2.37
S2	2.55	1.60	1.60		
S3	2.44	1.56			
S4	2.21	1.49	Middle zone		
S5	2.56	1.60	1.49		
S6	1.91	1.38			
S7	1.29	1.13	Outer zone		
S8	1.00	1.00	1.20		
S9	1.20	1.09			
S10	1.97	1.40			

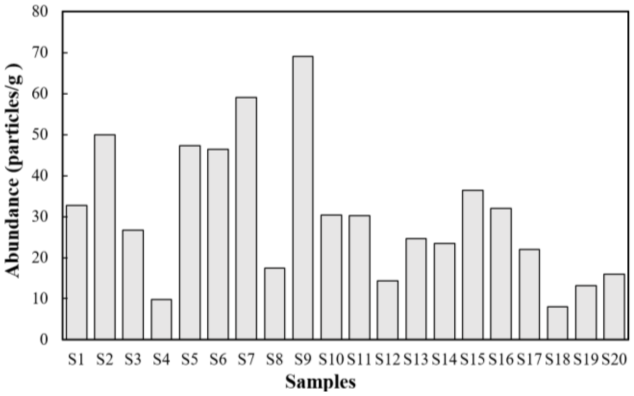

Figure 9. Microplastic abundance (in particles/g) of *Anadara granosa* from the Musi Estuary, South Sumatra, Indonesia

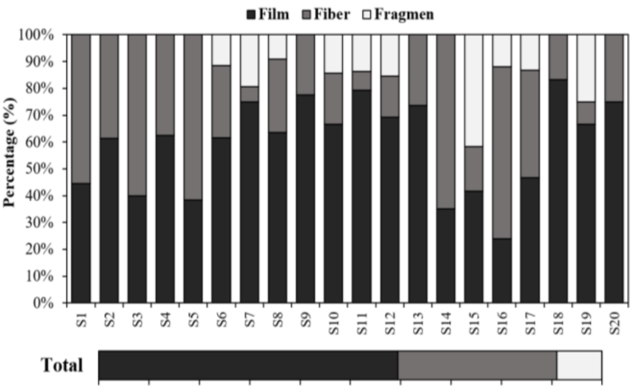

Figure 10. Shape of microplastics in *Anadara granosa* from the Musi Estuary, South Sumatra, Indonesia

Risk assessment of microplastics in sediments and *Anadara granosa*

A risk assessment of microplastic contamination in the Musi River Estuary was carried out by calculating the Pollution Load Index (PLI), the Nemerow Pollution Index (NPI), and the Bioconcentration Factor (BCF). The PLI values across all sediment samples indicate that the estuarine sediment is subject to minor pollution, with values ranging between 1.00 and 1.64, as shown in Table 3. In the three zones of the estuary (inner, middle, and outer), the PLI values were 1.60, 1.49, and 1.20, respectively. We calculated the overall average PLI for the Musi Estuary to be 1.37. All zones reported PLI values below 3.00, which suggests that the area experiences only minor microplastic pollution. The analysis of microplastic presence in sediment samples revealed a significantly high concentration of microplastics, with an NPI value of 2.37. This suggests a substantial bioavailability of microplastics in the estuarine environment. This elevated NPI underscores the ecological risk posed by microplastic contamination, despite the relatively low PLI observed across the study area.

Anadara granosa analyzed in this study exhibited significant risk values associated with microplastic contamination. The PLI for these clams ranged from 1 to 2.86, with an overall mean PLI value of 1.77 for the entire sample, as shown in Table 4. This indicates that the pollution load in *A. granosa* falls within the minor category (PLI<3). Furthermore, the bioavailability of microplastics in *A. granosa* was significantly higher, with an NPI value of 6.29, indicating a high bioavailability. The bioconcentration factor of microplastics from sediment to *A. granosa* was measured at 23.28, suggesting a significant potential for the transfer of microplastics from sediment to *A. granosa* in the Musi Estuary.

Our findings demonstrated that the bioavailability of microplastics in sediments and *A. granosa* was categorized as high (NPI = 2.37; NPI>2). In comparison, the bioavailability of microplastics in *A. granosa* was even higher, with an NPI value of 9.89. The elevated bioavailability in sediments suggests a greater potential for absorption by aquatic organisms, particularly benthic animals. Furthermore, the Bioconcentration Factor (BCF) calculated for *A. granosa* in sediment was 23.28, indicating a significant transfer of microplastics from sediments to these organisms in the Musi Estuary. This high BCF value is attributed to the non-discriminatory feeding process of *A. granosa*, allowing them to ingest microplastics along with other particles. When compared to several benthic species from the Yangtze River Estuary, which exhibited a BCF of 29.48±6.52 (Li et al. 2022c), the BCF of *A. granosa* in the Musi Estuary remains lower. Nonetheless, both sediments and *A. granosa* from the Musi Estuary are classified within the minor pollution risk index category (PLI<10). The bioaccumulation of microplastics by benthic animals like *A. granosa* poses a significant risk to human health for those consuming these clams (Wang et al. 2023; Winiarska et al. 2024). Therefore, periodic assessments are crucial to evaluate the risk of microplastic contamination in sediments and *A. granosa*, providing essential information to understand the ecological and health implications in the Musi Estuary.

The impact of high bioaccumulation extends beyond the toxicity of microplastic materials; it also facilitates the accumulation of other pollutants. Previous research has detected heavy metals, such as lead (Pb) and copper (Cu), adhering to the surfaces of microplastics in the Musi Estuary (Purwiyanto et al. 2020). Additionally, various hazardous heavy metals, including iron (Fe), cadmium (Cd), chromium (Cr), lead (Pb), and zinc (Zn), were identified with high bioavailability in the aquatic environment of the Musi Estuary (Rahutami et al. 2022). This accumulation allows for the deposition of significant quantities of heavy metals on microplastic surfaces, thereby increasing the risk of microplastic toxicity for estuarine ecosystems. Moreover, the involvement of microorganism vectors, misidentification in aquatic organisms' diets, and their harmful toxicological effects on benthic animals heighten the risk associated with microplastics (Gong and Xie 2020). Consequently, the high output of microplastics from the Musi Estuary has the potential to jeopardize the condition of the surrounding aquatic environment, including fisheries and migratory birds, which are critical to the ecosystem (Rozirwan et al. 2019, 2022a).

This study holds significant ecological implications for the Musi Estuary ecosystem, as the presence of microplastics poses a long-term threat to ecosystem stability. Previous studies have shown that microplastics can affect the physicochemical properties of sediments, such as electrical conductivity, organic matter content, and nutrients, and well as impact enzymatic activity in sediment bacteria (Rillig 2012; Li et al. 2022b; Yuan et al. 2023). These changes can lead to structural and functional alterations in aquatic habitats (Li et al. 2022b). Microplastics can also enter various levels of the food chain through bioaccumulation and biomagnification processes. For example, microplastics in plankton can cause a decline in zooplankton populations, which impacts food availability for small fish and predatory species at higher trophic levels (Malinowski et al. 2023). The accumulation of microplastics in *A. granosa* in this study indicates that the pressure of plastic waste in the Musi Estuary is already quite high. Microplastics can act as vectors for other pollutants, such as microorganisms, heavy metals, and other inorganic pollutants can increase the risk of toxicity for aquatic organisms, including *A. granosa* (Purwiyanto et al. 2020; Rafa et al. 2024). Research indicates that exposure to microplastics can lead to behavioral and physiological changes in aquatic organisms, including changes in diet and reproductive success (Guo et al. 2020; Liang et al. 2023). Moreover, microplastics disrupt endocrine functions and metabolic pathways, causing oxidative stress, cell necrosis, and apoptosis, which can ultimately lead to mortality (Pannetier et al. 2020; Jeyavani et al. 2021). Disruption of any component of the food chain can trigger a domino effect, threatening the balance of the Musi Estuary ecosystem. However, this study only examines microplastic pollution in sediment and *A. granosa* as environmental indicators. Additional research is needed to understand microplastic buildup in other species, such as fish, shrimp, and benthic organisms, for a more complete picture of microplastic pollution in the Musi Estuary and its impact on the global marine environment.

Microplastic contamination of *A. granosa* in the Musi Estuary poses a significant threat to local communities, particularly clam fishers. Microplastics that accumulate in *A. granosa* may pose health risks to community members who consume them regularly as a primary source of protein. Long-term exposure to microplastics can potentially disrupt various human body systems, including the digestive, respiratory, reproductive, nervous, and cardiovascular systems (Li et al. 2024b). Furthermore, microplastics may cause both acute and subchronic toxicity and are considered potentially carcinogenic and disruptive to human development (Yuan et al. 2022). Once in the bloodstream, microplastics can be transported to the liver, the primary organ responsible for detoxification. Accumulation in the liver may trigger adverse physiological reactions, including increased oxidative stress, liver fibrosis, and impaired lipid metabolism. In addition to health risks, microplastic contamination in *A. granosa* in the Musi Estuary may reduce consumer confidence and decrease market demand due to food safety concerns (Unuofin and Igwaran 2023). The long-term effect could weaken local economic resilience as marine products in the region are perceived to be contaminated with microplastics (Barrientos et al. 2024). Therefore, it is crucial for governments and communities to recognize these risks and collaborate on mitigation efforts to protect ecosystems, public health, and local economies.

Furthermore, seafood hygiene practices in local communities and fishing industries can help reduce microplastic contamination (Lusher et al. 2017; Smith et al. 2018). For example, *A. granosa* and other seafood, when thoroughly cleaned by repeated washing and clam removal before cooking, may reduce microplastic intake (Li et al. 2022a). The concentration of microplastics in shellfish is significantly lower after boiling and steaming compared to frying, suggesting that cooking methods affect microplastic retention in seafood (Evode et al. 2021). This method can also be applied to shrimp, fish, and other shellfish to lower the risk of microplastic exposure. Implementing these recommendations will help reduce microplastic pollution and provide long-term benefits for public health, ecosystem stability, and the economic resilience of local fisheries (Prata et al. 2019).

Table 4. Risk factors for microplastics in *Anadara granosa* from the Musi Estuary, South Sumatra, Indonesia

***A. granosa* sample**	**CF**	**PLI**	**PLI A. granosa**	**NPI**	**BCF**
S1	3.00	1.73	1.77	6.29	23.28
S2	5.17	2.27			
S3	3.33	1.83			
S4	1.33	1.15			
S5	4.33	2.08			
S6	4.33	2.08			
S7	6.00	2.45			
S8	1.83	1.35			
S9	8.17	2.86			
S10	3.50	1.87			
S11	4.83	2.20			
S12	2.17	1.47			
S13	3.17	1.78			
S14	3.33	1.83			
S15	4.00	2.00			
S16	4.17	2.04			
S17	2.50	1.58			
S18	1.00	1.00			
S19	2.00	1.41			
S20	2.00	1.41			

In conclusion, this study demonstrates the significant presence of microplastics in the sediment and *A. granosa* of the Musi Estuary, Indonesia. These findings indicate a serious threat to the aquatic ecosystem and to local public health, as microplastics can enter the food chain and potentially harm organisms across trophic levels, including humans (Ningrum and Patria 2022; Edwin et al. 2023; Patria et al. 2023). This pollution heightens environmental risks, particularly for species integral to both the community's diet and economy (Jeong et al. 2024). The microplastics likely originate from human activities, especially urban waste from upstream areas that flows downstream and accumulates in the estuary (Diansyah et al. 2024). These results highlight the urgent need for routine monitoring and stricter waste management practices, particularly for plastic disposal, to reduce further contamination (Barletta et al. 2019). A comprehensive strategy is essential to controlling plastic waste throughout the river system—from source to estuary. Effective measures should include coordinated waste management practices, public education on the impact of pollution, and cross-sector collaboration to preserve estuarine health (Wakwella et al. 2023; Ihenetu et al. 2024). Such initiatives are crucial to protecting ecosystem health and sustaining local fisheries, ensuring these resources continue to support community well-being.

ACKNOWLEDGEMENTS

The authors disclose receipt of the following financial support for the research, authorship, and publication of this article: Indonesian Directorate of Research, Technology, and Community Service Directorate General of Higher Education, Research, and Technology under the Contract for Implementation of the State Higher Education Operational Assistance Program Research Program for Fiscal Year 2024 Number: 090/E5/PG.02.00.PL/2024.

REFERENCES

Abd Rahman NN, Mazlan N, Shukhairi SS, Nazahuddin MNA, Shawel AS, Harun H, Baktir A. 2024. Evaluation of the microplastics in bivalves and water column at Pantai Teluk Likas, North Borneo, Malaysia. Environ Sci Pollut Res Intl 31 (15): 23178-23192. DOI: 10.1007/s11356-024-32628-z.

Abelouah MR, Ben-Haddad M, Hajji S, Nouj N, Ouheddou M, Mghili B, De-la-Torre GE, Costa LL, Banni M, Alla AA. 2024. Exploring marine biofouling on anthropogenic litter in the Atlantic coastline of Morocco. Mar Pollut Bull 199: 115938. DOI: 10.1016/j.marpolbul.2023.115938.

Alam MJ, Shammi M, Tareq SM. 2023. Distribution of microplastics in shoreline water and sediment of the Ganges River Basin to Meghna Estuary in Bangladesh. Ecotoxicol Environ Saf 266: 115537. DOI: 10.1016/j.ecoenv.2023.115537.

Almiza G, Patria MP. 2021. Distribution and abundance of macroplastic at Musi estuary, South Sumatera, Indonesia. J Phys: Conf Ser 1869: 012178. DOI: 10.1088/1742-6596/1869/1/012178.

Aunurrahman A, Anggoro S, Muskananfola MR, Saputra SW. 2023. Detection and analysis of mangrove cover change in Kepalajerih Island, Batam, Indonesia using Landsat Imagery. Biodiversitas 24 (11): 6126-6133. DOI: 10.13057/biodiv/d241134.

Barletta M, Lima ARA, Costa MF. 2019. Distribution, sources and consequences of nutrients, persistent organic pollutants, metals and microplastics in South American estuaries. Sci Total Environ 651 (Pt 1): 1199-1218. DOI: 10.1016/j.scitotenv.2018.09.276.

Barnes DKA, Galgani F, Thompson RC, Barlaz M. 2009. Accumulation and fragmentation of plastic debris in global environments. Philos Trans R Soc Lond B Biol Sci 364 (1526): 1985-1998. DOI: 10.1098/rstb.2008.0205.

Barrientos M, Lavín FV, Oliva RDP, Nayga Jr RM, Gelcich S. 2024. Microplastics in seafood: Consumer preferences and valuation for mitigation technologies. Food Res Intl 187: 114342. DOI: 10.1016/j.foodres.2024.114342.

Bayo J, Rojo D, Olmos S. 2022. Weathering indices of microplastics along marine and coastal sediments from the harbor of Cartagena (Spain) and its adjoining urban beach. Mar Pollut Bull 178: 113647. DOI: 10.1016/j.marpolbul.2022.113647.

Belzagui F, Gutiérrez-Bouzán C. 2022. Review on alternatives for the reduction of textile microfibers emission to water. J Environ Manag 317: 115347. DOI: 10.1016/j.jenvman.2022.115347.

Boerema A, Meire P. 2017. Management for estuarine ecosystem services: A review. Ecol Eng 98: 172-182. DOI: 10.1016/j.ecoleng.2016.10.051.

Bonifacio PSP, Metillo EB, Romano Jr EF. 2022. Microplastic in sediments and ingestion rates in three edible bivalve mollusc species in a Southern Philippine Estuary. Water Air Soil Pollut 233 (11): 455. DOI: 10.1007/s11270-022-05926-w.

Borrelle SB, Ringma J, Law KL et al. 2020. Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science 369 (6510): 1515-1518. DOI: 10.1126/science.aba3656.

Caruso G. 2019. Microplastics as vectors of contaminants. Mar Pollut Bull 146: 921-924. DOI: 10.1016/j.marpolbul.2019.07.052.

Castro-Jiménez J, Aminot Y, Bely N, Pollono C, Idjaton BIT, Bizzozero L, Pierre-Duplessix O, Phuong NN, Gasperi J. 2024. Organophosphate ester additives and microplastics in benthic compartments from the Loire estuary (French Atlantic coast). Mar Pollut Bull 201: 116256. DOI: 10.1016/j.marpolbul.2024.116256.

Cheng Z, Ma Y, Fan X, Wang Q, Liu Y, You Z. 2024. Historical behaviors of microplastic in estuarine and riverine reservoir sediment. Mar Pollut Bull 202: 116331. DOI: 10.1016/j.marpolbul.2024.116331.

da Costa MB, Otegui MBP, Zamprogno GC, Caniçali FB, Dos Reis Cozer C, Pelletier E, Graceli JB. 2023. Abundance, composition, and distribution of microplastics in intertidal sediment and soft tissues of four species of Bivalvia from Southeast Brazilian urban beaches. Sci Total Environ 857 (Pt 3): 159352. DOI: 10.1016/j.scitotenv.2022.159352.

Dai L, Wang Z, Guo T, Hu L, Chen Y, Chen C, Yu G, Ma LQ, Chen J. 2022. Pollution characteristics and source analysis of microplastics in the Qiantang River in southeastern China. Chemosphere 293: 133576. DOI: 10.1016/j.chemosphere.2022.133576.

Diansyah G, Rozirwan, Rahman MA, Nugroho RY, Syakti AD. 2024. Dynamics of microplastic abundance under tidal fluctuation in Musi estuary, Indonesia. Mar Pollut Bull 203: 116431. DOI: 10.1016/j.marpolbul.2024.116431.

Ding J, Sun C, He C, Li J, Ju P, Li F. 2021. Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. Sci Total Environ 782: 146830. DOI: 10.1016/j.scitotenv.2021.146830.

Ding J-F, Li J-X, Sun C-J, He C-F, Jiang F-H, Gao F-L, Zheng L. 2018. Separation and identification of microplastics in digestive system of bivalves. Chin J Anal Chem 46 (5): 690-697. DOI: 10.1016/S1872-2040(18)61086-2.

Dwiyitno D, Schwanen C, Januar HI, Ariyani F, Irianto HE, Schwarzbauer J. 2024. Microplastic profile in the sediment of Jakarta Bay Estuary, Indonesia: Characterization based on size fraction and the potential risk to the ecosystem. Reg Stud Mar Sci 73: 103465. DOI: 10.1016/j.rsma.2024.103465.

Edwin T, Primasari B, Annisa Purnama R. 2023. Characterization of microplastic in trawl fish caught in Padang City (Indonesia) coastal area. Biodiversitas 24 (1): 516-522. DOI: 10.13057/biodiv/d240160.

Eo S, Hong SH, Cho Y, Song YK, Han GM, Shim WJ. 2023. Spatial distribution and historical trend of microplastic pollution in sediments from enclosed bays of South Korea. Mar Pollut Bull 193: 115121. DOI: 10.1016/j.marpolbul.2023.115121.

Evode N, Qamar SA, Bilal M, Barceló D, Iqbal HMN. 2021. Plastic waste and its management strategies for environmental sustainability. Case Stud Chem Environ Eng 4: 100142. DOI: 10.1016/j.cscee.2021.100142.

Fauziyah, Ningsih EN, Arnando E, Fatimah, Agustriani F, Supriyadi F. 2023. Effect of hauling and soaking time of stationary lift nets on fish aggregation using a hydroacoustic monitoring approach. Egypt J Aquat Res 49 (3): 339-346. DOI: 10.1016/j.ejar.2023.05.003.

Fauziyah, Setiawan A, Agustriani F, Rozirwan, Melki, Ningsih EN, Ulqodry TZ. 2022. Distribution pattern of potential fishing zones in the Bangka Strait waters: An application of the remote sensing technique. Egypt J Remote Sens Space Sci 25 (1): 257-265. DOI: 10.1016/j.ejrs.2021.12.003.

Feng Q, An C, Chen Z, Lee K, Wang Z. 2023a. Identification of the driving factors of microplastic load and morphology in estuaries for improving monitoring and management strategies: A global meta-analysis. Environ Pollut 333: 122014. DOI: 10.1016/j.envpol.2023.122014.

Feng Q, Chen Z, An C, Yang X, Wang Z. 2023b. Tide-induced infiltration and resuspension of microplastics in shorelines: Insights from tidal tank experiments. Water Res 236: 119970. DOI: 10.1016/j.watres.2023.119970.

Firdaus M, Trihadiningrum Y, Lestari P. 2020. Microplastic pollution in the sediment of Jagir estuary, Surabaya City, Indonesia. Mar Pollut Bull 150: 110790. DOI: 10.1016/j.marpolbul.2019.110790.

Fitri S, Patria MP. 2019. Microplastic contamination on *Anadara granosa* Linnaeus 1758 in Pangkal Babu mangrove forest area, Tanjung Jabung Barat District, Jambi. J Phys: Conf Ser 1282: 012109. DOI: 10.1088/1742-6596/1282/1/012109.

Fitria Y, Rozirwan, Fitrani M, Nugroho RY, Fauziyah, Putri WAE. 2023. Gastropods as bioindicators of heavy metal pollution in the Banyuasin estuary shrimp pond area, South Sumatra, Indonesia. Acta Ecol Sin 43 (6): 1129-1137. DOI: 10.1016/j.chnaes.2023.05.009.

Frias JPGL, Nash R. 2019. Microplastics: Finding a consensus on the definition. Mar Pollut Bull 138: 145-147. DOI: 10.1016/j.marpolbul.2018.11.022.

Fu L, Li J, Wang G, Luan Y, Dai W. 2021. Adsorption behavior of organic pollutants on microplastics. Ecotoxicol Environ Saf 217: 112207. DOI: 10.1016/j.ecoenv.2021.112207.

Gan Q, Cui J, Jin B. 2023. Environmental microplastics: Classification, sources, fates, and effects on plants. Chemosphere 313: 137559. DOI: 10.1016/j.chemosphere.2022.137559.

Gong J, Xie P. 2020. Research progress in sources, analytical methods, eco-environmental effects, and control measures of microplastics. Chemosphere 254: 126790. DOI: 10.1016/j.chemosphere.2020.126790.

Griffiths JR, Kadin M, Nascimento FJA et al. 2017. The importance of benthic-pelagic coupling for marine ecosystem functioning in a changing world. Glob Change Biol 23 (6): 2179-2196. DOI: 10.1111/gcb.13642.

Guo J-J, Huang X-P, Xiang L, Wang Y-Z, Li Y-W, Li H, Cai Q-Y, Mo C-H, Wong M-H. 2020. Source, migration and toxicology of microplastics in soil. Environ Intl 137: 105263. DOI: 10.1016/j.envint.2019.105263.

Han X, Wu H, Li Q, Cai W, Hu S. 2024. Assessment of heavy metal accumulation and potential risks in surface sediment of estuary area: A case study of Dagu River. Mar Environ Res 196: 106416. DOI: 10.1016/j.marenvres.2024.106416.

Harris PT. 2020. The fate of microplastic in marine sedimentary environments: A review and synthesis. Mar Pollut Bull 158: 111398. DOI: 10.1016/j.marpolbul.2020.111398.

Hasan V, Andaini NE, Isroni W et al. 2023. Fish diversity of the Bengawan Solo River Estuary, East Java, Indonesia. Biodiversitas 24 (4): 2207-2216. DOI: 10.13057/biodiv/d240433.

Hasan V, South J, Katz AM, Ottoni FP. 2022. First record of the Smalleyed loter *Prionobutis microps* (Weber, 1907) (Teleostei: Eleotridae: Butinae) in Java, Indonesia. Cybium 46 (1): 49-51. DOI: 10.15560/19.1.51.

Hecker M, Peijnenburg W, Lam PKS, Brinkmann M. 2023. Emerging issues in aquatic toxicology-plastic pollution. Aquat Toxicol 264 (11): 106729. DOI: 10.1016/j.aquatox.2023.106729.

Ihenetu SC, Enyoh CE, Wang C, Li G. 2024. Sustainable urbanization and microplastic management: Implications for human health and the environment. Urban Sci 8 (4): 252. DOI: 10.3390/urbansci8040252.

Islamy RA, Hasan V. 2020. Checklist of mangrove snails (Mollusca: Gastropoda) in south coast of pamekasan, Madura Island, East Java, Indonesia. Biodiversitas 21 (7): 3127-3134. DOI: 10.13057/biodiv/d210733.

Ismanto A, Hadibarata T, Kristanti RA, Sugianto DN, Widada S, Atmodjo W, Satriadi A, Anindita MA, Al-Mohaimeed AM, Abbasi AM. 2023. A novel report on the occurrence of microplastics in Pekalongan River Estuary, Java Island, Indonesia. Mar Pollut Bull 196: 115563. DOI: 10.1016/j.marpolbul.2023.115563.

Isroni W, Sari PDW, Sari LA, Daniel K, South J, Islamy RA, Wirabuana PYAP, Hasan V. 2023. Checklist of mangrove snails (Gastropoda: Mollusca) on the coast of Lamongan District, East Java, Indonesia. Biodiversitas 24 (3): 1676-1685. DOI: 10.13057/biodiv/d240341.

Issac MN, Kandasubramanian B. 2021. Effect of microplastics in water and aquatic systems. Environ Sci Pollut Res Intl 28 (16): 19544-19562. DOI: 10.1007/s11356-021-13184-2.

Jacq K, Debret M, Gardes T, Demarest M, Humbert K, Portet-Koltalo F. 2024. Spatial distribution of polycyclic aromatic hydrocarbons in sediment deposits in a Seine estuary tributary by hyperspectral imaging. Sci Total Environ 950: 175306. DOI: 10.1016/j.scitotenv.2024.175306.

Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL. 2015. Marine pollution. Plastic waste inputs from land into the ocean. Science 347 (6223): 768-771. DOI: 10.1126/science.1260352.

Jeong E, Lee J-Y, Redwan M. 2024. Animal exposure to microplastics and health effects: A review. Emerg Contam 10 (4): 100369. DOI: 10.1016/j.emcon.2024.100369.

Jeyavani J, Sibiya A, Shanthini S, Ravi C, Vijayakumar S, Rajan DK, Vaseeharan B. 2021. A review on aquatic impacts of microplastics and its bioremediation aspects. Curr Pollut Rep 7: 286-299. DOI: 10.1007/s40726-021-00188-2.

Karami A, Golieskardi A, Choo CK, Romano N, Ho YB, Salamatinia B. 2017. A high-performance protocol for extraction of microplastics in fish. Sci Total Environ 578: 485-494. DOI: 10.1016/j.scitotenv.2016.10.213.

Kılıç S, Kılıç Ö, Belivermiş M, Ergül HA. 2023. Chronology of PAH and PCB pollution using sediment core in the Golden Horn Estuary (Sea of Marmara). Mar Pollut Bull 187: 114570. DOI: 10.1016/j.marpolbul.2023.114570.

Kunz A, Schneider F, Anthony N, Lin H-T. 2023. Microplastics in rivers along an urban-rural gradient in an urban agglomeration: Correlation with land use, potential sources and pathways. Environ Pollut 321: 121096. DOI: 10.1016/j.envpol.2023.121096.

Lee H, Kim S, Sin A, Kim G, Khan S, Nadagouda MN, Sahle-Demessie E, Han C. 2023. Pretreatment methods for monitoring microplastics in soil and freshwater sediment samples: A comprehensive review. Sci Total Environ 871: 161718. DOI: 10.1016/j.scitotenv.2023.161718.

Li G, Chen Z, Bowen M, Coco G. 2024a. Transport and retention of sinking microplastics in a well-mixed estuary. Mar Pollut Bull 203: 116417. DOI: 10.1016/j.marpolbul.2024.116417.

Li J, Zhang L, Dang X, Su L, Jabeen K, Wang H, Wang Z. 2022a. Effects of cooking methods on microplastics in dried shellfish. Sci Total Environ 837: 155787. DOI: 10.1016/j.scitotenv.2022.155787.

Li W, Wang Z, Li W, Li Z. 2022b. Impacts of microplastics addition on sediment environmental properties, enzymatic activities and bacterial diversity. Chemosphere 307 (Pt 3): 135836. DOI: 10.1016/j.chemosphere.2022.135836.

Li Y, Chen L, Zhou N, Chen Y, Ling Z, Xiang P. 2024b. Microplastics in the human body: A comprehensive review of exposure, distribution, migration mechanisms, and toxicity. Sci Total Environ 946: 174215. DOI: 10.1016/j.scitotenv.2024.174215.

Li Z, Chao M, He X, Lan X, Tian C, Feng C, Shen Z. 2022c. Microplastic bioaccumulation in estuary-caught fishery resource. Environ Pollut 306: 119392. DOI: 10.1016/j.envpol.2022.119392.

Liang W, Li B, Jong M-C, Ma C, Zuo C, Chen Q, Shi H. 2023. Process-oriented impacts of microplastic fibers on behavior and histology of fish. J Hazard Mater 448: 130856. DOI: 10.1016/j.jhazmat.2023.130856.

Liebezeit G, Dubaish F. 2012. Microplastics in beaches of the East Frisian Islands Spiekeroog and Kachelotplate. Bull Environ Contam Toxicol 89 (1): 213-217. DOI: 10.1007/s00128-012-0642-7.

Lin L, Zhang X, Yuan B, Li H, Lu H, Liu J, Hong H, Yan C. 2023. Effects of biofouling on the properties and sinking behavior of disposable face masks in seawater: A systematic comparison with microplastic films and particles. Environ Sci Technol Lett 10 (9): 792-797. DOI: 10.1021/acs.estlett.3c00460.

Lonsdale J-A, Leach C, Parsons D, Barkwith A, Manson S, Elliott M. 2022. Managing estuaries under a changing climate: A case study of the Humber Estuary, UK. Environ Sci Policy 134: 75-84. DOI: 10.1016/j.envsci.2022.04.001.

Lusher A, Hollman P, Mendoza-Hill J. 2017. Microplastics in Fisheries and Aquaculture: Status of Knowledge on Their Occurrence and Implications for Aquatic Organisms and Food Safety. FAO, Roma.
Mahary A, Effendi I, Hendrik H, Darwis D. 2023. Strategy for development of blood cockles (*Anadara granosa*) cultivation in Batubara Regency, North Sumatera, Indonesia. AACL Bioflux 16 (3): 1636-1647.
Maherlsa R, Purwiyanto AIS, Agustriani F, Putri WAE, Fauziyah, Ferdiansyah. 2019. Identification of surface macro debrisin river flow and estuary of Musi River, South Sumatera Province, Indonesia. J Phys: Conf Ser 1282: 012106. DOI: 10.1088/1742-6596/1282/1/012106.
Malinowski CR, Searle CL, Schaber J, Höök TO. 2023. Microplastics impact simple aquatic food web dynamics through reduced zooplankton feeding and potentially releasing algae from consumer control. Sci Total Environ 904: 166691. DOI: 10.1016/j.scitotenv.2023.166691.
Malli A, Corella-Puertas E, Hajjar C, Boulay A-M. 2022. Transport mechanisms and fate of microplastics in estuarine compartments: A review. Mar Pollut Bull 177: 113553. DOI: 10.1016/j.marpolbul.2022.113553.
Mohan P, Hamid FS, Furumai H, Nishikawa K. 2024. Beneath the surface: Exploring microplastic intricacies in *Anadara granosa*. Mar Environ Res 199: 106581. DOI: 10.1016/j.marenvres.2024.106581.
Namira N, Daud A, Mallongi A, Amqam H, Wahyu A, Irwandy I. 2023. Risk analysis of microplastic exposure through consumption of Anadara granosa at coastal area. Pharmacogn J 15 (4): 558-562. DOI: 10.5530/pj.2023.15.119.
Napper IE, Bakir A, Rowland SJ, Thompson RC. 2015. Characterisation, quantity and sorptive properties of microplastics extracted from cosmetics. Mar Pollut Bull 99 (1-2): 178-185. DOI: 10.1016/j.marpolbul.2015.07.029.
Natsir M, Ulya Z, Fitriani R. 2022. Mangrove forest utilization policies reconceptualized with a view to improving the regional economy in Aceh Tamiang District, Indonesia. Biodiversitas 23 (12): 6570-6578. DOI: 10.13057/biodiv/d231256.
Ningrum EW, Patria MP. 2022. Microplastic contamination in Indonesian anchovies from fourteen locations. Biodiversitas 23 (1): 125-134. DOI: 10.13057/biodiv/d230116.
Pannetier P, Morin B, Le Bihanic F, Dubreil L, Clérandeau C, Chouvellon F, Van Arkel K, Danion M, Cachot J. 2020. Environmental samples of microplastics induce significant toxic effects in fish larvae. Environ Intl 134: 105047. DOI: 10.1016/j.envint.2019.105047.
Patria MP, Kholis N, Anggreini D, Buyong F. 2023. Abundance and distribution of microplastics in seawater, sediment, and macroalgae sea grapes *Caulerpa racemosa* from Semak Daun Island, Jakarta Bay, Indonesia. Biodiversitas 24 (6): 3424-3430. DOI: 10.13057/biodiv/d240638.
Perumal K, Muthuramalingam S. 2022. Global sources, abundance, size, and distribution of microplastics in marine sediments-A critical review. Estuar Coast Shelf Sci 264: 107702. DOI: 10.1016/j.ecss.2021.107702.
Potipat J, Srimoon R, Mekprayoon S. 2024. Microplastic contamination in the Chanthaburi estuarine ecosystem, Eastern part of Thailand. J Environ Biol 45 (2): 152-160. DOI: 10.22438/jeb/45/2/MRN-5210.
Prasetiyono E, Nirmala K, Supriyono E, Sukenda, Hastuti YP. 2022. Analysis of environmental quality, production performance and economic feasibility of *Anadara granosa* cultivation in Sukal, Bangka Belitung Province. AACL Bioflux 15 (6): 2881-2891.
Prata JC, Silva ALP, da Costa JP, Mouneyrac C, Walker TR, Duarte AC, Rocha-Santos T. 2019. Solutions and integrated strategies for the control and mitigation of plastic and microplastic pollution. Intl J Environ Res Public Health 16 (13): 2411. DOI: 10.3390/ijerph16132411.
Praveena SM, Shaifuddin SNM, Akizuki S. 2018. Exploration of microplastics from personal care and cosmetic products and its estimated emissions to marine environment: An evidence from Malaysia. Mar Pollut Bull 136: 135-140. DOI: 10.1016/j.marpolbul.2018.09.012.
Purwiyanto AIS, Prartono T, Riani E, Koropitan AF, Naulita Y, Takarina ND, Cordova MR. 2022. The contribution of estuaries to the abundance of microplastics in Jakarta Bay, Indonesia. Mar Pollut Bull 184: 114117. DOI: 10.1016/j.marpolbul.2022.114117.
Purwiyanto AIS, Suteja Y, Trisno, Ningrum PS, Putri WAE, Agustriani F, Fauziyah, Cordova MR, Koropitan AF. 2020. Concentration and adsorption of Pb and Cu in microplastics: Case study in aquatic environment. Mar Pollut Bull 158: 111380. DOI: 10.1016/j.marpolbul.2020.111380.
Rafa N, Ahmed B, Zohora F, Bakya J, Ahmed S, Ahmed SF, Mofijur M, Chowdhury AA, Almomani F. 2024. Microplastics as carriers of toxic pollutants: Source, transport, and toxicological effects. Environ Pollut 343: 123190. DOI: 10.1016/j.envpol.2023.123190.
Rahmatin NM, Soegianto A, Irawan B, Payus CM, Indriyasari KN, Marchellina A, Mukholladun W, Irnidayanti Y. 2024. The spatial distribution and physico-chemical characteristic of microplastics in the sediment and cockle (*Anadara granosa*) from the coastal waters of East Java, Indonesia, and the health hazards associated with cockle consumption. Mar Pollut Bull 198: 115906. DOI: 10.1016/j.marpolbul.2023.115906.
Rahutami S, Said M, Ibrahim E, Herpandi H. 2022. Actual status assessment and prediction of the Musi River water quality, Palembang, South Sumatra, Indonesia. J Ecol Eng 23 (10): 68-79. DOI: 10.12911/22998993/152284.
Retnaningdyah C, Febriansyah SC, Hakim L. 2022. Evaluation of the quality of mangrove ecosystems using macrozoobenthos as bioindicators in the Southern Coast of East Java, Indonesia. Biodiversitas 23 (12): 6480-6491. DOI: 10.13057/biodiv/d231247.
Rillig MC. 2012. Microplastic in terrestrial ecosystems and the soil? Environ Sci Technol 46 (12): 6453-6454. DOI: 10.1021/es302011r.
Rozirwan, Az-Zahrah SAF, Khotimah NN, Nugroho RY, Putri WAE, Fauziyah, Melki, Agustriani F, Siregar YI. 2024. Ecological risk assessment of heavy metal contamination in water, sediment, and Polychaeta (*Neoleanira tetragona*) from coastal areas affected by aquaculture, urban rivers, and ports in South Sumatra. J Ecol Eng 25 (1): 303-319. DOI: 10.12911/22998993/175365.
Rozirwan, Fauziyah, Nugroho RY, Melki, Ulqodry TZ, Agustriani F, Ningsih EN, Putri WAE, Absori A, Iqbal M. 2022a. An ecological assessment of crab's diversity among habitats of migratory birds at Berbak-Sembilang National Park Indonesia. Intl J Conserv Sci 13 (3): 961-972.
Rozirwan, Fauziyah, Wulandari PI, Nugroho RY, Agutriani F, Agussalim A, Supriyadi F, Iskandar I. 2022b. Assessment distribution of the phytoplankton community structure at the fishing ground, Banyuasin Estuary, Indonesia. Acta Ecol Sin 42 (6): 670-678. DOI: 10.1016/j.chnaes.2022.02.006.
Rozirwan, Iskandar I, Hendri M, Apri R, Supardi, Azhar N, Mardiansyah W. 2019. Distribution of phytoplankton diversity and abundance in Maspari Island waters, South Sumatera, Indonesia. J Phys: Conf Ser 1282: 012105. DOI: 10.1088/1742-6596/1282/1/012105.
Rozirwan, Khotimah NN, Putri WAE, Fauziyah, Aryawati R, Damiri N, Isnaini, Nugroho RY. 2023a. Environmental risk assessment of Pb, Cu, Zn, and Cd concentrations accumulated in selected mangrove roots and surrounding their sediment. Biodiversitas 24 (12): 6733-6742. DOI: 10.13057/biodiv/d241236.
Rozirwan, Melki, Apri R, Fauziyah, Agussalim A, Hartoni, Iskandar I. 2021. Assessment the macrobenthic diversity and community structure in the Musi Estuary, South Sumatra, Indonesia. Acta Ecol Sin 41 (4): 346-350. DOI: 10.1016/j.chnaes.2021.02.015.
Rozirwan, Nanda, Nugroho RY, Diansyah G, Muhtadi, Fauziyah, Putri WAE, Agussalim A. 2023b. Phytochemical composition, total phenolic content and antioxidant activity of *Anadara granosa* (Linnaeus, 1758) collected from the east coast of South Sumatra, Indonesia. Baghdad Sci J 20 (4): 6. DOI: 10.21123/bsj.2023.6941.
Rozirwan, Ramadani S, Putri WAE, Fauziyah, Khotimah NN, Nugroho RY. 2023c. Evaluation of calcium and phosphorus content in scallop shells (*Placuna placenta*) and blood cockle shells (*Anadara granosa*) from Banyuasin Waters, South Sumatra. Egypt J Aquat Biol Fish 27 (3): 1053-1068. DOI: 10.21608/EJABF.2023.309326.
Sahidin A, Zahidah Z, Herawati H, Wardianto Y, Setyobudiandi I, Partasasmita R. 2018. Macrozoobenthos as bioindicator of ecological status in Tanjung Pasir Coastal, Tangerang District, Banten Province, Indonesia. Biodiversitas 19 (3): 1123-1129. DOI: 10.13057/biodiv/d190347.
Saleh R, Daud A, Ishak H, Amqam H, Wahyu A, Stang, Birawida AB, Mallongi A. 2023. Spatial distribution of microplastic contamination in blood clams (*Anadara granosa*) on the Jeneponto Coast, South Sulawesi. Pharmacogn J 15 (4): 680-690. DOI: 10.5530/pj.2023.15.137.
Samuels W, Awe A, Sparks C. 2024. Microplastic pollution and risk assessment in surface water and sediments of the Zandvlei catchment and estuary, Cape Town, South Africa. Environ Pollut 342: 122987. DOI: 10.1016/j.envpol.2023.122987.

Santucci L, Fernández-Severini MD, Rimondino GN, Colombo CV, Prieto G, Forero-López AD, Carol ES. 2024. Assessment of meso- and microplastics distribution in coastal sediments and waters at the middle estuary of the Rio De La Plata, Argentina (SW Atlantic Ocean). Sci Total Environ 914: 170026. DOI: 10.1016/j.scitotenv.2024.170026.

Sari A, Tuwo A, Saru A, Rani C. 2022. Diversity of fauna species in the mangrove ecosystem of Youtefa Bay Tourism Park, Papua, Indonesia. Biodiversitas 23 (9): 4490-4500. DOI: 10.13057/biodiv/d230915.

Sathish MN, Jeyasanta KI, Patterson J. 2020. Monitoring of microplastics in the clam *Donax cuneatus* and its habitat in Tuticorin coast of Gulf of Mannar (GoM), India. Environ Pollut 266 (Pt 1): 115219. DOI: 10.1016/j.envpol.2020.115219.

Smith M, Love DC, Rochman CM, Neff RA. 2018. Microplastics in seafood and the implications for human health. Curr Environ Health Rep 5 (3): 375-386. DOI: 10.1007/s40572-018-0206-z.

Surbakti H, Nurjaya IW, Bengen DG, Prartono T. 2023. Temporal variation of freshwater as control of mangrove in Banyuasin Estuary, South Sumatra, Indonesia. Biodiversitas 24 (3): 1502-1510. DOI: 10.13057/biodiv/d240320.

Suteja Y, Purwiyanto AIS, Purbonegoro T, Cordova MR. 2024. Spatial and temporal trends of microplastic contamination in surface sediment of Benoa Bay: An urban estuary in Bali-Indonesia. Mar Pollut Bull 202: 116357. DOI: 10.1016/j.marpolbul.2024.116357.

Ta AT, Babel S. 2023. Occurrence and spatial distribution of microplastic contaminated with heavy metals in a tropical river: Effect of land use and population density. Mar Pollut Bull 191: 114919. DOI: 10.1016/j.marpolbul.2023.114919.

Tang C, Li Y, He C, Acharya K. 2020. Dynamic behavior of sediment resuspension and nutrients release in the shallow and wind-exposed Meiliang Bay of Lake Taihu. Sci Total Environ 708: 135131. DOI: 10.1016/j.scitotenv.2019.135131.

Thacharodi A, Meenatchi R, Hassan S, Hussain N, Bhat MA, Arockiaraj J, Ngo HH, Le QH, Pugazhendhi A. 2024. Microplastics in the environment: A critical overview on its fate, toxicity, implications, management, and bioremediation strategies. J Environ Manag 349: 119433. DOI: 10.1016/j.jenvman.2023.119433.

Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, McGonigle D, Russell AE. 2004. Lost at sea: Where is all the plastic? Science 304 (5672): 838. DOI: 10.1126/science.1094559.

Tomlinson DL, Wilson JG, Harris CR, Jeffrey DW. 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgoländer Meeresunters 33: 566-575. DOI: 10.1007/BF02414780.

Truchet DM, López ADF, Ardusso MG, Rimondino GN, Buzzi NS, Malanca FE, Spetter CV, Severini MDF. 2021. Microplastics in bivalves, water and sediments from a touristic sandy beach of Argentina. Mar Pollut Bull 173 (Pt B): 113023. DOI: 10.1016/j.marpolbul.2021.113023.

Ukhrowi HR, Wardhana W, Patria MP. 2021. Microplastic abundance in blood cockle *Anadara granosa* (Linnaeus, 1758) at Lada Bay, Pandeglang, Banten. J Phys: Conf Ser 1725: 012053. DOI: 10.1088/1742-6596/1725/1/012053.

Unuofin JO, Igwaran A. 2023. Microplastics in seafood: Implications for food security, safety, and human health. J Sea Res 194: 102410. DOI: 10.1016/j.seares.2023.102410.

Vital SA, Cardoso C, Avio C, Pittura L, Regoli F, Bebianno MJ. 2021. Do microplastic contaminated seafood consumption pose a potential risk to human health? Mar Pollut Bull 171: 112769. DOI: 10.1016/j.marpolbul.2021.112769.

Wakwella A, Wenger A, Jenkins A, Lamb J, Kuempel CD, Claar D, Corbin C, Falinski K, Rivera A, Grantham HS, Jupiter SD. 2023. Integrated watershed management solutions for healthy coastal ecosystems and people. Camb Prism: Coast Futures 1: e27. DOI: 10.1017/cft.2023.15.

Walker TR, Fequet L. 2023. Current trends of unsustainable plastic production and micro(nano)plastic pollution. TrAC-Trends Anal Chem 160: 116984. DOI: 10.1016/j.trac.2023.116984.

Wang G, Lu J, Li W, Ning J, Zhou L, Tong Y, Liu Z, Zhou H, Xiayihazi N. 2021. Seasonal variation and risk assessment of microplastics in surface water of the Manas River Basin, China. Ecotoxicol Environ Saf 208: 111477. DOI: 10.1016/j.ecoenv.2020.111477.

Wang Y, Wu Y, Pu Q, Sun P, Zhao W, Liu M, Li Y. 2023. Aquatic toxicity of tire microplastics on marine and freshwater organisms: An in silico approach. Chemosphere 313: 137523. DOI: 10.1016/j.chemosphere.2022.137523.

Ward JE, Zhao S, Holohan BA, Mladinich KM, Griffin TW, Wozniak J, Shumway SE. 2019. Selective ingestion and egestion of plastic particles by the blue mussel (*Mytilus edulis*) and eastern oyster (*Crassostrea virginica*): Implications for using bivalves as bioindicators of microplastic pollution. Environ Sci Technol 53 (15): 8776-8784. DOI: 10.1021/acs.est.9b02073.

Winiarska E, Jutel M, Zemelka-Wiacek M. 2024. The potential impact of nano- and microplastics on human health: Understanding human health risks. Environ Res 251 (Pt 2): 118535. DOI: 10.1016/j.envres.2024.118535.

Xu K, Shahab A, Rinklebe J, Xiao H, Li J, Ye F, Li Y, Wang D, Bank MS, Wei G. 2024. Spatial distribution, morphology, and risk assessment of microplastics in sediment from the Pearl River Estuary, China. Emerg Contam 10: 100383. DOI: 10.1016/j.emcon.2024.100383.

Xu P, Peng G, Su L, Gao Y, Gao L, Li D. 2018. Microplastic risk assessment in surface waters: A case study in the Changjiang Estuary, China. Mar Pollut Bull 133: 647-654. DOI: 10.1016/j.marpolbul.2018.06.020.

Xu Q, Xing R, Sun M, Gao Y, An L. 2020. Microplastics in sediments from an interconnected river-estuary region. Sci Total Environ 729: 139025. DOI: 10.1016/j.scitotenv.2020.139025.

Yang X, An C, Feng Q, Boufadel M, Ji W. 2022. Aggregation of microplastics and clay particles in the nearshore environment: Characteristics, influencing factors, and implications. Water Res 224: 119077. DOI: 10.1016/j.watres.2022.119077.

Yuan B, Gan W, Sun J, Lin B, Chen Z. 2023. Depth profiles of microplastics in sediments from inland water to coast and their influential factors. Sci Total Environ 903: 166151. DOI: 10.1016/j.scitotenv.2023.166151.

Yuan Z, Nag R, Cummins E. 2022. Human health concerns regarding microplastics in the aquatic environment-From marine to food systems. Sci Total Environ 823: 153730. DOI: 10.1016/j.scitotenv.2022.153730.

Yulinda E, Saad M, Yusuf M. 2020. A study on the economic potential of blood cockles (*Anadara granosa*) in Rokan Hilir, Riau Province, Indonesia. AACL Bioflux 13 (3): 1504-1510.

Zhang K, Hamidian AH, Tubić A, Zhang Y, Fang JKH, Wu C, Lam PKS. 2021. Understanding plastic degradation and microplastic formation in the environment: A review. Environ Pollut 274: 116554. DOI: 10.1016/j.envpol.2021.116554.

Zhao J, Feng X, Shi X, Bai Y, Yu X, Shi X, Zhang W, Zhang R. 2015. Sedimentary organic and inorganic records of eutrophication and hypoxia in and off the Changjiang Estuary over the last century. Mar Pollut Bull 99 (1-2): 76-84. DOI: 10.1016/j.marpolbul.2015.07.060.

Zhao X, Chen H, Jia Q-L, Shen C-S, Zhu Y, Li L, Nie Y-H, Ye J-F. 2020. Pollution status and pollution behavior of microplastic in surface water and sediment of urban rivers. Huan Jing Ke Xue 41 (8): 3612-3620. DOI: 10.13227/j.hjkx.201912236. [Chinese]

Zheng Y, Li J, Cao W, Jiang F, Zhao C, Ding H, Wang M, Gao F, Sun C. 2020. Vertical distribution of microplastics in bay sediment reflecting effects of sedimentation dynamics and anthropogenic activities. Mar Pollut Bull 152: 110885. DOI: 10.1016/j.marpolbul.2020.110885.

Zhou Z, Zhang P, Zhang G, Wang S, Cai Y, Wang H. 2021. Vertical microplastic distribution in sediments of Fuhe River estuary to Baiyangdian Wetland in Northern China. Chemosphere 280: 130800. DOI: 10.1016/j.chemosphere.2021.130800.