



Journal Homepage: [-www.journalijar.com](http://www.journalijar.com)

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/24221

DOI URL: <http://dx.doi.org/10.21474/IJAR01/24221>



RESEARCH ARTICLE

MACROBENTHOS: BIO-INDICATORS OF AQUATIC POLLUTION AND ECOSYSTEM HEALTH- A SYSTEMATIC REVIEW

Leena N. Meshram

1. Department of Zoology, Mahatma Phule Arts, Science & Commerce College, Panvel, Dist. – Raigad, Navi Mumbai – 410 206, Maharashtra, India.

Manuscript Info

Manuscript History

Received: 14 July 2026

Final Accepted: 16 August 2026

Published: September 2026

Key words:-

Anthropogenic disturbance; Bio-indicators; Ecological health; Macrobenthos; Organic pollution; Water quality

Abstract

Marine ecosystem is facing the threat of degradation due to climate change, eutrophication, physical damage, and pollution. Use of indicator species is a simple, reliable, and effective method to monitor and assess the ecological environment. Due to the sensitivity of indicator species to environmental changes and pollution, they are widely used to monitor environmental changes. Macrobenthos are bottom-dwelling aquatic organisms larger than 0.5 mm, such as worms, molluscs, and crustaceans, that serve as reliable biological indicators of water and sediment quality. Due to their abundance and ease of collection, different tolerance levels, longer life cycles, and sedentary lifestyle; macrobenthos are serving as an ideal bio-indicator of environmental quality, in particular aquatic pollution and ecosystem health. Due to their sedentary lifestyle on the seafloor, they cannot escape local pollution, reflecting spatial changes in their immediate habitat. Their relatively long lifespan enables them to record and integrate the effects of long-term environmental stress over time. Different species of macrobenthos possess distinct sensitivities to pollutants; as a result, sensitive species die off under stress, while opportunistic or tolerant ones thrive. Also, they are widespread, numerous, and large enough to be easily sampled and identified without complex microscopic tracking. Present study involves a comprehensive review of macrobenthos species used for monitoring the aquatic pollution, ecosystem health, and highlight the applications of macrobenthos in bio-monitoring the sustainability of aquatic resources. 59 selected publications span across diverse geographical regions and aquatic environments were referred for the review. The findings suggest that shifts in species composition and diversity indices serve as early warning signals for ecosystem degradation, offering critical insights for policymakers and environmental managers.

"© 2026 by the Author(s). Published by IJAR under CC BY 4.0. Unrestricted use allowed with credit to the author."

Corresponding Author:-Leena N. Meshram

Address:-Department of Zoology, Mahatma Phule Arts, Science & Commerce College, Panvel, Dist. – Raigad, Navi Mumbai – 410 206, Maharashtra, India.

Introduction:-

Benthos refers to the organisms that live on, in, or near the bottom of aquatic environments like lakes, rivers, and oceans. Benthic organisms are classified into different types based on their location relative to the sediment, and size (Kakde and Yeole, 2025). Based on the size, benthos was categorized into meiobenthos (medium-sized organisms between 0.1 mm and 1 mm, e. g. nematodes and copepods), and macrobenthos (organisms larger than 1 mm, e. g. polychaetes, bivalves, gastropods, and crustaceans). On the basis of their position on the substrate, they are divided into infauna (organisms that live buried inside the bottom sediment, e. g. worms, clams, and burrowing crustaceans), and epifauna (organisms that live on top of the sediment surface or attached to substratum, e. g. crabs, starfish, and sponges) (Bhandarkar and Paliwal, 2020).

Macrobenthos are aquatic bottom-dwelling organisms with size ranging from 0.5 mm to 4.0 mm, and retained in a 0.5 mm to 1 mm mesh. They live on (epifauna) or in (infauna) the sediment, mud, sand, or rocks of marine, estuarine, and freshwater beds (Bonne, 2010). Macrobenthos composition is dominated by polychaetes, crustaceans, molluscs, and echinoderms, etc (Yokoyama et al., 2007). They exhibit various feeding modes such as filter-feeders, deposit-feeders, grazers, and predators that process organic matter (Wang et al., 2014). Macrobenthos are highly sensitive to physical and chemical parameters such as sediment grain size, water depth, dissolved oxygen, and organic enrichment (Borja et al., 2000).

Macrobenthos are also referred to as, macro-infauna and macro-endobenthos (Speybroeck, 2007). They live freely in and on the sea bottom, in burrow systems between the sand grains or in self-constructed tubes consisting of sand grains cemented together with slime produced by the animals themselves (Colen, 2009). Generally, the macrobenthos fixes the sediment and ensure a better oxygen distribution in the bottom (Abroguena et al., 2021). The presence of macrofauna also plays an important structural part in the composition of the entire ecosystem of the sea bottom (Anderson et al., 2025).

Benthic communities are important to any aquatic ecosystem and form important food source for most organisms especially fish (Bonne, 2010). They also accelerate the breakdown of decaying organic matter into simpler inorganic forms such as phosphates and nitrates (Barua et al., 2019). The ecological importance of benthic organisms is well known and reflected in nature protection law, as a key biological quality element (Wang et al., 2014). Therefore, analyzing the interaction of benthic diversity with environmental factors is crucial for the fields of ecology where changes in hydrological factors play a decisive role in community structure (Ge et al., 2025).

Bio-indicators are living organisms that indicate the health of the natural ecosystem in the environment (Asif et al., 2018). They are used as tools to assess environmental changes such as chemical, physiological or behavioural nature (Belal, 2019). Bio-indicators are used to monitor the presence of pollution and its effects on ecosystems (Han and Han, 2024). Macrobenthos serve as essential biological indicators for assessing aquatic ecosystem health and water quality because they are sedentary, abundant, and show varying sensitivities to pollution (Singhal et al., 2026).

Macrobenthos exhibit high environmental sensitivity to ecological disturbances, a narrow dispersal range, distinct taxonomic features, longer life cycles and the unique ability to retain specific ecological memories of their habitats (Amri et al., 2014). Therefore, large benthic organisms have become crucial biological indicators for assessing anthropogenic disturbances and are extensively leveraged in the environmental monitoring of estuarine and coastal ecosystems (Anderson et al., 2013; Xue et al., 2025). Hence, macrobenthos have been regarded as key biological indicators of health of aquatic ecosystem due to their direct contact with the sediment and are highly sensitive to changes in physio-chemistry of the environment (Fu et al., 2022).

Macrobenthos, due to their low mobility, relatively fixed habitat, and high vulnerability to environmental changes; are used as a valuable and excellent tool for monitoring aquatic ecosystems (Herman et al., 1999). They are also used as indicator organisms for the biological assessment of water resources and for monitoring of water quality (Li et al., 2023). Macrobenthos are highly sensitive to increasing levels of pollutants, fragmentation, eutrophication, and are influenced by physico-chemical parameters based on species diversity (Pratiwi et al., 2024).

Benthic species play an important role in the food web and the ecosystem; they contribute to the biodiversity and productivity of the sea and act as key indicators of the 'health' of marine systems (Degraer et al., 2006). Macrobenthos provide essential supporting, regulating, and provisioning services that maintain aquatic and coastal health (Fule et al., 2016). They act as vital biological indicators because their community structure, density, diversity, and uniformity reflect ecosystem health and pollution levels (Pawar, 2017; Gupta and Mahrotra, 2020).

Different groups of macrobenthos used as bioindicators of environmental health with respect to clean water, habitat health, long-term heavy metal and chemical accumulation, low oxygen (hypoxia), organic enrichment, organic stress, sediment pollution, and sediment toxicity include: crustaceans (amphipods and small crabs), echinoderms (starfish and sea urchins), gastropods and bivalves (Mussels, clams, and oysters), and polychaete worms (*Capitella capitata* and *Heteromastus filiformis*) (Kim et al., 2023; Anderson et al., 2025).

The present study involves a comprehensive review of various macrobenthos used for monitoring the aquatic pollution and ecosystem health of various aquatic resources. This review article aims to highlight the applications of macrobenthos in bio-monitoring, the sustainability of aquatic resources. It also summarizes the role of benthic macro-invertebrates as bio-indicators to evaluate the water quality of various water bodies using different bio-assessment approaches such as population density, biomass, species composition, and diversity indices.

Materials and Methods: -

Data retrieval was completed with the adoption of detailed searches in electronic databases such as Google Scholar, ScienceDirect, Scopus, and Web of Science. The search terms used for present review included population density, biomass, bio-indicator, species composition, diversity indices, macrobenthos, pollution, etc. 59 selected publications span across diverse geographical regions and aquatic environments were referred for the review.

Key Ecosystem Services provided by Macrobenthos: -

Macrobenthos provide essential ecological functions and play a vital role in maintaining ocean health, energy flow, and chemical balance that support human well-being (Chertopruda et al., 2013). They provide the trophic base for macro-invertebrate assemblages and have either a direct source of primary producers or subsist on suspended or settled organic materials (Gwynne, 2018; Meena et al, 2025).

- **Bait and aquaculture support:** Many benthic species are harvested directly as live or frozen bait for recreational and commercial fisheries (Sukumaran et al., 2021).
- **Bio-geochemical fluxes:** Burrowing activities alter sediment structure, oxygen penetration, and gas exchange at the sediment-water interface (Li et al., 2022).
- **Environmental bio-indicators:** The population health and diversity of macrobenthos reflect long-term pollution levels, organic enrichment, and overall ecosystem stress (Priyadarshini et al., 2026).
- **Food supply and seafood stocks:** Edible bivalves (clams, oysters, mussels) and crustaceans (crabs, lobsters, shrimp) represent a major source of global seafood and local coastal protein (Geetha et al., 2010).
- **Food web support:** Macrobenthos serve as primary energy sources for fish, birds, and larger aquatic life (Kakde and Yeole, 2025).
- **Genetic and biochemical resources:** Benthic organisms are explored for novel biochemical compounds, natural pharmaceuticals, and genetic resources (Pavithran et al., 2009).
- **Nutrient cycling:** Break down organic matter and cycle nutrients (nitrogen, phosphorus) through bio-turbation (Sukumaran et al., 2013).
- **Raw materials and commercial goods:** Shells and hard parts of macrobenthic organisms are utilized for building materials, lime production, decorative crafts, and local jewelry (Kim et al., 2023).
- **Sediment stabilization:** Physical presence and activities of benthic assemblages help stabilize bottom sediments, reducing re-suspension and influencing local boundary-layer hydrodynamics (Shi et al., 2014).
- **Water quality and bio-filtration:** Filter-feeding macrobenthos (bivalves and certain polychaetes) remove suspended particulate matter, phytoplankton, and excess anthropogenic nutrients from the water column, improving water clarity and mitigating eutrophication (Culp et al., 2018).

Macrobenthos: Bio-indicators of Aquatic Pollution and Ecosystem Health:-

Worldwide, several studies have been conducted to assess the aquatic pollution and ecosystem health using the macrobenthos. (Parmar et al., 2016). Many investigators have used the macrobenthos as bio-indicator/natural indicator of the environmental pollution (Rashid and Pandit, 2014) (Table 1). Using macrobenthos for health assessment of aquatic ecosystem is a well-established approach, as they are affected by a wide range of stressors that reflect the effects of pollution conditions and changes in habitat and hydrological conditions (Shreya et al., 2022). Key marine macrobenthos taxa widely used as bio-indicators include opportunistic polychaetes, bivalves, gastropods, crustaceans, echinoderms, etc (Orozco-González and Ocasio-Torres, 2023).

Macrobenthos signal the environmental conditions such as changes in intertidal and estuarine health; chemical contamination; disturbed soft-bottom sediments; heavy organic pollution; hypoxia; and stable, unpolluted marine

and sub-tidal conditions (Kawnsner et al., 2007). Macrobenthos respond to the environmental conditions by behavioral changes (changes in feeding activities, bacterial mobility or web spinning); or by ecological changes (changes in population density, key species and species diversity), or by physiological changes (accumulation of heavy metal, CO₂ production, BOD and microbial activity) (Manickavasagam et al., 2019).

Table 1. Macrobenthos as the bio-indicators of environmental pollution

Study area	Matrices assessed	Macrobenthos as bio-indicator	Reference
Basque coast-line (North of Spain)	Water quality, richness, abundance, numerical diversity	Soft-bottom benthos	Borja et al., 2000
Virginian Biogeographic Province	Biodiversity, community condition, functional organization, taxonomic composition	Red worm (<i>Limnodrilushoffmeisteri</i>) Ram's horn worm (<i>Streblospio benedicti</i>)	Paul et al., 2001
Sungai Pulai estuary, Johor, Malaysia	Macrobenthos composition, distribution and abundance	Polychaete: Families Spionidae, Capitellidae, Glyceridae	Shi et al., 2014
Puducherry Coast, Southeast Coast of India	Physico-chemical parameters, sediment texture, benthic diversity	Polychaetes (<i>Eunice indica</i>) Bivalves (<i>Anadara granosa</i>) Gastropods (<i>Bullia vitata</i>) Decapod (<i>Emerita asiatica</i>)	Balachandar et al., 2016
Awerange Gulf, South Sulawesi, Indonesia	Environmental disturbance by fish farming activities	Dog whelks (<i>Nassarius castus</i>) Northern dwarf-tellin (<i>Ameritella agilis</i>), Screw shell (<i>Turritella</i> sp.)	Putro et al., 2017
Suez Bay, Gulf of Suez, Egypt	Water and sediment quality	Polychaeta: <i>Chaetozonesetosa</i> , Gastropoda: <i>Diodora ruppellii</i> , Bivalvia: <i>Gafrarium pectinatum</i> , Crustacea: <i>Mareotis depressus</i> , Echinodermata: <i>Astropecten polyacanthus</i>	Belal, 2019
South-Eastern Coastal Area, Bangladesh	Physico-chemical Parameters	Polychaetes, Oligochaetes, Bivalves, Crabs, etc.	Barua et al., 2019
Citarik River, West Java	Pollution status	<i>Progomphus</i> sp., <i>Enallagma</i> sp., <i>Lumbriculus</i> sp., <i>Melanoides</i> sp., <i>Lymnaea</i> sp., <i>Libellula</i> sp., <i>Ranatra</i> sp.	Herawati et al., 2020
Mossa creek, Iran	Industrial pollution	Clam worm (<i>Lycastopsis</i> sp.) Leech (<i>Apseudes</i> sp.)	Taybeh and Amiri 2010
Ganjiang River System, China	Aquatic Ecosystem Health	Asian clam (<i>Corbicula fluminea</i>) Red worm (<i>Limnodrilushoffmeisteri</i>)	Huang et al., 2022
Northern Yantai, China	Community structure and ecological quality of macrobenthos	Amphipods (suborder Gammaridea) as indicators for environmental remediation efforts.	Li et al., 2022
Cochin estuary, India	Ecological habitat quality assessment	Polychaetes: <i>Prionospio cirrifera</i> , <i>Cirratulus filiformis</i> , <i>Sigambra parva</i> , <i>Nephtys oligobranchia</i>	Thekkendavida et al., 2022
Lagos Lagoon, Nigeria	Environmental variables, microbiological quality, sediment properties	Nereis spp, Acorn barnacle (<i>Fistubalanus pallidus</i>) Mangrove hermit crab (<i>Clibanarius africanus</i>)	Adesakin et al., 2023
Rawang sub-basin, Selangor River, Malaysia	Organic Contamination	Macrobenthos from families: Baetidae, Chironomidae, Curbicullidae, Hydropchysidae, Libellulidae, Lumbriculiade, Naididae, Protoneuridae, and Tubificidae	Hettige et al., 2023
Huanghe River (Yellow River)	Taxonomic diversity of the macrobenthos and	<i>Glycinde bonhourei</i> , <i>Sternaspisscutata</i> , <i>Moerella hiliaris</i> , <i>Liljeborgia serrata</i> ,	Li et al., 2023

estuary, China	environmental factors	<i>Iphinoetenera</i> , <i>Lineus sp.</i>	
Gulf of Finland	Polychaete/Amphipod Ratio	Spionidpolychaete (<i>Marenzelleriaarctica</i>), Pontoporeiid amphipod (<i>Monoporeiaaffinis</i>)	Maximov and Berezina, 2023
The Lapa River, Puerto Rico	Water quality	Macro-invertebrates from families Calamoceratidae, Elmidae, Leptophlebiidae, Libellulidae, Thiaridae, and Veliidae	Orozco- González and Ocasio-Torres, 2023
Coastal waters of Malaysia	Water quality and Community structure	Annelida, Bivalvia, Crustacea, Decapoda, Echinodermata, Gastropoda, Oligochaete, Polychaetes	Chowdhury et al., 2024
Coast of Ghana	Water quality	Polychaeta (<i>Notomastus sp.</i>) Crustacea (<i>Penaeus sp.</i>) Gastropoda (<i>Pachymelania sp.</i>)	Dorothy et al., 2024
Citarum River, West Java, Indonesia	Effect of land use type	<i>Lumbriculus sp.</i> , <i>Hydrobius sp.</i> , <i>Pomaceasp.</i> , <i>Filopaludinasp.</i>	Pratiwi et al., 2024
Ulungu River Basin (Northwest China)	Water quality	Aquatic bugs, Midges, Mayflies	Song et al., 2024
Yuqu River Basin of the Tibet Autonomous Region of China	Relationship among macrobenthos communities with environmental factors	<i>Limecolabalthica</i> , <i>Marenzelleriaspp.</i> , <i>Monoporeiaaffinis</i>	Ge et al., 2025
Brantas River, Blitar, Indonesia	Water quality	Macrozoobenthos: Amphipterygidae, Baetidae, Chironomidae, Planorbidae, Thiaridae	Wahyu et al., 2025
Rushikulya Estuary, Ganjam district, Odisha, India	Macrobenthos and their relationship with environmental drivers	Nereids: <i>Namalycastis indica</i> , Gastropods: <i>Pirenella cingulata</i> , Venerid bivalve: <i>Meretrix casta</i> Brachiopod: <i>Lingula sp.</i> Amphipods: <i>Orchestoideasp.</i>	Priyadarshini et al., 2026

According to available literature, the study attempts to provide a comprehensive review of use of macrobenthos as bio-indicators of environmental health. Ecological aspects of macrobenthos such as abundance, community condition, distribution, diversity indices, functional organization, species diversity, and taxonomic composition were used for monitoring the environmental variables (water quality, microbiological quality, sediment properties, and organic contamination) (Paul et al, 2001; Putro et al, 2017; Taybeh and Amiri, 2010; Adesakin et al, 2023). Also, relationship among the macrobenthos communities with environmental drivers supports the concept of macrobenthos as of aquatic pollution and environmental health (Pratiwi et al, 2024; Ge et al, 2025; Priyadarshini et al, 2026).

Conclusion:-

The findings based on the macrobenthos as bio-indicator reveal relationship among taxonomic diversity of the macrobenthos and environmental factors. Macro-benthic invertebrates are helpful bio-indicators providing accurate understanding for adjusting aquatic conditions than chemical and microbiological information, by giving short-term fluctuations. Macro-benthic community structure, abundance, and distribution are typically affected by water and sediment quality. Therefore, in recent years, use of macrobenthos as indicator species have received significant attention from ecologists.

Acknowledgements:-

The author expresses her gratitude to Hon. Prin. Dr. Ganesh Thakur, Principal, Mahatma Phule Arts, Science & Commerce College, Panvel, Dist. Raigad, for encouragement and support. The author is thankful to the Head, Department of Zoology, for providing the necessary facilities.

References:-

1. Abroguena, J.B.R., Joydas, T.V., Pappathy, M., et al. (2021). Structure and composition of the macrobenthic community associated to shallow mangrove-seagrass habitat along the southern Red Sea coast, Saudi Arabia. *Egyptian Journal of Aquatic Research*, 47, 61–66. <https://doi.org/10.1016/j.ejar.2020.10.001>.
2. Adesakin, T.A., Erhomosele, E.I., et al. (2023). Using benthic macroinvertebrates as bioindicators to evaluate the impact of anthropogenic stressors on water quality and sediment properties of a West African lagoon. *Heliyon*, 9, e19508. <https://doi.org/10.1016/j.heliyon.2023.e19508>.
3. Amri, N., Jamili, S., & Abdolbaghian, S. (2014). Diversity of macrobenthos communities and their relationships with environmental factors in Jajroud River, Iran. *Resources and Environment*, 4(2), 95–103. <https://doi.org/10.5923/j.re.20140402.03>.
4. Anderson, M.P.B.C., Reid, W.D.K., Bohrmann, G., Dohrmann, I., Hollyman, P.R., et al. (2025). The abundance, diversity, and assemblage structure of the macrobenthos at the South Georgia shelf methane seeps. *Frontiers in Marine Science*, 12, 1589660. <https://doi.org/10.3389/fmars.2025.1589660>.
5. Anderson, T.J., MacDiarmid, A., & Stewart, R. (2013). Benthic habitats, macrobenthos and surficial sediments of the nearshore South Taranaki Bight. NIWA Client Report No. NEL2013-012. NIWA.
6. Asif, N., Malik, M.F., & Chaudhry, F.N. (2018). A review of environmental pollution. *Pollution*, 4(1), 111–118. <https://doi.org/10.22059/poll.2017.237440.296>.
7. Balachandar, K., Sundaramanickam, A., & Kumaresan, S. (2016). Spatial and seasonal variation of macrobenthos from Puducherry Coast, southeast coast of India. *International Journal of Current Microbiology and Applied Sciences*, 5(10), 33–49. <https://doi.org/10.20546/ijemas.2016.510.006>.
8. Barua, P., Meah, M.M., & Rahman, S.H. (2019). Abundance of macrobenthos with special reference to some physico-chemical parameters of south-eastern coastal area, Bangladesh. *Asian Journal of Water, Environment and Pollution*, 16(4), 51–60. <https://doi.org/10.3233/AJW190048>.
9. Belal, A.A.M. (2019). Macro-benthic invertebrates as a bio-indicator for water and sediment quality in Suez Bay, Red Sea. *Egyptian Journal of Aquatic Research*, 45, 123–130. <https://doi.org/10.1016/j.ejar.2019.03.003>.
10. Bhandarkar S V, G T Paliwal. Short Notes on Types of Benthic Invertebrates. *Limnology*. Bhumi Publishing, India. 2020. pp. 25-32. (ISBN: 978-93-88901-01-7)
11. Bonne, W. (2010). Macrobenthos characteristics and distribution, following intensive sand extraction from a subtidal sandbank. *Journal of Coastal Research*, Special Issue 51, 141–150. <https://doi.org/10.2112/SI51-013.1>.
12. Borja, A., Franco, J., & Pérez, V. (2000). A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. *Marine Pollution Bulletin*, 40(12), 1100–1114. [https://doi.org/10.1016/S0025-326X\(00\)00061-8](https://doi.org/10.1016/S0025-326X(00)00061-8).
13. Chertoprud, M.V., Chertoprud, E.S., Saravanakumar, A., Thangaradjoub, T., & Mazei, Y.A. (2013). Macrobenthic communities of the Vellar Estuary in the Bay of Bengal in Tamil Nadu in South India. *Oceanology*, 53(2), 225–236. <https://doi.org/10.1134/S0001437013010049>.
14. Chowdhury, A.J.K., John, A., Nurul Syaza Aqilah, et al. (2024). Macrobenthic community towards sustainable aquatic ecosystem: a systematic review along the coastal waters of Malaysia. *Geology, Ecology, and Landscapes*, 8(1), 57–70. <https://doi.org/10.1080/24749508.2022.2095088>.
15. Van Colen, C. (2009). Tidal flat macrobenthos ecology, recolonisation and succession. PhD thesis, Ghent University, Belgium. 300 pp. ISBN 978-90-902416-6-1.
16. Culp, J.M., Glozier, N.E., Baird, D.J., Baird, W., Wrona, F.J., et al. (2018). Assessing ecosystem health in benthic macroinvertebrate assemblages of the Athabasca River main stem, tributaries, and Peace-Athabasca Delta. *Oil Sands Monitoring Technical Report Series No. 1.7*.
17. Degraer, S., Wittoeck, J., Appeltans, W., Cooreman, K., et al. (2006). The Macrobenthos Atlas of the Belgian Part of the North Sea. Belgian Science Policy, Brussels. 164 pp.
18. Dorothy, K.L., Mensah, P.K., Asare, N.K., et al. (2024). Benthic macroinvertebrates as indicators of water quality: A case study of estuarine ecosystems along the coast of Ghana. *Heliyon*, 10, e28018. <https://doi.org/10.1016/j.heliyon.2024.e28018>.
19. Fu, X., Yang, W., Zheng, L., Liu, D., & Li, X. (2022). Spatial patterns of macrobenthos taxonomic and functional diversity throughout the ecotones from river to lake: A case study in Northern China. *Frontiers in Ecology and Evolution*, 10, 922539. <https://doi.org/10.3389/fevo.2022.922539>.
20. Fule, U.W., Nimgare, S.S., & Telkhade, P.M. (2016). Studies of macrobenthos in Sarangpuri Lake, Dist. Wardha (M.S.). *International Journal of Research in Bioscience, Agriculture and Technology*, IV(2), 11–13. VERIFY journal metadata.
21. Ge, J., Chen, J., Zi, F., Song, T., Hu, L., He, Z., Wu, L., Ding, Y., & Li, H. (2025). Seasonal variations in macrobenthos communities and their relationship with environmental factors in the Alpine Yuqu River. *Biology*, 14, 120. <https://doi.org/10.3390/biology14020120>.

22. Geetha, P.N., Thasneem, T.A., & Nandan, S.B. (2010). Macrobenthos and its relation to ecosystem dynamics in the Cochin Estuary. In LAKE 2010: Wetlands, Biodiversity and Climate Change, 22–24 December 2010, pp. 1–12. VERIFY proceedings details.
23. Gupta, S., & Mahrotra, P. (2020). Bio-monitoring and use for aquatic ecosystem. In J. Zaidi & A.H. Khan (Eds.), Current Research Trends in India, pp. 2–17. VERIFY publisher/editor metadata.
24. Gwynne, S.R. (2018). Ecosystem services provided by benthic macroinvertebrate assemblages in marine coastal zones. IntechOpen. <https://doi.org/10.5772/intechopen.73150>.
25. Han, W., & Han, Q. (2024). Macrobenthic indicator species: From concept to practical applications in marine ecology. Global Ecology and Conservation, 55, e03262. <https://doi.org/10.1016/j.gecco.2024.e03262>.
26. Herawati, H., Patria, E., Hamdani, H., & Rizal, A. (2020). Macrozoobenthos diversity as a bio-indicator for the pollution status of Citarik River, West Java. IOP Conference Series: Earth and Environmental Science, 535, 012008. <https://doi.org/10.1088/1755-1315/535/1/012008>.
27. Herman, P.M.J., Middelburg, J.J., van de Koppel, J., & Heip, C.H.R. (1999). Ecology of estuarine macrobenthos. Advances in Ecological Research, 29, 195–240. VERIFY final page range against publisher record.
28. Hettige, N.D., Hashim, R., Kutty, A.A., & Ashaari, Z.H. (2023). A new model for organic contamination assessments using benthic macroinvertebrates as biological indicators. Turkish Journal of Fisheries and Aquatic Sciences, 23(8), TRJFAS22423. <https://doi.org/10.4194/TRJFAS22423>.
29. Huang, X., Xu, J., Liu, B., Guan, X., & Li, J. (2022). Assessment of aquatic ecosystem health with indices of biotic integrity (IBIs) in the Ganjiang River System, China. Water, 14, 278. <https://doi.org/10.3390/w14030278>.
30. Kakde, S.P., & Yeole, S.M. (2025). Biodiversity and ecological roles of benthic fauna in freshwater aquatic habitats. International Journal of Scientific Development and Research, 10(4), 628–635. VERIFY.
31. Yaqoob, K., Wani, S.A., & Pandit, A.K. (2007). A comparative study of macrobenthic community in Dal and Nilnag lakes of Kashmir Himalaya. Journal of Himalayan Ecology and Sustainable Development, 2, 55–60.
32. Kim, S.L., Kang, S.M., Lee, H.G., Han, G.H., & Yu, O.H. (2023). Species diversity and community structure of macrobenthos in the Ulleung Basin, East Sea, Republic of Korea. Journal of Marine Science and Engineering, 11, 92. <https://doi.org/10.3390/jmse11010092>.
33. Li, F., Ma, Y., Song, X., Li, S., Zhang, X., Wang, X., Wang, T., & Sun, Z. (2022). Community structure and ecological quality assessment of macrobenthos in the coastal sea areas of Northern Yantai, China. Frontiers in Marine Science, 9, 989034. <https://doi.org/10.3389/fmars.2022.989034>.
34. Li, S., Zhang, X., Su, H., Chen, S., Chen, W., et al. (2023). Taxonomic diversity of the macrobenthos and its relationship with environmental factors in the Huanghe River (Yellow River) estuary and adjacent seas, China. Journal of Sea Research, 194, 102402. <https://doi.org/10.1016/j.seares.2023.102402>.
35. Manickavasagam, S., Sudhan, C., Bharathi, A.S., & Aanand, S. (2019). Bioindicators in aquatic environment and their significance. Journal of Aquaculture in the Tropics, 34(1), 73–79. <https://doi.org/10.32381/JAT.2019.34.01.6>.
36. Maximov, A.A., & Berezina, N.A. (2023). Benthic opportunistic polychaete/amphipod ratio: An indicator of pollution or modification of the environment by macroinvertebrates? Journal of Marine Science and Engineering, 11, 190. <https://doi.org/10.3390/jmse11010190>.
37. Meena, D.K., Das, B.K., Rathod, S.K., et al. (2025). Macrobenthic communities as sentinels of freshwater ecosystem health: A systematic review. International Aquatic Research. <https://doi.org/10.22034/IAR.2025.2009583.1928>.
38. Orozco-González, C.E., & Ocasio-Torres, M.E. (2023). Aquatic macroinvertebrates as bioindicators of water quality: A study of an ecosystem regulation service in a tropical river. Ecologies, 4, 209–228. <https://doi.org/10.3390/ecologies4020015>.
39. Parmar, T.K., Rawtani, D., & Agrawal, Y.K. (2016). Bioindicators: The natural indicator of environmental pollution. Frontiers in Life Science, 9(2), 110–118. <https://doi.org/10.1080/21553769.2016.1162753>.
40. Paul, J.F., Scott, K.J., Campbell, D.E., et al. (2001). Developing and applying a benthic index of estuarine condition for the Virginian Biogeographic Province. Ecological Indicators, 1, 83–99. [https://doi.org/10.1016/S1470-160X\(01\)00010-3](https://doi.org/10.1016/S1470-160X(01)00010-3).
41. Pavithran, S., Ingole, B.S., Nanajkar, M., Raghukumar, C., Nath, B.N., & Valsangkar, A.B. (2009). Composition of macrobenthos from the Central Indian Ocean Basin. Journal of Earth System Science, 118(6), 689–700. <https://doi.org/10.1007/s12040-009-0051-4>.
42. Pawar, P.R. (2017). Macrobenthos from coastal zones of Uran, India: A comprehensive species list with local distribution and photographs. Research Journal of Pharmacy, Biological and Chemical Sciences, 8(4), 1066–1085. VERIFY DOI/indexing.

43. Pratiwi, D., Sumiarsa, D., Oktavia, D., Fatharani, R.H., & Sunardi. (2024). Effect of land use type on macrobenthos assemblages, distribution, and functional guild in Upstream Citarum River. *Ecological Indicators*, 160, 111849. <https://doi.org/10.1016/j.ecolind.2024.111849>.
44. Priyadarshini, P., Bellerby, R.G.J., Lakra, R.K., Behera, R., & Raut, D. (2026). Macrobenthos and their relationship with environmental drivers in Rushikulya, an Olive Ridley turtle rookery-associated tropical estuary. *Frontiers in Marine Science*, 13, 1788896. <https://doi.org/10.3389/fmars.2026.1788896>.
45. Putro, S.P., Fuad, M., Amalia, A., Widowati, & Suhartana. (2017). The roles of macrobenthic mollusks as bio-indicator in response to environmental disturbance: Cumulative k-dominance curves and bubble plots ordination approaches. *IOP Conference Series: Earth and Environmental Science*, 55, 012022. <https://doi.org/10.1088/1755-1315/55/1/012022>.
46. Rashid, R., & Pandit, A.K. (2014). Macroinvertebrates (oligochaetes) as indicators of pollution: A review. *Journal of Ecology and the Natural Environment*, 6(4), 140–144. <https://doi.org/10.5897/JENE2014.0443>.
47. Shi, G.W., Lee, D.M., Mazlan, A.G., et al. (2014). Macrobenthos composition, distribution and abundance within Sungai Pulai estuary, Johor, Malaysia. *AIP Conference Proceedings*, 1614, 591–596. <https://doi.org/10.1063/1.4895269>.
48. Shreya, R., Canciyal, J., Supriti, B., Trupti, R.M., Archisman, R., Manisha, B., et al. (2022). Macrobenthic pollution bio-indicator for ecological monitoring in riverine ecosystem. *International Journal of Environmental Sciences & Natural Resources*, 29(5), 556273. <https://doi.org/10.19080/IJESNR.2022.29.556273>.
49. Singhal, S., Srivastava, A., & Verma, J. (2026). Benthic macroinvertebrates as bioindicators of aquatic health: A review and comparative analysis of diversity indices for water quality assessment. *Aquatic Life and Ecosystems*, 2(2), 9. <https://doi.org/10.53941/ale.2026.100009>.
50. Song, Y., Huo, Q., Zi, F., Ge, J., Qiu, X., Yun, L., Serekbol, G., Yang, L., Wang, B., & Chen, S. (2024). Macrobenthic community structure and water quality evaluation in Ulungu River Basin (Northwest China). *Water*, 16, 918. <https://doi.org/10.3390/w16070918>.
51. Speybroeck, J. (2007). Ecology of macrobenthos as a baseline for an ecological adjustment of beach nourishment. PhD thesis, Ghent University, Belgium. 189 pp.
52. Sukumaran, S., Vijapure, T., Mulik, J., & Ridha, H. (2021). Marine macrobenthos of Northwest India—reviewing the known and unknown. *Frontiers in Marine Science*, 8, 671245. <https://doi.org/10.3389/fmars.2021.671245>.
53. Sukumaran, S., Vijapure, T., Mulik, J., Rokade, M.A., & Gajbhiye, S.N. (2013). Macrobenthos in anthropogenically influenced zones of a coralline marine protected area in the Gulf of Kachchh, India. *Journal of Sea Research*, 76, 39–49. <https://doi.org/10.1016/j.seares.2012.11.001>.
54. Taybeh, T., & Amiri, F. (2010). The impact of industrial pollution on macrobenthic fauna communities. *African Journal of Environmental Science and Technology*, 4(9), 547–557. <https://doi.org/10.5897/AJEST09.070>.
55. Thekkendavida, V.R., Gopinath, V., & Nikathithara, V.M. (2022). Ecological habitat quality assessment of a tropical estuary using macrobenthic functional characteristics and biotic indices. *Environmental Science and Pollution Research*, 29(31), 47629–47646. <https://doi.org/10.1007/s11356-022-19295-8>.
56. Isoni, W., Mamat, N.B., Kurniawan, A., Fuad, Maulida, N., Bahri, A.S., & Aji, B.P. (2025). Assessment of water quality in the Upper Brantas River using macrozoobenthos as bioindicators. *International Journal of Design & Nature and Ecodynamics*, 20(6), 1419–1426. <https://doi.org/10.18280/ijdne.200622>.
57. Wang, J., Lin, H., He, X., Lin, J., Huang, Y., et al. (2014). Biodiversity and community structural characteristics of macrobenthos in the Chukchi Sea. *Acta Oceanologica Sinica*, 33(6), 82–89. <https://doi.org/10.1007/s13131-014-0492-8>.
58. Xue, X., Yun, L., Sun, Z., Zan, J., Xu, X., Liu, X., Gao, S., Wang, G., Liu, M., & Si, F. (2025). Community structure and influencing factors of macrobenthos in bottom-seeded marine pastures: A case study of Caofeidian, China. *Biology*, 14(7), 901. <https://doi.org/10.3390/biology14070901>.
59. Yokoyama, H., Nishimura, A., & Inoue, M. (2007). Macrobenthos as biological indicators to assess the influence of aquaculture on Japanese coastal environments. In T.M. Bert (Ed.), *Ecological and Genetic Implications of Aquaculture Activities* (pp. 407–423). Springer. https://doi.org/10.1007/978-1-4020-6148-6_22.