

Macrobenthos: Bio-indicators of Aquatic Pollution and Ecosystem Health- A Systematic Review.

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 seafloor, they cannot escape local pollution, reflecting spatial changes in their immediate habitat. Their extended lifespan compared allows them to record 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.

Keywords:

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

1. Introduction

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 behavioral 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).

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.

2. 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. Search concepts included macrobenthos, bio-indicator/bioindicator, population density, biomass, species composition, diversity indices, pollution, water quality, sediment quality, and ecosystem health. The search strategy was designed to identify studies in which benthic macroinvertebrates were used to characterize aquatic environmental condition. A total of 58 articles were selected for review.

3. 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).

4. 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 as (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 marinemacrobenthostaxawidely 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 (Kawnser 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>Limnodriushoffmeisteri</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>Anadaragranosa</i>) Gastropods (<i>Bulliavitata</i>) Decapod (<i>Emerita asiatica</i>)	Balachandar et al., 2016
Awerange Gulf, South Sulawesi, Indonesia	Environmental disturbance by fish farming activities	Dog whelks (<i>Nassariuscastus</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>Gafrariumpectinatum</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	Progomphus sp., Enallagma sp., Lumbriculus sp., Melanoides sp., Lymnaea sp., Libellula sp., Ranatra 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>	Thekkendavi da 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) estuary, China	Taxonomic diversity of the macrobenthos and environmental factors	<i>Glycinde bonhourei</i> , <i>Sternaspisscutata</i> , <i>Moerella hilaris</i> , <i>Liljeborgia serrata</i> , <i>Iphinoetenera</i> , <i>Lineus</i> sp.	Li et al., 2023
Gulf of Finland	Polychaete/Amphipod Ratio	Spionid polychaete (<i>Marenzelleria arctica</i>), Pontoporeiid amphipod (<i>Monoporeia affinis</i>)	Maximov and Berezina, 2023
The Lapa River, Puerto Rico	Water quality	Macroinvertebrates 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</i> sp.) Crustacea (<i>Penaeus</i> sp.) Gastropoda (<i>Pachymelania</i> sp.)	Dorothy et al., 2024
Citarum River, West Java, Indonesia	Effect of land use type	<i>Lumbriculus</i> sp., <i>Hydrobius</i> sp., <i>Pomacea</i> sp., <i>Filopaludina</i> sp.	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>Marenzelleria</i> spp., <i>Monoporeia affinis</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,	Macrobenthos and their relationship with	Nereids: <i>Namalycastis indica</i> , Gastropods: <i>Pirenella cingulata</i> ,	Priyadarshini et al., 2026

Odisha, India	environmental drivers	Venerid bivalve: <i>Meretrix casta</i> Brachiopod: <i>Lingula</i> sp. Amphipods: <i>Orchestoidea</i> sp.	
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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).

4. 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.

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