

Freshwater Meiobenthos And Benthic Macroinvertebrates of Maharashtra, India: Diversity, Distribution, Ecological Significance and Environmental Implications—A Review

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Abstract

Freshwater benthic communities constitute an essential biological component of rivers, streams, lakes, reservoirs, wetlands and irrigation systems. In Maharashtra, a large network of river basins and artificial water bodies creates a wide range of sedimentary and substrate-associated habitats, yet the biodiversity and ecological functioning of their meiobenthic and benthic macroinvertebrate communities remain incompletely documented. This review synthesizes available evidence on freshwater meiobenthos and benthic macroinvertebrates with particular emphasis on Maharashtra and, where state-level evidence is sparse, uses relevant Indian studies to place Maharashtra observations in a broader context. Meiobenthos occupy the interstitial sediment environment and include nematodes, rotifers, gastrotrichs, harpacticoid copepods, ostracods, tardigrades and other small metazoans. Benthic macroinvertebrates include aquatic insects, molluscs, annelids and crustaceans. Together, these communities contribute to organic-matter decomposition, nutrient regeneration, sediment bioturbation, microbial regulation and trophic transfer to fishes and other consumers. Their community structure responds to sediment grain size, organic matter, dissolved oxygen, current velocity, water temperature, nutrients, aquatic vegetation and anthropogenic disturbance. Maharashtra studies from western districts, the Godavari basin, Wainganga-associated systems, Chandrapur and Yavatmal demonstrate substantial local diversity, but also reveal strong geographic and taxonomic gaps. Recent work elsewhere in India confirms that macroinvertebrate-based assessment can complement physicochemical monitoring, while international freshwater biomonitoring literature stresses the need for harmonized sampling and taxonomic protocols. The review identifies pollution, eutrophication, sedimentation, flow regulation, habitat alteration, agricultural runoff, urbanization and climate-related hydrological changes as major pressures. It concludes that Maharashtra requires a standardized, basin-wide and long-term benthic biodiversity programme integrating conventional taxonomy, functional traits, physicochemical measurements, sediment quality, DNA-based methods and spatial analysis. Such a framework would strengthen freshwater conservation, ecological restoration, fisheries management and evidence-based water-quality assessment.

Keywords: Freshwater benthos; meiobenthos; meiofauna; benthic macroinvertebrates; Maharashtra; freshwater biodiversity; bioindicators; biomonitoring; aquatic pollution; ecological health; sediment ecology; conservation

Introduction

Freshwater ecosystems occupy a relatively small fraction of the Earth's surface but support disproportionately high biological diversity and provide essential ecosystem services. Rivers, streams, lakes, wetlands and reservoirs regulate water availability, sustain fisheries, recycle nutrients and provide habitat for numerous organisms. Biological communities living on or within sediments are especially important because the sediment-water interface is a major zone of organic-matter transformation, microbial activity and nutrient exchange. Benthic organisms also provide an important pathway by which energy produced or deposited at lower trophic levels becomes available to fishes and other consumers (Wallace & Webster, 1996; Rosenberg & Resh, 1993).

Benthic macroinvertebrates have long been used in freshwater assessment because their relatively limited mobility, varied environmental tolerances and integration of environmental conditions over time allow them to reveal ecological stress that may not be captured by a single chemical measurement. International biomonitoring programmes have consequently developed taxonomic, diversity, tolerance, functional and multimetric approaches for assessing ecological condition (Bonada et al., 2006; Hering et al., 2004; Rosenberg & Resh, 1993). More recent global assessments have emphasized that the effectiveness of these approaches depends on standardized sampling, consistent taxonomic resolution and regionally appropriate metrics (Cantonati et al., 2024).

Meiobenthos or meiofauna represent a smaller size fraction of sediment-associated organisms. Although the operational definition depends on sieve size, meiofauna generally occupy the size range between microfauna and macrobenthos. Freshwater meiofauna can be taxonomically diverse and ecologically important, yet they have received much less attention than macroinvertebrates. Recent syntheses show that meiofauna participate in decomposition, microbial grazing and energy transfer and can serve as sensitive indicators of environmental change (Schmid-Araya et al., 2020; Majdi et al., 2020; Balsamo et al., 2022).

Maharashtra is especially suitable for an integrated benthic review because the state includes portions of the Western Ghats, the Deccan Plateau and several major drainage systems, including the Godavari, Krishna, Bhima, Tapi and Wainganga basins. Large reservoirs and irrigation networks have further increased the range of lentic and semi-lotic habitats. Published studies have demonstrated local benthic diversity in western Maharashtra, Chandrapur, Yavatmal and other regions, but there is no unified state-level inventory. The present review therefore brings together Maharashtra-specific evidence with carefully selected Indian and international literature to develop a framework for future biodiversity assessment and biomonitoring.

Literature Search and Review Methodology

A narrative evidence-synthesis approach was adopted to review the available literature on freshwater meiobenthos and benthic macroinvertebrates, with particular emphasis on Maharashtra, India. The review focused on published information concerning taxonomic diversity, distribution, habitat associations, community structure, ecological functions, environmental controls, pollution responses, biomonitoring and conservation of sediment-associated freshwater fauna. Maharashtra-specific studies were given priority in order to establish the present state of knowledge within the region, while studies from other parts of India and relevant international literature were examined to provide ecological and methodological context where information from Maharashtra was limited.

The review considered peer-reviewed research articles, review papers, authoritative taxonomic and ecological publications, methodological protocols, governmental reports and selected institutional documents containing verifiable information on freshwater benthic communities. Studies were considered particularly relevant when they provided information on species or higher-taxon composition, abundance, diversity indices, habitat characteristics, physicochemical conditions, sediment properties, pollution gradients or biological assessment. Literature dealing exclusively with marine environments was not considered part of the freshwater evidence base. However, selected estuarine and coastal meiofaunal studies were consulted where they provided useful methodological or ecological information relevant to understanding meiobenthic communities. Such studies were interpreted separately and were not used as direct evidence of inland freshwater biodiversity in Maharashtra.

Particular attention was given to studies conducted in the major freshwater systems of Maharashtra, including the Godavari, Krishna, Bhima, Tapi, Wainganga, Wardha and associated tributaries, reservoirs, lakes and wetlands. Published records from different districts were examined to identify geographic patterns in benthic biodiversity and to determine which regions and habitat types remain poorly investigated. Information on sampling season, habitat type, taxonomic resolution, sampling methodology and environmental variables was also considered because differences in these factors can substantially influence estimates of benthic abundance and diversity.

The retrieved literature was organized according to the major objectives of the review. The first category comprised studies documenting the occurrence and diversity of meiobenthic and benthic macroinvertebrate taxa. The second included investigations examining environmental controls such as substrate type, dissolved oxygen, temperature, flow

velocity, nutrients, organic matter and aquatic vegetation. The third comprised studies addressing anthropogenic pressures, including domestic sewage, industrial effluents, agricultural runoff, eutrophication, sedimentation, urbanization, dam construction and flow regulation. The fourth category included investigations applying benthic organisms or community-based metrics for water-quality assessment and ecological biomonitoring. Finally, recent literature concerning molecular identification, environmental DNA, metabarcoding, functional traits and standardized freshwater assessment was examined to identify emerging directions for future research.

Because the available literature differs considerably in geographical coverage, sampling design, taxonomic resolution and analytical methodology, numerical estimates of diversity reported by individual studies were not pooled statistically. Instead, the evidence was synthesized qualitatively, with emphasis on recurring ecological patterns, documented taxa, habitat associations and environmental responses. Diversity indices and biological assessment methods reported in the literature were interpreted in relation to their sampling context rather than assuming that values obtained from different ecosystems were directly comparable.

An important outcome of the literature assessment was the recognition of an imbalance between research on benthic macroinvertebrates and research on freshwater meiobenthos in Maharashtra. Macroinvertebrate studies are available from several rivers, reservoirs and lakes, whereas systematic investigations of freshwater meiofaunal communities remain comparatively scarce. This disparity was considered when interpreting the present status of biodiversity knowledge. Consequently, the absence of published records for a particular taxon or region was not interpreted as evidence of biological absence, but rather as a possible indication of insufficient sampling or taxonomic investigation.

The review therefore combines Maharashtra-specific evidence with appropriately selected Indian and international literature while maintaining a clear distinction between documented observations and broader ecological interpretations. This approach provides a basis for identifying established knowledge, recognizing uncertainties and research gaps, and developing priorities for systematic assessment of freshwater meiobenthos and benthic macroinvertebrates across Maharashtra.

Freshwater Habitats of Maharashtra

Maharashtra contains a pronounced east-west environmental gradient. The Western Ghats support comparatively high-rainfall headwater systems, while the Deccan interior contains seasonal streams, reservoirs, irrigation networks and semi-arid freshwater habitats. The major river systems include the Godavari and its tributaries in the north-central and eastern parts of the state, the Krishna and Bhima systems in the south, the Tapi in the north and the Wainganga-Wardha system in eastern Maharashtra. The ecological character of benthic habitats varies with flow regime, geology, catchment land use, substrate, water retention and monsoon dynamics.

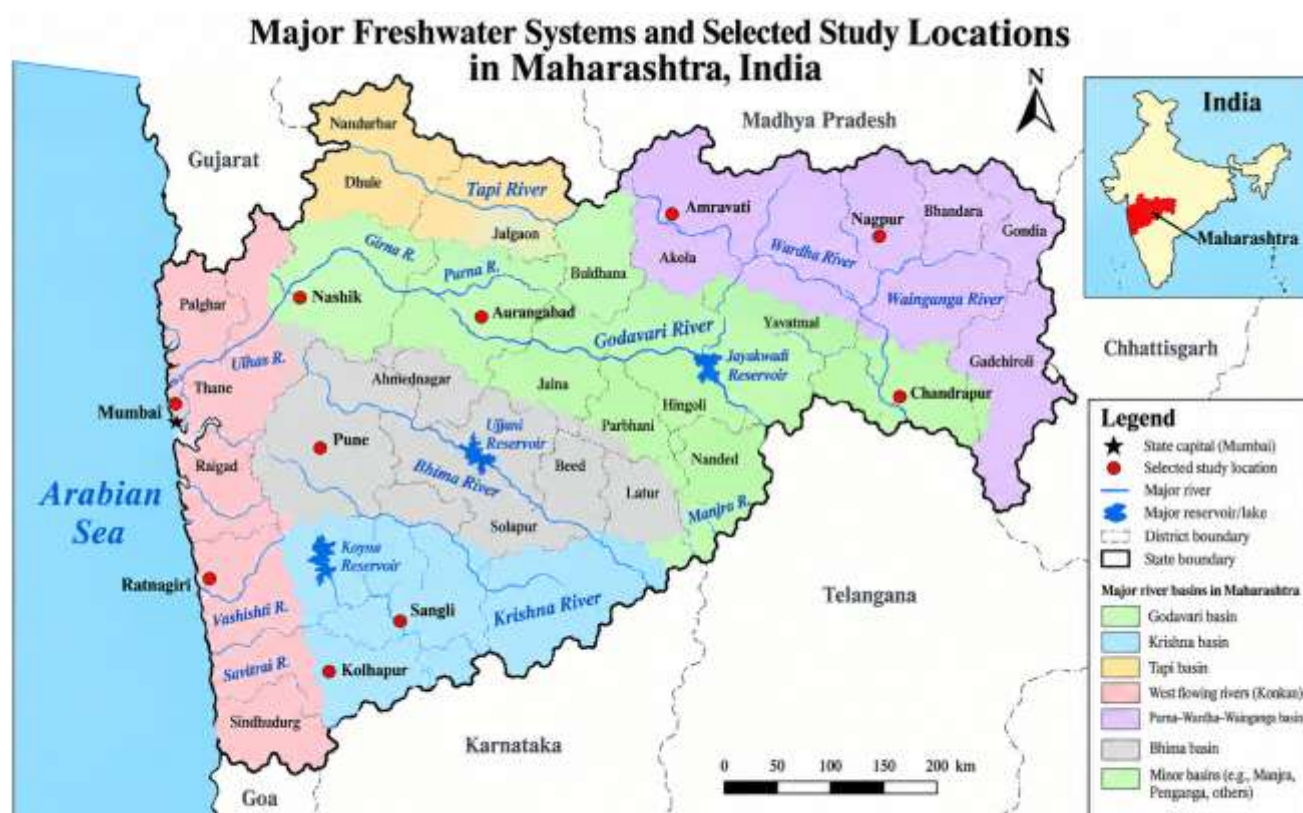


Figure 1. Schematic map of Maharashtra showing major freshwater systems and selected locations represented in the literature. The map is for orientation and is not a GIS-accurate administrative or hydrographic map.

Meiobenthos of Freshwater Ecosystems

Meiobenthos are small sediment-associated organisms that inhabit interstitial spaces and the sediment-water interface. The operational size range is method-dependent. A commonly used definition retains meiofauna between approximately 44–63 μm and 500–1000 μm , but methodological studies have shown that sieve size can alter apparent abundance and taxonomic composition, particularly for nematodes (Higgins & Thiel, 1988; Giere, 2009; Majdi et al., 2020). Consequently, future Maharashtra surveys should report sieve size explicitly and, where possible, use nested sieves to reduce methodological bias.

Freshwater meiofaunal assemblages can include nematodes, rotifers, gastrotrichs, harpacticoid and cyclopoid copepods, ostracods, tardigrades, small oligochaetes, turbellarians and other microscopic metazoans. Their ecological significance is linked to high abundance, short generation times, intimate association with sediments and strong interactions with bacteria, fungi and detrital particles. Meiofauna can also form a direct food resource for chironomids, shrimps, flatworms and juvenile fish, demonstrating that they are not simply a trophic dead end (Schmid-Araya et al., 2020).

Indian meiofaunal literature remains more developed for estuarine and marine systems than for inland freshwater habitats. A review of peninsular Indian estuaries emphasized the limited taxonomic coverage and the concentration of Indian meiofaunal research on nematodes and harpacticoid copepods (Sumesh & Abraham, 2023). Studies of the Matla estuarine system further demonstrate that meiofaunal abundance and composition respond to seasonal and environmental gradients (Sarkar et al., 2021). These studies provide methodological and ecological guidance but should not be treated as direct evidence for Maharashtra inland freshwater systems.

The scarcity of Maharashtra freshwater meiofaunal records should itself be considered a significant finding of this review. It indicates that a large component of sediment biodiversity remains effectively invisible in conventional macroinvertebrate surveys. A state-level meiofaunal programme would therefore have high potential for discovering previously undocumented diversity and for developing sensitive sediment-quality indicators.

Benthic Macroinvertebrate Fauna

Freshwater macroinvertebrates include aquatic insects, molluscs, annelids, crustaceans and other larger invertebrates associated with sediments, stones, woody debris and aquatic vegetation. In Maharashtra, the available literature demonstrates that aquatic insects and molluscs are prominent components of freshwater benthos. A survey of selected freshwater bodies in western Maharashtra recorded 51 taxa representing 43 genera and 29 families, including insect, molluscan and crustacean elements (Bhandarkar et al., 2020). More recent work in Borda Dam, Yavatmal, recorded 22 macroinvertebrate species, with Mollusca representing the largest component (Patharde & Telkhade, 2024). Studies in Tamasi Lake, Chandrapur, have reported 23 species in one survey and 44 species in a subsequent two-year assessment, illustrating both local richness and the influence of sampling duration (Tekade & Telkhade, 2025a, 2025b).

Aquatic insects are particularly valuable because immature stages integrate habitat and water-quality conditions while occupying diverse functional feeding roles. Ephemeroptera, Plecoptera and Trichoptera are widely used as sensitive components in stream assessment, although their distribution in tropical Indian systems differs from temperate systems and must be interpreted in regional context. Diptera, especially chironomids, often tolerate greater organic enrichment. Odonates, coleopterans and hemipterans occupy diverse lentic and littoral habitats. Molluscs, including gastropods and bivalves, are important grazers, filter feeders and sediment-associated consumers and can be useful in studies of habitat alteration and pollution.

The Godavari basin is particularly relevant to Maharashtra benthic biodiversity. A study of native bivalve molluscs along selected Godavari sites in western Maharashtra reported four pelecypod species and emphasized the effects of anthropogenic activity and pollution on molluscan diversity (Shinde, 2016). Such records indicate that benthic biodiversity can also contribute to understanding long-term ecological change in large rivers.

Table 1. Major freshwater meiobenthic and benthic macroinvertebrate groups and their ecological significance

Group	Typical representatives	Principal habitat	Ecological role / indicator value
Nematoda	Free-living nematodes	Fine sediments, interstitial spaces	Microbial grazing; rapid response to sediment conditions
Rotifera & Gastrotricha	Small sediment-associated forms	Periphyton and fine sediments	Microbial grazing; short generation times
Copepoda	Harpacticoids, cyclopoids	Interstitial sediment, vegetation	Grazing and trophic transfer
Ostracoda	Freshwater ostracods	Sediment, macrophytes	Detritivory/grazing; environmental sensitivity
Tardigrada	Sediment-associated tardigrades	Moss, periphyton, sediments	Microhabitat indicators
Oligochaeta	Naidids, tubificid worms	Fine organic sediments	Detritus processing; some taxa pollution tolerant
Ephemeroptera	Mayfly nymphs	Stones, gravel, riffles	Often sensitive to oxygen and habitat alteration
Trichoptera	Caddisfly larvae	Stones, vegetation, woody debris	Sensitive taxa; diverse feeding guilds
Plecoptera	Stonefly nymphs	Cold, oxygenated streams	Strong sensitivity; restricted in warmer lowlands
Diptera	Chironomidae and others	Sediment, vegetation	Wide tolerance range;

			useful pollution-gradient taxa
Odonata	Dragonfly/damselfly nymphs	Littoral vegetation, sediments	Predators; habitat indicators
Coleoptera/Hemiptera	Aquatic beetles and bugs	Vegetation, margins, open water	Littoral diversity and habitat indicators
Mollusca	Gastropods and bivalves	Sediment, stones, macrophytes	Grazing/filtering; habitat and pollution response
Crustacea	Shrimps, crabs, microcrustaceans	Sediment, vegetation, stones	Food-web links and sediment processing

Biodiversity and Distribution Patterns

Benthic biodiversity is strongly structured by habitat heterogeneity. River reaches containing riffles, pools, woody debris, leaf packs, gravel and submerged vegetation can support more ecological niches than simplified channels. Reservoirs produce strong horizontal and vertical gradients, with littoral zones often differing markedly from deeper depositional sediments. Small ponds and tanks may support rich molluscan and insect assemblages despite their limited size.

In Maharashtra, available studies show that benthic diversity is distributed across multiple habitat types rather than being restricted to major rivers. The western Maharashtra survey of 51 taxa, the Borda Dam survey in Yavatmal, the Tamasi Lake studies in Chandrapur and the Godavari mollusc investigation collectively demonstrate a broad but fragmented evidence base. Because the sampling designs, taxonomic resolution and durations differ, their numerical richness values should not be directly compared as if they represented a standardized statewide inventory.

Table 2. Maharashtra-specific evidence currently available for freshwater benthic biodiversity

Region / water body	Study period / scope	Main evidence	Interpretive significance
Western Maharashtra: Mula, Bhima, Nira and associated waters	Multiple selected freshwater bodies	51 taxa; 43 genera; 29 families	Demonstrates broad macroinvertebrate richness across river, reservoir and tank habitats
Wainganga, Gadhavi and Khobragadhi systems, Gadchiroli	Riverine assessment	Diversity indices used for benthic community and water-quality interpretation	Shows usefulness of benthic assemblages for ecological assessment
Godavari, Nashik–Ahmednagar region	Selected river sites	Native bivalve fauna documented; pollution linked with faunal change	Highlights sensitivity of molluscan biodiversity to river degradation
Ghotnimbala reservoir, Chandrapur	Reservoir assessment	Benthic macroinvertebrates and aquatic insects recorded	Supports reservoir-scale biomonitoring
Borda Dam, Yavatmal	June 2022–May 2023	22 species; Mollusca dominant	Shows contribution of lentic habitats to benthic diversity

Tamasi Chandrapur	Lake,	May 2022–April 2023	23 macroinvertebrate species	Shows seasonal/spatial variation in lake benthos
Tamasi Chandrapur	Lake,	January 2023–December 2024	44 species; 4 phyla, 18 orders, 30 families	Longer monitoring revealed greater documented richness

Environmental Drivers of Benthic Community Structure

Sediment grain size is a fundamental driver because it determines pore space, hydraulic exchange, organic-matter retention and the availability of refugia. Coarse substrates tend to favour attached or clinging taxa, whereas fine organic sediments provide favourable conditions for burrowing worms and other deposit feeders. In meiofaunal studies, even small changes in sediment texture can alter the distribution of nematodes and microcrustaceans.

Dissolved oxygen is another major control. Oxygenated sediments can support sensitive taxa and diverse functional communities, while oxygen depletion favours tolerant organisms and may simplify community structure. Organic enrichment can initially increase food availability but, beyond a threshold, stimulates oxygen-consuming decomposition and shifts the community towards tolerant forms.

Hydrology is particularly important in monsoon-dominated Maharashtra. Flood pulses can scour sediments, transport organisms and reorganize substrate mosaics, whereas subsequent deposition creates new habitats. Reservoir regulation can dampen natural flow variability and alter downstream sediment transport. These processes mean that benthic monitoring should incorporate discharge, depth, velocity and seasonal hydrological context rather than treating water chemistry alone as the environmental driver.

Aquatic vegetation increases structural complexity and provides attachment, feeding and refuge sites. However, excessive macrophyte proliferation under eutrophic conditions can also modify oxygen dynamics and organic deposition. Catchment land use, agricultural runoff, urban wastewater, industrial discharge and sediment disturbance act through these physical and chemical pathways to reshape benthic assemblages.

Pollution and Anthropogenic Stress

Freshwater benthic communities are exposed to multiple and interacting stressors. Domestic sewage increases organic loading and nutrient concentrations; industrial effluents can introduce metals and toxic compounds; agricultural runoff contributes nutrients, pesticides and eroded sediment; urbanization changes hydrology and contaminant delivery; and sand extraction can directly remove benthic habitat. Because sediment can accumulate organic matter and contaminants, benthic organisms may experience chronic exposure even when the overlying water appears chemically acceptable.

Indian studies demonstrate that benthic macroinvertebrate communities can distinguish relatively less disturbed from more impacted river reaches. For example, integrated assessment of the Mahi River using physicochemical variables and benthic macroinvertebrates found moderate pollution under the applied biological scoring framework (Khatri et al., 2021). Seasonal assessment of the Mahisagar River similarly combined physicochemical measurements, diversity indices and multivariate analysis to identify pollution-related patterns (Khatri et al., 2022). Studies in highly urbanized aquatic systems have shown that macroinvertebrate-based indices can complement conventional water-quality measurements (e.g., Jamshedpur; Ecological Indicators, 2020).

For Maharashtra, the Godavari bivalve study and recent Chandrapur and Yavatmal investigations indicate that benthic communities respond to local environmental conditions, but statewide comparisons remain constrained by differences in sampling methodology. Pollution should therefore be interpreted as a multi-stressor phenomenon involving organic matter, nutrients, toxic substances, sedimentation and habitat simplification rather than as a single chemical variable.

Table 3. Major stressors and expected benthic responses

Stressors	Primary environmental pathway	Expected community response	Recommended measurements
Domestic sewage	Organic enrichment, nutrients, microbial load	Decline of sensitive taxa; increase of tolerant collectors/deposit feeders	BOD, COD, DO, NH ₄ -N, PO ₄ -P, coliforms
Industrial effluent	Metals, toxic organics, altered pH/conductivity	Reduced richness; tolerant taxa or community simplification	Metals, conductivity, pH, specific contaminants
Agricultural runoff	Nutrients, pesticides, sediment	Eutrophication, toxicity, substrate smothering	Nitrate, phosphate, pesticide screening, TSS
Urbanization	Hydrologic alteration, runoff, sewage	Loss of sensitive taxa; altered functional structure	Flow, impervious cover, nutrients, contaminants
Sedimentation	Fine-particle deposition and habitat burial	Loss of coarse-substrate specialists; increased burrowers	Grain size, TSS, sediment depth
Dam regulation	Changed flow, temperature and sediment transport	Shift in habitat specialists and feeding groups	Discharge, velocity, temperature, sediment load
Climate variability	Temperature and monsoon-flow changes	Range shifts, phenological changes, altered seasonal abundance	Long-term temperature and hydrological records

Benthic Macroinvertebrates as Bioindicators

The value of macroinvertebrates as bioindicators derives from the combination of ecological diversity, relatively limited mobility, different tolerance levels and comparatively straightforward sampling. Unlike a single chemical measurement, a biological assemblage reflects cumulative environmental conditions over a period of time. For this reason, benthic assessment is increasingly regarded as a complementary approach rather than a replacement for physicochemical monitoring (Rosenberg & Resh, 1993; Bonada et al., 2006).

Common metrics include taxon richness, Shannon diversity, Simpson dominance, Margalef richness, evenness, EPT richness, percentage composition of sensitive groups, tolerance-weighted indices, BMWP/ASPT-type scores and multimetric indices. The choice of metric should be validated against local reference conditions. A metric developed for a temperate river should not automatically be transferred to a tropical reservoir without calibration.

Recent global guidance emphasizes that sampling, laboratory processing, identification, metrics and assessment must be harmonized to permit comparisons among regions (Cantonati et al., 2024). This is especially relevant to India, where methods and taxonomic resolution vary widely. A Maharashtra-specific protocol should therefore define habitat stratification, sampling effort, mesh size, preservation, taxonomic level, voucher deposition and minimum dataset requirements.

Table 4. Recommended bioassessment metrics for Maharashtra freshwater benthos

Metric / approach	Ecological interpretation	Main limitation	Recommended use
Taxon richness	Breadth of recorded biodiversity	Sensitive to sampling effort	Core biodiversity metric
Shannon diversity	Richness plus relative abundance	Affected by natural habitat complexity	Compare standardized sites/seasons
Simpson dominance	Dominance by common taxa	Less sensitive to rare taxa	Detect community simplification
Margalef richness	Taxonomic richness relative to abundance	Sample-size effects	Supplementary richness measure
EPT richness	Sensitive insect diversity	Naturally low outside suitable habitats	Headwater/flowing-water assessment
BMWP/ASPT-type scores	Tolerance-weighted biological condition	Requires regional validation	Use after Maharashtra calibration
Functional feeding groups	Ecosystem-process response	Requires reliable trait assignment	Assess functional change
Trait-based metrics	Mechanistic response to stressors	Data-intensive	Research and advanced monitoring
eDNA/metabarcoding	Broad taxonomic detection	Reference databases and contamination issues	Supplement morphology, not replace it initially

Ecological Functions and Linkages with Fish

Benthic organisms are central to freshwater food webs. Shredders and detritivores process coarse and fine organic matter; grazers regulate periphyton; collectors exploit suspended or deposited particles; predators transfer energy among consumer levels. Meiofauna contribute to microbial pathways and can be consumed by macroinvertebrates and juvenile fishes. Experimental and synthesis work indicates that meiofauna can constitute an important food resource for freshwater macroinvertebrates and young fish, challenging the older view that their trophic contribution is negligible (Schmid-Araya et al., 2020).

For Maharashtra fisheries, benthic biodiversity therefore has indirect significance. Changes in benthic food availability can influence fish growth, recruitment and habitat use. Reservoir and river fisheries assessments should consequently consider benthic productivity and habitat condition alongside fish abundance. This is particularly relevant in large reservoirs where changes in sediment and littoral habitats can alter both benthic communities and fish feeding opportunities.

Seasonal Dynamics

Seasonality is one of the most important considerations in tropical freshwater benthic studies. The southwest monsoon changes discharge, sediment transport, turbidity and nutrient delivery. High flows may reduce benthic densities through physical disturbance, whereas the post-monsoon period can facilitate recolonization and increased productivity. Summer warming and declining water levels may concentrate pollutants and reduce dissolved oxygen in smaller water bodies. A single-season survey can therefore provide an incomplete picture of biodiversity. For Maharashtra, a minimum seasonal design should include pre-monsoon, monsoon or immediate post-monsoon, and post-monsoon/winter observations, with additional summer sampling where drying or thermal stress is important.

Molecular and Digital Approaches

Conventional morphology remains essential for biodiversity inventories, but DNA barcoding, environmental DNA and metabarcoding offer opportunities to improve detection of cryptic and small taxa. These methods may be particularly valuable for meiobenthos, where species-level identification can be difficult and taxonomic expertise is limited. However, molecular methods should be integrated with voucher-based morphology, validated reference sequences and contamination controls. GIS, remote sensing and machine-learning approaches can further connect benthic records with catchment land use, habitat fragmentation and environmental change. The recommended strategy is therefore integrative rather than purely molecular.

Research Gaps

The most obvious gap is the absence of a comprehensive statewide inventory of freshwater meiofauna and macroinvertebrates. Existing Maharashtra studies are spatially scattered and often concentrate on individual reservoirs, lakes or short river reaches. This makes it difficult to estimate state-level richness, endemism, rarity or conservation status.

Freshwater meiobenthos represent an even larger gap. The available Indian literature is comparatively richer for marine and estuarine meiofauna than for inland freshwater habitats, and much of the work focuses on nematodes and harpacticoid copepods. Maharashtra requires dedicated sampling of sediment meiofauna across rivers, reservoirs, wetlands and seasonal water bodies.

Methodological inconsistency is another limitation. Different studies use different mesh sizes, sampling areas, preservation methods, taxonomic resolutions and indices. Consequently, apparent differences in diversity may reflect methodology rather than ecological change. The international literature now strongly emphasizes harmonized sampling and assessment protocols (Cantonati et al., 2024).

Long-term datasets are also scarce. Repeated annual surveys are necessary to distinguish natural monsoon-driven variability from persistent anthropogenic change. Finally, functional traits, sediment contaminants, molecular taxonomy and climate-related hydrological changes remain underrepresented in Maharashtra benthic research.

Table 5. Research gaps and proposed priorities

Research gap	Why it matters	Priority action
No statewide benthic inventory	Unknown total diversity and distribution	Basin-wide standardized atlas
Limited freshwater meiofaunal work	Large component of sediment biodiversity remains undocumented	Nested-sieve meiofaunal surveys
Taxonomic uncertainty	Limits species-level conservation and comparison	Voucher collections, expert identification, DNA barcoding
Inconsistent sampling	Reduces comparability among studies	State protocol with fixed effort and metadata
Few long-term datasets	Natural variability can be confused with degradation	Multi-year seasonal monitoring
Limited trait data	Weak understanding of functional change	Develop Indian/Maharashtra trait database
Weak sediment-contaminant integration	Water chemistry alone may miss chronic exposure	Pair benthos with sediment metals/organics
Limited molecular surveillance	Cryptic and small taxa may be missed	eDNA/metabarcoding validation
Fragmented spatial data	Difficult to identify hotspots and	GIS-based freshwater benthic

	refugia	database
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Future Perspectives

A Maharashtra Freshwater Benthic Biodiversity Network could provide a practical institutional framework for future work. Representative reference sites should first be identified in each major basin, followed by a gradient of minimally disturbed, moderately disturbed and highly impacted sites. Sampling should cover rivers, streams, reservoirs, natural and artificial lakes, wetlands and irrigation channels.

The network should use standardized field protocols, paired water and sediment chemistry, taxonomic vouchers and a common digital database. A core dataset could include abundance, biomass, taxon richness, Shannon diversity, functional feeding groups, EPT richness where applicable, tolerance scores and selected environmental variables. Molecular records could be added progressively as reference libraries improve.

The resulting database could support ecological status maps, pollution-risk assessment, restoration planning and freshwater biodiversity conservation. It would also provide baseline data for evaluating future impacts of climate variability, altered monsoon regimes, dam operation, urban growth and agricultural intensification.

Conclusions

Freshwater meiobenthos and benthic macroinvertebrates are integral components of Maharashtra's aquatic ecosystems, yet their biodiversity remains incompletely documented. Existing studies demonstrate that rivers, reservoirs, lakes and smaller freshwater bodies support diverse assemblages of aquatic insects, molluscs, annelids, crustaceans and microscopic sediment-dwelling organisms. Maharashtra-specific evidence is strongest for macroinvertebrates, while freshwater meiofaunal research remains a major frontier. The ecological importance of these organisms extends from decomposition and nutrient cycling to food-web support and biological assessment. Their sensitivity to oxygen conditions, sediment characteristics, organic enrichment, nutrient loading and habitat disturbance makes them valuable indicators when interpreted within a standardized regional framework. The future of freshwater benthic research in Maharashtra should therefore move from isolated site inventories towards coordinated basin-scale monitoring that integrates taxonomy, functional ecology, sediment science, physicochemical measurements, molecular tools and spatial analysis. Such an approach would strengthen biodiversity documentation and provide a scientific basis for pollution control, river restoration, reservoir management and sustainable fisheries conservation.

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