

SCUBA-Assisted Assessment of Environmental Stress and Habitat Vulnerability of Bivalve Communities in Coastal Backwaters of Raigad District, Maharashtra, India

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Abstract

Coastal backwaters and mangrove-fringed mudflats support productive molluscan communities but are also exposed to increasing local anthropogenic pressures. The present study evaluates habitat condition, bivalve occurrence and potential environmental stress across four coastal backwater sites of Raigad District, Maharashtra, India, using biodiversity observations collected from October 2018 to September 2020. Turbadi, Waral, Mendadi and Pabhara represented contrasting muddy, mangrove-associated and rocky-jetty environments. Five 1×1 m quadrats were examined per site during each visit, with two surveys per season, and low-tide hand collection was complemented by SCUBA-assisted reconnaissance of adjacent submerged habitats, including direct observation of substrate characteristics and bivalve-associated microhabitats. Six principal bivalve taxa were recorded across the combined study framework: *Arca granosa*, *Polymesoda maxima*, *Marcia opima*, *Crassostrea cutuckensis*, *Saccostrea cucullata* and *Meretrix meretrix*. Site-level density ranges showed marked taxon-specific patterns. At Turbadi, *Marcia opima* and *Meretrix meretrix* reached 6–8 individuals m^{-2} and *Crassostrea cutuckensis* 7–8 individuals m^{-2} ; *Crassostrea cutuckensis* also reached 7–8 individuals m^{-2} at Mendadi and Pabhara. *Arca granosa* occurred across all four sites at approximately 2–4 individuals m^{-2} . Observational field notes documented domestic discharge at Turbadi and Waral and oil-related discharge at Waral, but no chemical concentrations were measured; these observations are therefore treated as potential environmental stressors rather than evidence of quantified toxicity. A preliminary one-way comparison of the available site data yielded $F \approx 0.013$ with $p > 0.05$, indicating no statistically significant site-level difference in the analysed dataset. The study emphasizes the value of integrating molluscan assemblage data with SCUBA-assisted habitat observations as a baseline indicator of habitat condition while demonstrating the need to combine biodiversity surveys with direct water, sediment and tissue chemistry before attributing ecological patterns to contamination. Long-term integrated monitoring of backwater molluscs, mangrove condition and environmental quality is recommended for sustainable management of Raigad's coastal resources.

Keywords: SCUBA; bivalves; coastal backwaters; environmental stress; habitat vulnerability; mangroves; Raigad; biodiversity monitoring

1. Introduction

Estuaries, creeks, mangrove margins and coastal backwaters are among the most dynamic habitats of the tropical coastal zone. Their ecological functioning depends on interactions among tidal exchange, sediment type, salinity, organic matter, vegetation and local hydrodynamics. These habitats also receive material from terrestrial settlements, transport activities and other human uses. Because benthic organisms live at the sediment-water interface, changes in habitat quality can be reflected in their occurrence, density and community structure.

Molluscs are important components of mangrove and estuarine food webs and include filter feeders, deposit-associated forms, grazers and predators. Bivalves are particularly relevant to environmental assessment because many species are relatively sedentary and continuously interact with suspended particles and sediments. Recent Indian studies have used bivalves to investigate trace metals, microplastics, pesticides, histopathological alterations and other indicators of coastal environmental quality. Such work demonstrates the potential of bivalves for biomonitoring, while also showing that biological observations alone cannot identify a specific contaminant without direct chemical or biomarker measurements.

Raigad District on the west coast of India contains mangrove-fringed creeks, mudflats, rocky margins and sheltered backwaters. Earlier work from Raigad has documented productive bivalve and gastropod assemblages in mangrove, muddy, rocky and sandy habitats. The present study develops a habitat-vulnerability perspective using a 2018–2020 bivalve dataset from four coastal backwater sites. Rather than labelling a site as chemically polluted from visual observations, the study distinguishes observed anthropogenic pressures from measured contamination. The objectives were to: (i) document bivalve occurrence and density patterns across contrasting backwater habitats; (ii) describe field-observed environmental pressures; (iii) compare the available site-level data statistically; and (iv) propose an integrated biodiversity-and-chemistry framework for future environmental monitoring.

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2. Literature Review

Khade and Mane (2012) documented bivalve and gastropod diversity in mangrove ecosystems of Raigad District and reported productive molluscan fauna across selected localities. Their work established the ecological importance of Raigad's mangrove habitats and the need for continued conservation-oriented research. A related Raigad study also demonstrated that molluscan composition differs among mangrove, rocky, sandy and muddy habitats, reinforcing the importance of substrate and habitat heterogeneity.

On the nearby Mumbai coast, Kantharajan et al. (2017) documented 61 molluscan species from eight mangrove areas and identified habitat destruction and pollution as important pressures on molluscan fauna. The study emphasized the use of regional biodiversity inventories for conservation planning. More recent work on the Maharashtra coast has shown that bivalves can support direct pollution assessment when biodiversity observations are combined with contaminant analysis and biomarkers. For example, a 2026 study of *Gafrarium divaricatum* measured potentially toxic elements in tissues together with oxidative-stress, genotoxic and molecular responses, demonstrating site- and season-specific pollutant effects.

Studies elsewhere on the Indian coast provide similar methodological lessons. *Polymesoda erosa* has been used to evaluate metal pollution and bioaccumulation in the Zuari Estuary, while *Meretrix casta* has been investigated as a bioindicator of genotoxic agents in estuarine environments. Histopathological studies of Indian bivalves have further linked tissue-level responses with trace-metal exposure. These investigations show that molluscan community data are valuable as ecological baselines, but robust ecotoxicological conclusions require contaminant measurements in water, sediment and/or tissues.

3. Research Work

3.1 Study area and sampling design

Field observations were undertaken from October 2018 to September 2020 at Turbadi (Site A), Waral (Site B), Mendadi (Site C) and Pabhara (Site D) in Raigad District, Maharashtra. Turbadi was characterized by soft mud with mangrove vegetation including *Rhizophora mucronata*, *Ceriops tagal* and *Avicennia alba*, together with oyster beds and later-occurring stones and bricks. Waral comprised a mudflat near a bridge with *Avicennia marina* and *Sonneratia alba*. Mendadi was broadly comparable to Turbadi but included rocky patches, whereas Pabhara represented a rocky jetty environment.

Sampling was conducted twice per season. Five 1 × 1 m quadrats were examined per site during each visit at low tide, and bivalves were collected by hand where appropriate. SCUBA reconnaissance was used as a complementary method to examine submerged habitat features. The sampling design was intended primarily for biodiversity and habitat assessment rather than contaminant quantification.

3.2 Role of SCUBA-assisted habitat assessment

The transition from exposed intertidal habitat to permanently submerged shallow-water habitat can be difficult to characterize using low-tide quadrats alone. SCUBA-assisted reconnaissance extended direct field observation below the conventional intertidal sampling boundary and enabled visual assessment of submerged substrates and bivalve-associated microhabitats. This was particularly useful where rocky patches, oyster beds or other hard surfaces continued below water. The underwater component supported direct confirmation of substrate characteristics, in-situ observation of organisms and attachment surfaces, and photographic or video documentation where conditions permitted. Because the SCUBA reconnaissance was not conducted as a fully standardized replicated transect or photoquadrat experiment, underwater observations were treated as supporting ecological evidence and were not pooled with intertidal quadrat counts for inferential statistical analysis. Future monitoring should standardize this component using fixed-depth belt transects or underwater photoquadrats repeated seasonally alongside the intertidal quadrats.

3.3 Observed anthropogenic pressures

Field notes recorded domestic discharge in the vicinity of Turbadi and Waral and oil-related discharge at Waral. These observations indicate possible exposure pathways and justify classifying these locations as sites requiring environmental-quality investigation. However, the study did not measure petroleum hydrocarbons, nutrients, trace metals, pesticides, microplastics or other contaminants. Accordingly, the terms 'potential environmental stressor' and 'observed anthropogenic pressure' are used throughout this paper. No causal relationship between the observed discharge and bivalve abundance is asserted.

3.4 Recorded bivalve assemblage

Six principal bivalve taxa were represented in the combined study records: *Arca granosa*, *Polymesoda maxima*, *Marcia opima*, *Crassostrea cutuckensis*, *Saccostrea cucullata* and *Meretrix meretrix*. *Polymesoda maxima* was subsequently taxonomically verified through the Zoological Survey of India. Species occurrence differed among sites, reflecting the mixture of soft-sediment, mangrove-associated and hard-substrate conditions.

Site	Habitat notes	Selected taxa with available density	Density (ind. m ⁻²)	Observed pressure
Turbadi (A)	Soft mud; mangroves; oyster beds	<i>Arca granosa</i> ; <i>Polymesoda maxima</i> ; <i>Marcia opima</i> ; <i>Crassostrea cutuckensis</i> ; <i>Meretrix meretrix</i>	3–4; 1–2; 6–8; 7–8; 6–8	Domestic discharge observed
Waral (B)	Mudflat near bridge; mangroves	<i>Arca granosa</i>	2–3	Domestic and oil-related discharge observed
Mendadi (C)	Mud/mangrove habitat with rocky patches	<i>Arca granosa</i> ; <i>Crassostrea cutuckensis</i> ; <i>Meretrix meretrix</i>	3–4; 7–8; 6–8	No quantified contaminant data
Pabhara (D)	Rocky jetty	<i>Arca granosa</i> ; <i>Crassostrea cutuckensis</i>	2–3; 7–8	No quantified contaminant data

3.5 Density patterns and habitat interpretation

The available density ranges show that no single taxon characterized every habitat in the same way. *Arca granosa* occurred across all four sites, with approximately 3–4 individuals m⁻² at Turbadi and Mendadi and 2–3 individuals m⁻² at Waral and Pabhara. *Crassostrea cutuckensis* reached approximately 7–8 individuals m⁻² at Turbadi, Mendadi and Pabhara, consistent with the availability of firm attachment surfaces or oyster-associated substrate. At Turbadi, *Marcia opima* and *Meretrix meretrix* reached approximately 6–8 individuals m⁻², while *Polymesoda maxima* occurred at approximately 1–2 individuals m⁻². *Meretrix meretrix* also reached approximately 6–8 individuals m⁻² at Mendadi.

These patterns are most appropriately interpreted as habitat-associated observations. Soft sediment, mangrove vegetation, oyster beds and rocky patches create different settlement and feeding opportunities. The data do not support attributing lower or higher density at any site specifically to pollution, because contaminant concentrations and physiological responses were not measured.

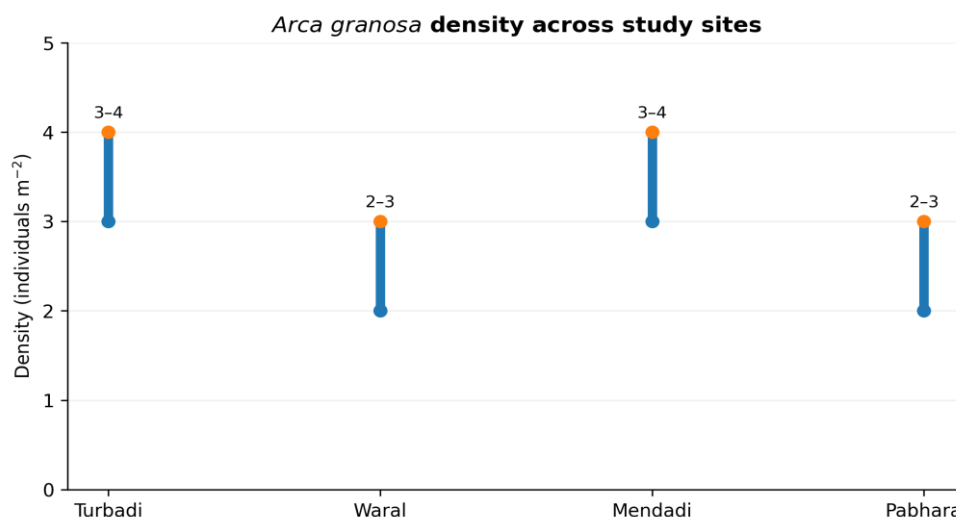


Figure 1. Recorded density ranges of *Arca granosa* at the four study sites. The vertical segments show the observed minimum–maximum density range; endpoints are plotted directly, avoiding use of an artificial mean.

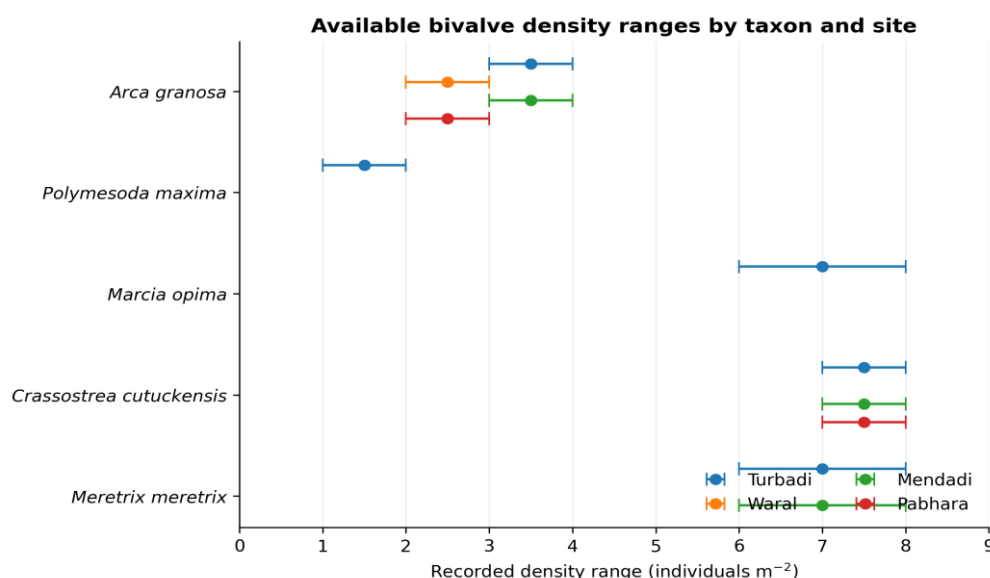


Figure 2. Available density ranges of major bivalve taxa across study sites. Points represent the midpoint of each reported range only to position the interval; horizontal error bars extend to the recorded minimum and maximum. Missing site–taxon combinations indicate that no density range was available in the dataset used for this paper.

3.6 Statistical assessment

A preliminary one-way analysis of variance applied to the available site-level dataset produced an F value of approximately 0.013 with $p > 0.05$. Thus, the null hypothesis of no site-level difference was not rejected for the analysed data. This result should not be interpreted as proof that all sites are ecologically identical. The dataset contains relatively small density ranges, uneven species representation among sites and habitat differences that may not be captured by a single univariate comparison. The statistical result is therefore treated as descriptive support rather than evidence of environmental equivalence.

For future work, a species-by-site abundance matrix with standardized repeated sampling would allow multivariate analyses such as Bray–Curtis similarity, non-metric multidimensional scaling and PERMANOVA. When combined with measured salinity, pH, dissolved oxygen, sediment grain size, organic carbon and contaminant concentrations, these analyses could test which environmental variables best explain assemblage structure.

3.7 Environmental vulnerability and bioindicator perspective

The ecological significance of the present dataset lies in its ability to identify where more intensive environmental monitoring is justified. Waral is especially relevant because both domestic and oil-related discharge were observed in the field, while Turbadi combined domestic discharge observations with a productive muddy-mangrove habitat. Bivalves at such sites can provide a bridge between biodiversity assessment and environmental chemistry. Filter-feeding and sediment-associated species may integrate exposure over time, but their use as bioindicators requires appropriate chemical, histological or molecular endpoints.

Recent evidence from the Maharashtra coast supports this integrated approach: contaminant concentrations in bivalve tissues have been evaluated together with oxidative stress, DNA damage and stress-responsive gene expression. Comparable Indian studies have assessed microplastics, trace metals and pesticides in bivalves. A future Raigad monitoring programme could therefore pair the present quadrat framework with water and sediment chemistry, tissue bioaccumulation, condition index and selected biomarkers. Such a design would convert observed environmental pressure into testable exposure-response relationships.

4. Environmental and Conservation Implications

The backwaters of Raigad are ecological mosaics rather than uniform water bodies. Mangrove roots, mudflats, oyster beds, rocky patches and artificial hard surfaces each provide distinct microhabitats. Conservation planning should therefore protect habitat heterogeneity while simultaneously reducing avoidable discharge into creeks and backwaters. Loss of mangrove cover or modification of sediment and hard-substrate habitats may alter the ecological niches available to molluscan communities.

Bivalves also have potential socioeconomic relevance because several coastal species are harvested or have aquaculture potential. Environmental deterioration can consequently affect both biodiversity and coastal resource use. Regular monitoring should prioritize sites where biological resources overlap with visible anthropogenic pressures. Community-based observations, standardized quadrats and photographic records can provide low-cost continuity, while periodic laboratory analysis can establish whether visual pressures correspond to measurable contamination.

The study further illustrates an environmental-ethics principle relevant to sustainable coastal management: uncertainty should not be converted into unsupported claims, but lack of chemical data should not justify ignoring visible pressure. A precautionary monitoring response is appropriate. Biodiversity baselines provide the reference against which future environmental change can be evaluated.

5. Conclusion

The 2018–2020 survey of Turbadi, Waral, Mendadi and Pabhara demonstrates that Raigad's coastal backwaters support bivalve assemblages across contrasting muddy, mangrove-associated and rocky habitats. Six principal taxa were represented in the combined records, with site-specific density patterns reflecting habitat heterogeneity. *Crassostrea cutuckensis* reached approximately 7–8 individuals m⁻² at three sites, while *Arca granosa* occurred across all four study locations. Field observations identified domestic discharge at Turbadi and Waral and oil-related discharge at Waral, but the absence of chemical measurements prevents these observations from being interpreted as quantified pollution or ecotoxicological effects.

The preliminary statistical comparison ($F \approx 0.013$, $p > 0.05$) did not identify a significant site-level difference in the analysed dataset. The principal contribution of the study is therefore a biodiversity-based environmental baseline and a framework for identifying vulnerable habitats that merit direct environmental-quality assessment. SCUBA-assisted reconnaissance adds an important underwater habitat dimension, but future work should standardize it through fixed transects or photoquadrats. Future monitoring should integrate intertidal quadrats, standardized SCUBA surveys, water and sediment chemistry, tissue bioaccumulation and, where feasible, biomarker approaches. Such integration would strengthen evidence-based conservation and sustainable management of the coastal backwaters of Raigad District.

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Declarations

Conflict of interest: The authors declare no conflict of interest.

Funding: No external funding is declared for this study.

Data availability: The field dataset supporting this paper is maintained by the corresponding author and may be made available on reasonable request.

Ethics: The study involved field observations of marine invertebrates and did not involve human participants or experimental vertebrate animals.

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