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Spatiotemporal variation in intertidal isopod diversity along the southern Kerala coast: Indicators of coastal ecosystem health under environmental changes

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Original Article

Abstract

Diverse benthic communities that are essential to coastal resilience are supported by intertidal zones, which are among the most dynamic and climate-sensitive ecosystems. Over the course of two years (2018–2020), this study examines the spatiotemporal diversity and abundance of four intertidal isopod species (*Ligia dentipes, Alloniscus perconvexus, Dynamenella lauticauda*, and *Cirolana bovina*) at three coastal sites on the southern Kerala coast: Kovalam, Thirumullavaram, and Varkala. Tidal gradients (high, mid, and low tide) and seasonal intervals (pre-monsoon, monsoon, and post-monsoon) were sampled using stratified quadrats. Community structure was assessed using diversity indices, such as Shannon-Wiener, Simpson's, Fisher's Alpha, and Berger-Parker Dominance. With low species richness and strong dominance, Varkala demonstrated biotic impoverishment, whereas Kovalam displayed the greatest diversity and ecological stability. Seasonal trends showed that the best conditions for isopod proliferation occurred after the monsoon, perhaps as a result of better moisture regimes and organic detritus input. These patterns show how sensitive isopod assemblages are to changes in the environment, making them useful bioindicators of the health of intertidal ecosystems. With implications for SDG 14 (Life Below Water) and wetland conservation policies, the findings support climate-responsive biodiversity monitoring. The significance of baseline faunal evaluations in predicting and controlling ecological change along India's sensitive coastal habitats is highlighted by this study.

Keywords: *Marine isopods, intertidal diversity, bioindicators, climate variability, Kerala coast, ecosystem health*

Introduction

Coastal ecosystems are among the most dynamic and ecologically significant environments, supporting high biological diversity and complex trophic interactions that contribute to ecosystem stability and productivity (Henseler *et al*., 2019). Intertidal zones, in particular, experience strong environmental gradients such as tidal fluctuations, wave action, and variable moisture conditions, making them highly sensitive to both natural and anthropogenic disturbances (Defeo and McLachlan, 2005). The structure and functioning of these ecosystems are therefore closely linked to the composition and diversity of benthic communities inhabiting them.

Among benthic organisms, free-living marine isopods play an important ecological role in coastal environments. They contribute significantly to organic matter decomposition, nutrient cycling, and energy transfer within food webs, while also serving as prey for higher trophic levels (Poore and Bruce, 2012; Unni *et al.,* 2023). Due to their close association with substrate conditions and environmental parameters, isopods are highly responsive to ecological changes and are widely recognised as effective bioindicators of habitat quality and ecosystem health (Gray, 2002; Warwick and Clarke, 1993). Biodiversity assessment in such systems is commonly carried out using a combination of diversity indices that capture species richness, evenness, and dominance patterns. These metrics provide a comprehensive understanding of community structure and are essential for detecting ecological imbalances and environmental stress (Clarke and Warwick, 2001). Spatial and temporal variations in diversity are particularly important in intertidal ecosystems, where factors such as tidal zonation, seasonal changes, and habitat heterogeneity strongly influence species distribution and abundance.

Despite the ecological importance of intertidal fauna, studies focusing on the spatiotemporal variation of free-living marine isopods along the southwest coast of India, particularly Kerala, remain limited. Most existing studies have addressed general benthic diversity or environmental influences, with relatively little emphasis on isopod community structure across multiple habitats, tidal gradients, and seasonal cycles. This lack of detailed baseline data restricts our ability to understand ecological patterns and assess environmental changes in these vulnerable coastal systems.

In this context, the present study investigates the diversity and abundance of four intertidal isopod species-*Ligia dentipes, Alloniscus perconvexus, Dynamenella lauticauda*, and *Cirolana bovina*-across three coastal sites (Kovalam, Thirumullavaram, and Varkala) along the southern Kerala coast. By integrating spatial (site and tidal depth) and temporal (seasonal) analyses over two years, the study aims to evaluate patterns of community structure and identify environmental factors influencing isopod distribution. The findings of this study are expected to provide baseline ecological data for intertidal isopod assemblages and contribute to biodiversity monitoring and conservation strategies. Furthermore, the use of isopods as bioindicators offers valuable insights into coastal ecosystem health, supporting sustainable management and climate-responsive assessment of marine habitats.

Material and methods

Study sites

The beaches of Kovalam, Varkala, and Thirumullavaram (Kerala, India) were selected based on the presence of rocky and structurally complex intertidal habitats, which provide suitable microhabitats known to support higher diversity and abundance of free-living marine isopods.

Sampling design

At each location, 100-meter transects parallel to the beach were used for stratified random quadrat sampling (25 cm x 25 cm). For two years, sampling took place at three tidal heights (high, mid, and low tide zones) throughout the premonsoon, monsoon, and postmonsoon seasons.

Specimen collection and identification

Isopods were selected by hand, sieved through a 0.5 mm mesh screen, preserved in 70% ethanol, and then identified in a laboratory. Specimens were identified using a comparative taxonomic approach based on published descriptions and regional taxonomic literature. As no single comprehensive key was available, diagnostic characters were cross-verified across multiple sources. Four different intertidal isopod species were identified - *Ligia dentipes, Dynamenella laticauda, Alloniscus perconvexus* and *Cirolana bovina*.

Data analysis

Species richness, evenness, and dominance were quantified by using Fisher's Alpha (Fisher *et al*., 1943), Shannon–Wiener Index (Shannon, 1948), Simpson's Index (Simpson, 1949), Pielou's Evenness (Pielou, 1966), Berger–Parker Dominance (Berger and Parker, 1970), Margalef Index (Margalef, 1958), and Menhinick Index (Menhinick, 1964). All diversity indices were calculated using PAST 4.03 (Paleontological Statistics Software) (Hammer *et al*., 2001). Abundance metrics included total count, relative abundance, and density. These indices are central to ecology, conservation biology, sociology, and other disciplines concerned with variation within complex systems (ScienceDirect, n.d. 2025).

Results

Site-wise diversity

The total diversity analysis shows that the three coastal areas differ significantly in species richness, evenness, and dominance.

Kovalam has the highest level of overall diversity among the three beaches. The Fisher's Alpha (0.4594), Margalef (0.3784), and Menhinick (0.07593) indices indicate comparatively higher species richness. The species' even distribution and high diversity are confirmed by both the Shannon-Wiener Index (H' = 1.373) and Simpson's Index (1–D = 0.7438). The distribution of individuals within the species is about equal, according to Kovalam's Pielou's Evenness (J' = 0.9906). Furthermore, the Berger-Parker Dominance Index (0.2868) is the lowest of all, indicating that the assemblage is not dominated by a single species. Together, these findings suggest that Kovalam is home to a more diversified and well-balanced isopod community.

The second-most species-diverse area is Thirumullavaram. Its Menhinick Index (0.06047), Margalef Index (0.2561), and Fisher's Alpha (0.3373) all show moderate richness. A community with a respectable degree of heterogeneity is indicated by diversity values like the Simpson's Index (0.6556) and the Shannon-Wiener Index (1.082). Pielou's Evenness (0.985), which remains high, shows that the distribution of species is fairly even. The Berger-Parker Dominance Index

(0.4124) shows moderate dominance, even if it is slightly higher than Kovalam's. This indicates that, while having somewhat less variation than Kovalam, Thirumullavaram maintains a stable and reasonably diverse isopod colony.

Varkala has the lowest species richness and diversity. With Fisher's Alpha (0.2283), Margalef (0.1373), and Menhinick (0.05245) scores in the lowest end, richness appears to be limited. Both the Shannon-Wiener Index (0.6931) and Simpson's Index (0.4999) indicate low diversity and a community that might be dominated by one or two species. Despite this, evenness (J′ = 0.9999) is strong, which could be explained by the small number of uniformly distributed species. The highest of all, the Berger-Parker Index (0.5062), indicates a single species' dominance, which lowers the variety of the community as a whole (Table 1).

Depth-wise diversity

A distinct depth-associated gradient appeared when data were examined by tidal zone for both years: Kovalam consistently displayed high species richness (Taxa_S = 4) at all depths. The mid and low tide zones showed the highest levels of evenness (J′ > 0.97), low dominance (Berger–Parker < 0.36), and diversity (Shannon's H′ > 1.35; Simpson's 1–D > 0.73). These patterns show a stable and rich colony that is supported by lower tidal level environmental circumstances. This pattern was also observed at Thirumullavaram, where diversity increased from high to low tide. In comparison to the high tide zone (H′ = 0.7239), the mid and low tide zones had greater Simpson's (1–D = 0.6418) and Shannon-Wiener values (H′ = 1.063), suggesting favourable conditions for species diversity in submerged areas. At all depths, Varkala's richness was restricted (Taxa_S = 1-2). One species dominated the whole high tide zone (Berger–Parker = 1.0; H′ = 0), while the mid and low zones showed only slight increases in diversity (H′ < 0.7). Here, high evenness ratings are more likely to result from consistently low species populations than from actual ecological balance (Table 2).

Seasonal variation

Over two years, the seasonal study showed significant temporal trends: In every season, Kovalam showed the greatest and most consistent diversity. The Shannon-Wiener Index varied from 1.267 (monsoon) to 1.353 (postmonsoon), with the postmonsoon having the lowest dominance (Berger–Parker = 0.3301). Ecological robustness to seasonal fluctuations was demonstrated by the consistently high richness (Fisher's Alpha = 0.5198–0.6339) and even distribution (J′ > 0.96). Throughout the seasons, Thirumullavaram's diversity remained steady, and its richness was moderate. With Shannon H′ ranging from 1.068 to 1.092 and Fisher's Alpha about 0.4074, there was little seasonal variation. The dominance and evenness indices stayed within reasonable boundaries. Varkala, on the other hand, maintained a straightforward composition throughout. In all seasons, species richness did not surpass two species, and diversity indices stayed constant (Shannon

Table 1. Overall Diversity Indices for Isopods at the Three Study Sites (Combined Data)

Diversity index	Varkala	Thirumullavaram	Kovalam
Number of Species (S)	2	3	4
Total individuals (N)	1454	2461	2775
Simpson's dominance Index (D)	0.5001	0.3444	0.2562
Simpson's index (1–D)	0.4999	0.6556	0.7438
Shannon–Wiener index (H′)	0.6937	0.9685	1.1674
Pielou's evenness (J′)	1.0000	0.8825	0.8413
Fisher's alpha	0.1134	0.2319	0.3554
Berger–Parker Dominance index	0.8123	0.6729	0.5423
Menhinick's index	0.0525	0.0604	0.0756
Margalef's richness index	0.2747	0.4572	0.6407

Table 2. Depth-wise diversity indices across Kovalam, Thirumullavaram, and Varkala (Combined 2018–2019)

Indices	K1K2H	K1K2L	K1K2M	T1T2H	T1T2L	T1T2M	V1V2H	V1V2L	V1V2M
Berger-Parker	0.4298	0.3604	0.3447	0.5654	0.5107	0.4605	1	0.6637	0.5721
Brillouin	1.232	1.344	1.355	0.7116	1.01	1.056	0	0.6335	0.6773
Chao-1	4	4	4	3	3	3	1	2	2
Dominance_D	0.3115	0.2676	0.2621	0.5019	0.3882	0.3582	1	0.5536	0.5104
Equitability_J	0.9067	0.976	0.9837	0.6589	0.9251	0.9675		0.9212	0.9849
Evenness_e^H/S	0.8786	0.9672	0.9776	0.6875	0.921	0.965	1	0.9469	0.9896
Fisher_alpha	0.636	0.5179	0.5122	0.4439	0.3795	0.3783	0.1442	0.2536	0.2561
Individuals	342	1171	1262	382	1028	1051	148	675	631
Margalef	0.5142	0.4246	0.4201	0.3364	0.2884	0.2875	0	0.1535	0.1551
Menhinick	0.2163	0.1169	0.1126	0.1535	0.09357	0.09254	0.0822	0.07698	0.07962
Shannon_H	1.257	1.353	1.364	0.7239	1.016	1.063	0	0.6385	0.6827
Simpson_1-D	0.6885	0.7324	0.7379	0.4981	0.6118	0.6418	0	0.4464	0.4896
Taxa_S	4	4	4	3	3	3	1	2	2

H′ ≈ 0.692; Berger–Parker > 0.52), indicating that seasonal change was restricted by environmental factors (Table 3).

Abundance trends

Kovalam had the highest total abundance (2,775 individuals) throughout all sampling efforts, followed by Thirumullavaram (2,461) and Varkala (1,454). In terms of depth, higher abundance was consistently supported by mid and low tidal zones throughout sites, with Kovalam mid tide producing the highest count (1,262 individuals). Because of the increased moisture, detritus availability, and substrate stability in the mid and lower intertidal zones, this depth-related pattern highlights their ecological favorability. All three sites—Kovalam (1,142), Thirumullavaram (1,124), and Varkala (659)—saw the highest abundance during the postmonsoon season. These patterns imply that isopod growth is encouraged by post-monsoon environmental factors, including stabilised salinity and organic intake (Table 4).

Species-level abundance

Alloniscus perconvexus and *Ligia dentipes* were the two most prevalent and dominant of the four species, especially in mid and low tidal zones. Although it was relatively limited, *Dynamenella lauticauda* made a substantial contribution in Kovalam. The least common species, *Cirolana bovina*, was mostly found at mid-depths beneath damp substrates.

Visual summary

Figures 1–6, represented through bar and radar charts, clearly illustrate the observed trends in species diversity across the study sites. Under all circumstances, Kovalam exhibited a broad

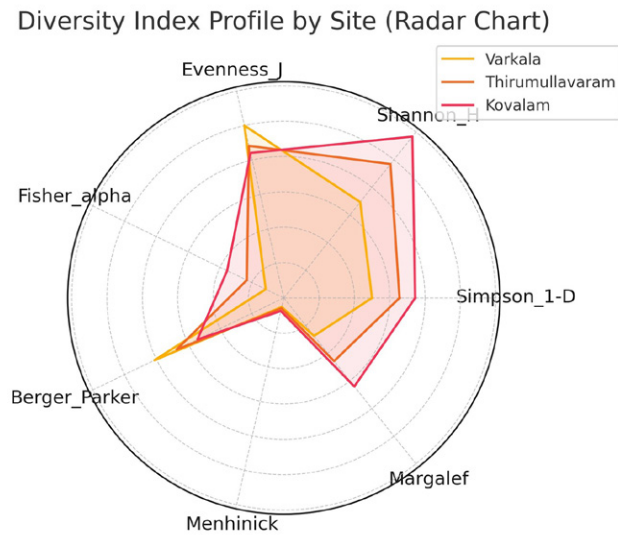

Fig. 1. Radar chart illustrating the multivariate diversity profile of isopod communities at the three study sites. Each axis represents a different diversity index, allowing visual comparison of species richness, evenness, and dominance patterns among Varkala, Thirumullavaram, and Kovalam based on aggregated data of 2018-2019

Table 3. Combined diversity indices of isopods across three coastal sites and three seasons over two years

Parameters	V(PRE)	V(M)	V(POST)	T(PRE)	T(M)	T(POST)	K(PRE)	K(M)	K(POST)
Taxa_S	2	2	2	3	3	3	4	4	4
Individuals	401	394	659	695	642	1124	734	899	1142
Dominance_D	0.5003	0.5016	0.5011	0.3469	0.3374	0.3537	0.2729	0.3177	0.2663
Simpson_1-D	0.4997	0.4984	0.4989	0.6531	0.6626	0.6463	0.7271	0.6823	0.7337
Shannon_H	0.6929	0.6916	0.692	1.077	1.092	1.068	1.337	1.267	1.353
Evenness_e^H/S	0.9997	0.9984	0.9989	0.979	0.9938	0.9699	0.9515	0.8878	0.9674
Brillouin	0.6849	0.6834	0.6868	1.068	1.082	1.062	1.323	1.256	1.344
Menhinick	0.09988	0.1008	0.07791	0.1138	0.1184	0.08948	0.1476	0.1334	0.1184
Margalef	0.1668	0.1673	0.1541	0.3056	0.3094	0.2847	0.4546	0.4411	0.4261
Equitability_J	0.9996	0.9977	0.9984	0.9806	0.9944	0.9722	0.9641	0.9141	0.9761
Fisher_alpha	0.2744	0.2752	0.2544	0.4024	0.4074	0.3747	0.5567	0.5391	0.5198
Berger-Parker	0.5112	0.5279	0.5235	0.4014	0.3769	0.4395	0.342	0.4739	0.3301
Chao-1	2	2	2	3	3	3	4	4	4

Table 4. Total Abundance of isopods by Site, Depth Zone, and Season. This table summarises the total number of individuals collected from three coastal sites (Kovalam, Thirumullavaram, and Varkala) over two years (2018–2020), categorised by tidal depth and seasonal period

Site	Total individuals	High tide zone	Mid tide zone	Low tide zone	Premonsoon	Monsoon	Postmonsoon
Kovalam	2775	342	1262	1171	734	899	1142
Thirumullavaram	2461	382	1051	1028	695	1124	1242
Varkala	1454	148	631	675	401	394	659

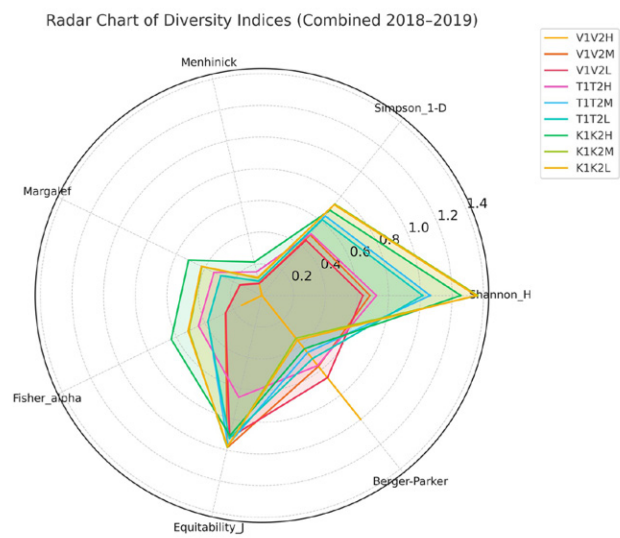

Fig. 2. Radar chart comparing diversity indices across combined site-depth zones (2018–2019) for the three coastal locations. Broader polygons associated with Kovalam low and mid tide zones (K1K2L, K1K2M) indicate consistently higher diversity and evenness. In contrast, the compact shape of Varkala high tide (V1V2H) reflects poor diversity and a dominance by a single species. This composite visualisation underscores depth- and site-related heterogeneity across the study area over two years

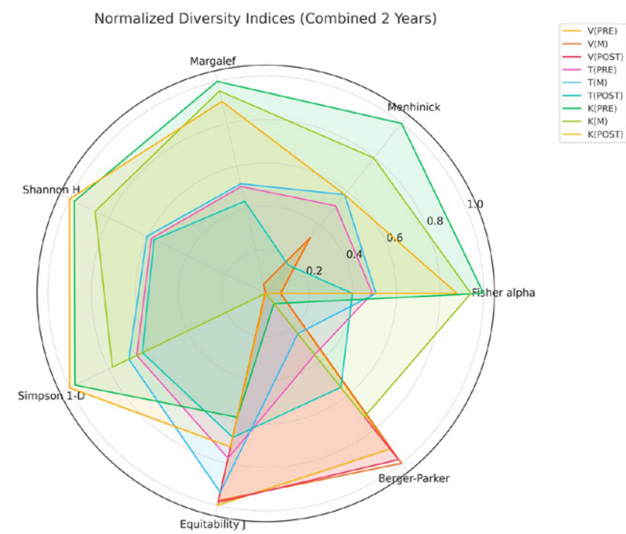

Fig. 3. Radar chart of normalised diversity indices across site-season combinations for the combined two-year dataset. Diversity indices are scaled between 0 and 1 to allow visual comparison of richness, dominance, and evenness patterns across sites and seasons. Each polygon represents one site-season unit (e.g., T(POST)), illustrating multi-dimensional ecological structure. The chart highlights the superior diversity profile of Kovalam and the relatively constrained but stable community structure at Varkala

and well-balanced diversity profile, indicating comparatively greater ecological stability and evenness. Thirumullavaram showed a steady but moderate diversity pattern, suggesting relatively consistent but less pronounced species variation. In contrast, Varkala appeared to be environmentally constrained, as reflected by its high species dominance and comparatively low species richness.

Discussion

Site-wise diversity

There were notable differences in diversity patterns among the three research locations. With the lowest Berger-Parker dominance (0.5423) and strong values in Fisher's Alpha (0.3554), Shannon-Wiener Index (H′ = 1.1674), and Simpson's 1-D (0.7438), Kovalam consistently showed the largest species diversity. Due to good sediment structure, complex habitats, and little human interference, this represents a rich, uniform, and ecologically stable isopod community (Gray, 2002; Poore and Bruce, 2012). Kovalam's ecological appropriateness is further supported by its overall abundance of 2,775 individuals. With three species, intermediate diversity values, and high evenness (J′ = 0.8825), Thirumullavaram had moderate variety. Its community displayed moderate dominance (Berger-Parker = 0.6729) and a significant total abundance (2,461 individuals), suggesting rather stable and resource-rich environments. With only two species and strong dominance, Varkala, on the other hand, had the lowest diversity and richness (Berger-Parker = 0.8123). Although evenness seemed excellent (J′ = 1.0000), this is a statistical consequence of its low species count. Varkala's low diversity and abundance—just 1,454 individuals—indicate ecological filtration or environmental stresses. These patterns are consistent with known relationships between environmental stability, habitat complexity, and diversity (Pearson and Rosenberg, 1978; Warwick and Clarke, 1993).

Depth-wise diversity

Community structure was significantly impacted by intertidal depth gradients. The mid and low tide zones at Kovalam had the largest diversity, with Simpson's 1-D values above 0.68 and Shannon's H′ exceeding 1.2. Additionally, compared to the high tide zone (342), these regions maintained reduced dominance and higher species richness (Fisher's Alpha up to 0.584), which correlated with higher isopod abundance (1,262 and 1,171 individuals, respectively). Similar trends were seen in Thirumullavaram, where variety and abundance were higher at low (1,028) and mid (1,051) tide levels than at high tide (382). Although diversity increased somewhat with depth, Varkala's upper zones were species-poor and dominated by a single taxon (H′ = 0; 1–D = 0). These results align with worldwide observations of vertical zonation caused by desiccation, wave exposure, and substrate moisture (Defeo and McLachlan, 2005; Duggins *et al.*, 1989).

Seasonal diversity

With Fisher's Alpha ranging from 0.5567 to 0.6339 and peak Shannon's H′ values in the postmonsoon (1.364), the seasonal study showed that Kovalam maintained the highest and most consistent diversity across seasons. A consistently balanced society was indicated by low dominance (Berger-Parker = 0.3247–0.3545) and high evenness (J′ > 0.96). The highest abundance (1,142 individuals) was likewise supported by the postmonsoon, indicating beneficial environmental circumstances following monsoonal disruptions. With reasonably consistent diversity indices (H′ = 1.07–1.09) and a peak in abundance (1,124 individuals) during the postmonsoon, Thirumullavaram showed moderate seasonal change. Wave-induced habitat alterations or species turnover may be the cause of a minor postmonsoon fall in richness. With only two species identified and a low Fisher's Alpha (<0.31), Varkala continued to be species-poor throughout the seasons. Low diversity was concealed by high evenness values, but its damaged ecological status is reflected in low seasonal abundance (401–659 individuals) and high dominance (Berger-Parker > 0.5). These findings align with the impact of seasonal environmental factors on intertidal communities, including salinity, rainfall, and organic input (Attrill and Rundle, 2002).

Integrated spatial-temporal insights

Radar and bar chart profiles revealed that the most varied and well-balanced isopod communities were located in Kovalam's mid and low tide zones throughout postmonsoon and premonsoon periods. Varkala's high tide zones, on the other hand, were always dominated and species-poor throughout the year. In line with other research that links diversity to habitat stability and less human disturbance, these patterns were reflected in abundance data, confirming that Kovalam maintains more ecological resilience (Bilyard, 1987).

Ecological implications

Kovalam is a priority for conservation because of its high diversity and low dominance, which show strong ecosystem functioning, including trophic complexity and niche complementarity. On the other hand, Varkala's streamlined and dominance-skewed community likely reflects environmental degradation, sediment instability, or anthropogenic influences. Here, lower isopod abundance indicates both decreased population density and decreased variety. These results support the usefulness of isopods as reliable bioindicators of the health of intertidal ecosystems (Salas *et al*., 2006; Warwick and Clarke, 1993).

Climate change implications and socio-ecological relevance

Intertidal ecosystems, including the habitats examined in this study, are seriously threatened by climate change. By changing moisture regimes, organic input, and sediment stability, variations in temperature, precipitation, and sea level rise can have a direct impact on intertidal isopod populations (Defeo and McLachlan, 2005; Attrill and Rundle, 2002). For example, if sea levels rise, there may be less habitat available in high and mid-tide zones, which could increase competition and perhaps result in the extinction of local species (Duggins *et al*., 1989). Furthermore, the seasonal availability of organic matter and detritus that supports isopod populations may be disrupted by changes in monsoon patterns, as predicted under climate change scenarios (Unni *et al*., 2023).

Intertidal isopods are essential to the health of nearshore ecosystems that sustain artisanal fisheries and wetland livelihoods because of their function in nutrient cycling and detritus decomposition (Salas *et al*., 2006). Fish nursery environments, organic matter recycling, and coastal food webs may all be impacted by changes in isopod diversity (Warwick and Clarke, 1993). As a result, keeping an eye on isopod assemblages offers an affordable bioindicator method for evaluating the health of ecosystems under shifting climate regimes (Gray, 2002). This study emphasises the necessity of combining isopod diversity monitoring with sustainable fishing methods, coastal management, and climate adaptation techniques. The results highlight the significance of biodiversity assessments in fostering resilience and sustainable livelihoods for coastal communities by being in line with the Sustainable Development Goals (SDG 14–Life Below Water) (Henseler *et al*., 2019; Protasov *et al*., 2019).

Conclusion

The study concludes that free-living isopod diversity and abundance along the southern Kerala coast vary distinctly across sites, depths and seasons. Kovalam supported the most diverse and ecologically balanced isopod community, indicating relatively stable habitat conditions, whereas Thirumullavaram showed moderate but consistent diversity. In contrast, the high dominance and low species richness observed at Varkala suggest a simplified community structure, possibly reflecting habitat degradation and ecological stress. Overall, the use of multiple diversity indices provided a comprehensive assessment of intertidal biodiversity and ecological integrity, highlighting the potential of free-living isopods as sensitive bioindicators for monitoring coastal ecosystem health.

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Author contributions

Conceptualisation: AU; Methodology: AU; Data Collection: AU, ASS; Data Analysis: AU, SAS; Writing Original Draft: AU; Writing Review and Editing: BRS; Supervision: BRS.

Data availability

The data are available and can be requested from the corresponding author.

Conflicts of interest

The authors declare that they have no conflict of financial or non-financial interests that could have influenced the outcome or interpretation of the results.

Ethical statement

No ethical approval is required as the study does not include activities that require ethical approval or involve protected organisms/ human subjects/ collection of samples/ protected environments.

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