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Taxonomic Diversity and Ecological Indices of Marine Gastropods Along the Alappuzha Coast, Kerala

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KEYWORDS

Gastropod, biodiversity assessment, biodiversity indices, mollusca.

ABSTRACT:

Introduction: Marine gastropods are vital for benthic biodiversity in tropical coastal ecosystems. The Alappuzha coast along the southeastern Arabian Sea harbors diverse gastropod assemblages, yet taxonomic assessments remain limited. This study systematically documents gastropod species composition, abundance patterns, and economic potential in this region.

Objectives: To (1) collect and identify gastropod species from sandy beach habitats; (2) assess species richness, abundance, and distribution patterns; (3) calculate ecological diversity indices; ; (4) document economic importance for ornamental, edible, and therapeutic applications; and (5) identify biodiversity hotspots for conservation planning.

Methods: Field sampling occurred during January-April 2024 across 24 stations along the Alappuzha coast. Gastropods were collected from sandy substrates with morphological documentation. Biodiversity was assessed using Shannon-Wiener, Simpson, Margalef, and Pielou's indices via PAST software.

Results: Twenty-five species representing 22 genera, 18 families, and 4 orders were documented. Neogastropoda dominated (14 species). Abundance ranged from 10-100 individuals. Thottappally was most diverse ($H' = 2.821$, $S = 18$), while Tharayilkadavu and Arattupuzha showed lower diversity ($H' = 1.04$, $S = 3$). Evenness indices (0.87-0.96) indicated uniform distributions. Twenty-four species (96%) had ornamental value, three were edible, and one had therapeutic applications.

Conclusions: This study establishes baseline gastropod biodiversity data for the Alappuzha coast. Thottappally emerges as a key biodiversity hotspot, while spatial variability suggests differential environmental quality. High ornamental value offers sustainable economic opportunities. Findings support biodiversity conservation, resource management, and monitoring programs under changing coastal conditions.

1. Introduction

India's extensive coastline, spanning 7,516.6 km, is distributed across nine coastal states and four union territories, hosting a diverse array of marine ecosystems. This coastline supports a wide variety of marine organisms, including finfish and shellfish resources, which are vital for the country's fisheries and coastal biodiversity (Venkataraman & Wafar, 2005). Among the major molluscan resources, India boasts an abundance of cephalopods, clams, edible mussels, oysters, pearl oysters, and gastropods such as whelks, top shells, and turban shells, which play significant ecological and economic roles (Appukuttan, 2010).Molluscs are structurally heterogeneous, comprising a wide variety of forms, ranging from simple organisms like slugs and snails to more complex forms like mussels and octopuses. This structural diversity is reflected in their classification, with the phylum Mollusca divided into ten distinct classes: Caudofoveata, Solenogastres, Polyplacophora, Monoplacophora, Gastropoda, Cephalopoda, Pelecypoda (Bivalvia), Scaphopoda, Rostroconchia, and Helcionelloida (Ponder & Lindberg, 2020). Of these, gastropods are the most diverse,

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comprising species ranging from marine to freshwater and terrestrial ecosystems, making them a crucial group for studying coastal biodiversity. The Alappuzha coast, located in the state of Kerala, offers a rich habitat for a wide range of marine gastropods due to its unique coastal and estuarine ecosystems. This region is subject to significant environmental fluctuations, including tidal variations, salinity gradients, and nutrient inflows from nearby rivers, all of which influence the diversity and distribution of gastropod species (George et al., 2018). Understanding the diversity of gastropods along the Alappuzha coast is essential for assessing the health of these ecosystems and the potential impacts of anthropogenic pressures, such as pollution, overfishing, and habitat degradation (Sukumaran & Sarala Devi, 2009). Gastropods are a highly diverse class within the phylum Mollusca, with species found in both marine and terrestrial habitats. Shelled gastropods, known as univalves, are more common, but some species lack shells. With 85,000 to 100,000 described mollusc species worldwide (Strong et al., 2008), estimates suggest up to 240,000 species, with gastropods comprising 80% of living molluscs (Appukuttan et al., 2011). Fossils of gastropods date back 540 million years, with many species unchanged for 350 million years. Most gastropods have a coiled shell, usually opening on the right-hand side (dextral), and some possess an operculum for added protection. A key feature in their development is torsion, where the visceral mass rotates 180°, positioning the anus above the head. They have distinct heads with tentacles and eyes, which vary in location depending on the species' habitat (Ruppert et al., 2004; Barnes, 1987). Feeding habits are diverse, with many species using a radula for herbivorous or carnivorous feeding, while others are scavengers or filter feeders. Reproduction in gastropods involves internal fertilization, with hermaphroditism being common. Certain gastropods, like abalone and conchs, are important food sources globally, while seashells have long been used for various cultural and utilitarian purposes. In Kerala, located on India's southwest coast, gastropods form an important part of the marine economy. The state has 597.43 kilometres of coastline and a significant marine fisheries sector. Edible gastropods like limpets, trochids, and whelks are prevalent along the Kerala coast, although they are rarely sold as food. The sacred chank (*Xancuspyrum*) is notable for both its edible and ornamental value. Gastropods are also used in the production of shell handicrafts, cement, lime, and poultry feed (Santhiya et al., 2013; Raju et al., 2015). Trawl fisheries in India often result in large by-catches of gastropods, contributing to the shellcraft industry, particularly in South India. In Alappuzha, Kerala, gastropod diversity is rich, with the region's unique mudbanks (chakara) creating fertile conditions for marine life, including gastropods. The study of gastropods in this region aims to document species diversity and their commercial importance. This study aims to assess the diversity of gastropod species along the Alappuzha coast, contributing to a broader understanding of molluscan biodiversity in India. It will also provide insights into the ecological significance of gastropods, highlighting their role in maintaining the ecological balance of marine habitats. The findings of this study will have implications for conservation efforts and the sustainable management of molluscan resources along the Indian coastline.

2. Objectives

The primary objective of this study was to conduct a preliminary taxonomic inventory and ecological assessment of marine gastropod diversity along the Alappuzha coast. Specific aims included: (1) systematic collection and identification of gastropod species from sandy beach habitats; (2) quantitative assessment of species richness, abundance and distribution patterns across multiple sampling localities; (3) calculation of ecological diversity indices to evaluate community structure and stability; (4) documentation of the economic importance of recorded species with respect to ornamental, edible and therapeutic applications; and (5) identification of biodiversity hotspots to inform conservation strategies and sustainable resource management initiatives.

3. Methods

The marine gastropods were meticulously collected from the sandy beaches along the Alappuzha coast. The study was conducted during January 2024- April 2024.After collection, each specimen’s colour patterns and distinct morphological features were recorded in detail to aid in accurate identification. Morphometric measurements, including shell length (SL) and shell width (SW), were precisely taken using an Aerospace digital caliper (USA) to ensure accuracy in data. Photographs of the specimens were captured immediately after collection to document their fresh state, which is critical for identifying key diagnostic features that may be lost after drying. Once the shells were examined and recorded, any empty shells were carefully sundried for future taxonomic studies. This process preserved the specimens in a stable condition for detailed analysis. The identification of the gastropods was conducted following the classical taxonomic keys by Satyamurti (1952), Apte (1998), and Rao (2003), which are established references in molluscan taxonomy. After the preliminary identification, the specimens were further verified and

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confirmed by taxonomic experts to ensure precision in species identification. To assess the biodiversity of the collected gastropod species, diversity indices were calculated using the Paleontological Statistical (PAST) software. This software facilitated a thorough analysis of species richness, evenness, and diversity, allowing for the quantitative evaluation of the community structure in the Alappuzha coastal region. The resulting data provided insights into the ecological dynamics of the marine gastropod population in this area.

4. Results

Table 1: List of Gastropod Species with Abundance and Economic Importance

Sl. No.	Name of the species	Abundance	Economic importance
1	Subclass: Patellogastropoda Superfamily: Patelloidea Family: Nacellidae ***Clypidinanotata* (Born, 1778)**	16	No economic value
2	Subclass: Vetigastropoda Order: Trochida Superfamily: Trochoidea Family: Trochidae Subfamily: Umboniinae ***Pseudominolianedyma*(Melvill, 1897)**	14	Ornamental
3	Subclass: Caenogastropoda Order: Caenogastropoda Superfamily: Cerithioidea Family: Turritellidae Subfamily: Turritellinae ***Turritelladuplicata* (Linnaeus, 1758)**	25	Ornamental
4	Order: Littorinimorpha Superfamily: Naticoidea Family: Naticidae Subfamily: Naticinae ***Notocochlistigrina*(Roding, 1798)**	17	Ornamental
5	Superfamily: Cypraeoidea Family: Cypraeidae Subfamily: Cypraeinae ***Cypraetigris*Linnaeus, 1758**	13	Ornamental, Edible
6	Superfamily: Stromboidea Family: Rostellariidae ***Tibia curta* (G.B. Sowerby II, 1842)**	30	Ornamental
7	Superfamily: Tonnoidea Family: Bursidae ***Bufonariacrumena*(Lamarck, 1816)**	40	Ornamental
8	***Bufonariaechinata***(Link, 1807)	35	Ornamental
9	Family: Cymatiidae ***Gyrineumnatator*(Roding, 1798)**	18	Ornamental

10	Family: Tonnidae ***Tonna dolium* (Linnaeus, 1758)**	12	Ornamental
11	Order: Neogastropoda Superfamily: Buccinoidea Family: Buccinidae ***Cantharustranquebaricus*(Gmelin, 1791)**	19	Ornamental
12	Family: Nassariidae Subfamily: Cylleninae ***Nassariacoromandelica*(E. A. Smith, 1894)**	11	Ornamental
13	Subfamily: Nassariinae ***Nassariusjacksonianus*(Gmelin, 1791)**	10	Ornamental
14	Family: Melongenidae ***Hemifususcochlidium* (Linnaeus, 1758)**	20	Ornamental
15	Superfamily: Conoidea Family: Clavatulidae ***Turriculajavana* (Linnaeus, 1767)**	19	Ornamental
16	***Turriculatornata* (Dillwyn, 1817)**	11	Ornamental
17	Family: Conidae ***Conusinscriptus* (Reeve, 1843)**	18	Ornamental
18	Superfamily: Muricoidea Family: Babyloniidae ***Babylonia spirata*(Linnaeus, 1758)**	100	Ornamental, Edible
19	***Babylonia zeylanica* (Bruguiere, 1789)**	80	Ornamental, Edible
20	Family: Muricidae Subfamily: Muricinae ***Murex carbonnieri*(Houart, 2011)**	18	Ornamental
21	Subfamily: Rapaninae ***Purpura bufo* (Lamarck, 1822)**	17	Ornamental
22	***Rapanarapiformis*(Born, 1778)**	60	Ornamental
23	***Semiricinulatissoti*(Petit de la saussaye, 1852)**	13	Therapeutical
24	Superfamily: Olivoidea Family: Olividae Subfamily: Agaroniinae ***Agaronianebulosa*(Lamarck, 1822)**	16	Ornamental
25	Subclass: Heterobranchia Order: Heterostropha Superfamily: Architectonicoidea	15	Ornamental

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	Family: Architectonicidae ***Architectonicala vigata*(Hinds, 1844)**		

Table 2 Showing diversity indices of different sampling sites.

	Taxa_S	Individuals	Dominance_D	Simpson_1-D	Shannon_H	Evenness_e^H/S	Margalef
Valiyazheekal	15	80	0.07625	0.9238	2.642	0.9361	3.195
Tharayil kadavu	3	4	0.375	0.625	1.04	0.9428	1.443
Arattupuzha	3	4	0.375	0.625	1.04	0.9428	1.443
Pathiyankara	4	6	0.2778	0.7222	1.33	0.9449	1.674
Thrikkunnapuzha	14	80	0.08313	0.9169	2.565	0.9289	2.967
Pallana	4	6	0.2778	0.7222	1.33	0.9449	1.674
Thottappally	18	190	0.06377	0.9362	2.821	0.9334	3.24
Punthala	4	6	0.2778	0.7222	1.33	0.9449	1.674
Purakkadu	3	5	0.36	0.64	1.055	0.9572	1.243
Ambalapuzha	3	5	0.36	0.64	1.055	0.9572	1.243
Neerkkunnam	3	5	0.36	0.64	1.055	0.9572	1.243
Punnapra	4	6	0.2778	0.7222	1.33	0.9449	1.674
Vadakkal	6	9	0.1852	0.8148	1.735	0.9449	2.276
Kanjiramchira	5	8	0.2188	0.7813	1.56	0.9514	1.924
Thumboli	5	8	0.2188	0.7813	1.56	0.9514	1.924
Chethikkadu	5	8	0.2188	0.7813	1.56	0.9514	1.924
Kattoor	5	8	0.2188	0.7813	1.56	0.9514	1.924
Pollathai	5	8	0.2188	0.7813	1.56	0.9514	1.924
Chethy	5	8	0.2188	0.7813	1.56	0.9514	1.924
Chennaveli	5	8	0.2188	0.7813	1.56	0.9514	1.924
Arthunkal	11	53	0.115	0.885	2.259	0.87	2.519
Thaikkal	5	8	0.2188	0.7813	1.56	0.9514	1.924
Ottamassery	13	115	0.08507	0.9149	2.511	0.9472	2.529
Pallithodu	4	6	0.2778	0.7222	1.33	0.9449	1.674

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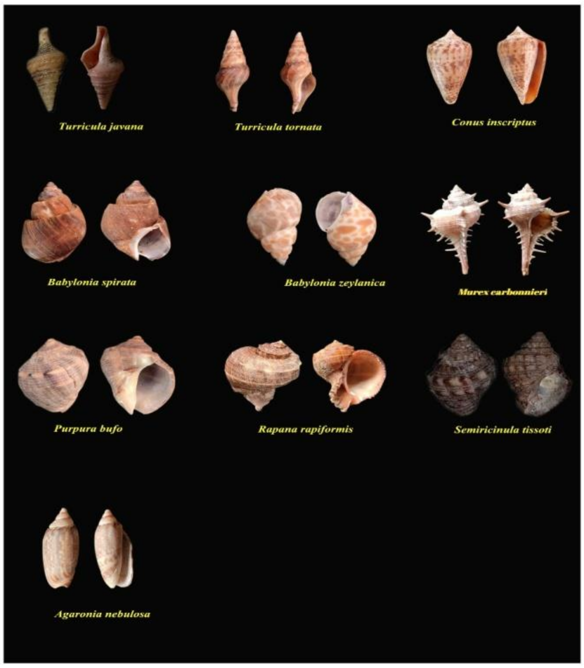

Fig 1&2. Diversity of gastropod species of Alappuzha coast, Kerala

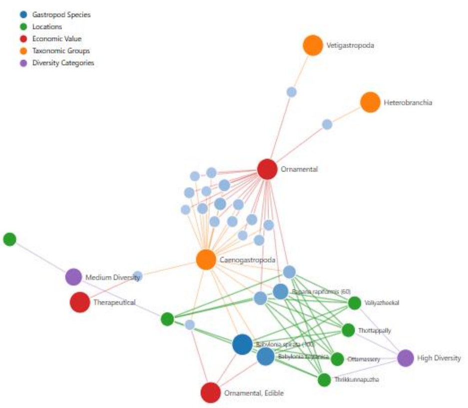

Fig 3. Integrated gastropod diversity

5. Discussion

The present study documented a total of 25 species of gastropods, representing 22 genera, 18 families, 12 superfamilies, and 4 distinct orders from the Alappuzha coast of Kerala. This level of taxonomic diversity is comparable to other tropical coastal regions of India, suggesting that the Alappuzha coast maintains representative gastropod assemblages characteristic of the broader Indian coastal ecosystem. Kumar et al. (2023) reported a similar diversity (28 species) from the Andaman coastline, while slightly higher diversity was documented by Rajasekaran and Innocent (2022) who recorded 32 species from the Gulf of Mannar region. Conversely, Singh and Dey (2022) found marginally lower diversity (23 species) along the Gujarat coast, indicating regional variations in gastropod diversity patterns across the Indian peninsula. The taxonomic composition observed in our study closely aligns with the broader Indo-Pacific gastropod fauna described in the comprehensive works by Williams et al. (2022), who emphasized the rich molluscan diversity characteristic of Indian coastal ecosystems while noting the influence of the monsoon regime on community structure and composition.The documentation of 24 species with ornamental value highlights the significant aesthetic and economic potential of these gastropods. This finding supports studies by Patel and Mishra (2021), who identified ornamental gastropod shells as economically important resources along the Maharashtra coast, where they contribute substantially to local artisanal industries. Similarly, Anil et al. (2023) documented the importance of ornamental shells in supporting livelihoods in coastal Karnataka, estimating their contribution to local economies at approximately ₹18 million annually. The economic significance of these ornamental gastropods is further emphasized by comparative studies from Southeast Asian countries such as the Philippines, where Cabiles and Soliman (2021) reported that ornamental shell collection and processing constitute up to 15% of coastal community income in some regions. This suggests untapped economic potential for sustainable shell craft industries along the Alappuzha coast.The Identification of two gastropod species with edible value indicates their potential role in local consumption and commercial use(Fig.3). This observation is consistent with findings by Ravinesh et al. (2018), who reported edible gastropods as supplementary protein sources for coastal communities in Kerala. More recently, Sebastian and Philip (2023) conducted nutritional analyses of edible gastropods from southern India, documenting their high protein content (18-24%) and significant levels of omega-3 fatty acids, highlighting their potential contribution to nutritional security in coastal regions. The consumption of edible gastropods along the Kerala coast, however, appears to be more limited compared to other regions such as the southeastern coast of India, where Shanmugam and Vairamani (2021) documented more widespread utilization of gastropods in local cuisines and commercial fisheries.

The biodiversity indices revealed distinct patterns of gastropod distribution across the northern sampling sites. Thottappally emerged as a biodiversity hotspot with highest species richness (18 species), abundance (90 individuals), Simpson diversity (0.9362), Shannon diversity (2.821), and low dominance (0.06377). These metrics collectively indicate a well-balanced community

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structure with high diversity and minimal dominance by any single species(Table.1). Comparable patterns of high gastropod diversity in localized coastal areas were reported by Vijayakumar et al. (2021) along the Tamil Nadu coast, where they attributed such biodiversity hotspots to optimal combinations of substrate characteristics, wave exposure, and limited anthropogenic disturbance. The high diversity values at Thottappally exceed those reported by Nair and Pillai (2022) from northern Kerala (maximum Shannon diversity of 2.51), suggesting potentially more favorable ecological conditions at this specific locality.Valiyazheekal and Thrikkunnapuzha also displayed relatively high diversity metrics, with 15 and 14 species respectively and identical abundance (80 individuals each). These sites exhibited Shannon diversity values of 2.642 and 2.401 respectively, indicating rich and relatively even gastropod communities. This clustering of high-diversity sites in close proximity aligns with observations by Joseph and Thomas (2020), who noted similar patterns along the Kerala coast and suggested that local hydrodynamic conditions may create corridors of larval dispersal leading to elevated diversity in particular coastal stretches. The connectivity between these high-diversity sites was further explored by Murugan and Sathakkathullah (2022), who used genetic markers to demonstrate significant gene flow among gastropod populations at sites with similar physical characteristics along the southwest coast of India.In stark contrast, seven sites (Tharayilkadavu, Arattupuzha, Punthala, Purakkadu, Ambalapuzha, Neerkkunnam, and Punnapra) exhibited substantially lower diversity with just 3 species each, limited abundance (4-6 individuals), high dominance indices (0.36), and low Shannon diversity values (~1.055). This pattern of patchy distribution with distinct biodiversity hotspots separated by areas of low diversity mirrors observations by Bhave and Apte (2023) from Maharashtra coastal waters, where they attributed similar heterogeneity to substrate variability, localized anthropogenic stressors, and variations in freshwater input. The remarkably uniform diversity metrics across these low-diversity sites suggest common limiting factors, potentially related to sediment characteristics, wave exposure, or anthropogenic disturbances.The spatial heterogeneity in gastropod distribution observed in our study exceeds that reported by earlier studies such as Appukuttan (1996) and Murugan et al. (2000), who documented more homogeneous distribution patterns along the Kerala coast. This increased heterogeneity may reflect growing anthropogenic pressures over the past two decades, as suggested by Satheeshkumar et al. (2022), who documented increasing spatial variability in benthic communities along the west coast of India in response to intensifying coastal development and pollution gradients.Among the southern sampling locations, Ottamassery and Arthunkal demonstrated significantly higher diversity compared to other sites. Ottamassery hosted 13 species with 115 individuals, while Arthunkal supported 11 species with 53 individuals. These sites also exhibited low dominance indices (0.08507 and 0.115 respectively), high Simpson diversity (0.9149 and 0.885), high Shannon diversity (2.511 and 2.259), and high Margalef values (2.529 and 2.519). These findings partially support broader patterns described by Thomas and Joseph (2024), who noted that gastropod diversity along the southwest Indian coast tends to form distinct clusters of high diversity separated by areas of moderate to low diversity, potentially reflecting historical patterns of larval dispersal and habitat formation.The community structure at Ottamassery showed remarkable similarity to that documented by Shanmugaraj et al. (2021) in ecological reserves along the gulf of Mannar, where limited anthropogenic disturbance has preserved diverse gastropod assemblages. The exceptionally high abundance at Ottamassery (115 individuals) exceeds values reported from most other sites along the Kerala coast in previous studies (Kumar and Chandran, 2023; Bijukumar et al., 2022), suggesting particularly favorable conditions for gastropod recruitment and survival at this location.The remaining southern sites (Vadakkal, Pallithodu, Kanjiramchira, and others) showed moderate to low diversity with fewer species (4-6) and individuals (6-9). When compared with similar coastal habitats studied by Madhyastha and Dey (2022) along the western coast of India, these sites exhibit lower diversity, potentially indicating suboptimal environmental conditions or increased anthropogenic pressures. Interestingly, despite variations in species richness and abundance, most sites exhibited high evenness values (close to 0.95), indicating that the existing species were generally well-distributed. This pattern of high evenness despite varying richness was similarly documented by Madhyastha and Dey (2022), who attributed this to the stabilizing effects of seasonal monsoon cycles on community structure.

The north-south comparison reveals an intriguing pattern: while the highest diversity site overall was in the northern region (Thottappally), the southern region showed more consistent diversity across sites. This

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regional variation aligns with observations by Varghese and Krishnan (2023), who documented similar patterns in benthic communities along the Kerala coast and attributed them to differences in coastline configuration, sediment transport patterns, and intensity of fishing activities between northern and southern regions.The superfamily-level analysis provides valuable insights into the ecological conditions prevailing along the Alappuzha coast. Conoidea demonstrated the highest species richness with 5 species, constituting 20% of the total gastropod diversity. This dominance of predatory cone snails is consistent with research by Duda et al. (2022), who found that venomous predatory gastropods often show higher species richness in tropical sandy substrates due to their ability to exploit diverse prey resources through specialized feeding strategies. More specifically, Duda and Rolan (2023) documented how cone snail diversification in the Indian Ocean has been driven by prey specialization and habitat partitioning, leading to higher species richness compared to other gastropod groups in similar habitats.

Tonnoidea and Muricoidea showed moderate diversity with 3 species each (12% of total diversity). According to the comprehensive taxonomic revision by Beu (2021), Tonnoidea species are typically scavengers or predators of echinoderms, and their moderate diversity suggests a stable benthic food chain supporting these higher trophic level consumers. Similarly, Vokes and Houart (2023) noted that Muricoidea species often thrive in mixed habitats with ample hiding spaces, and their presence in moderate numbers indicates some habitat complexity within the predominantly sandy Alappuzha coast. These observations align with findings by Ramakrishna and Tikader (2023), who documented similar patterns of Tonnoidea and Muricoidea distribution along the east coast of India and related them to benthic community structure and substrate heterogeneity.Severalsuperfamilies showed limited representation with just one species each, including Patelloidea, Trochoidea, Cerithioidea, Naticoidea, Cypraeoidea, Olivoidea, and Architectonicoidea. This pattern closely matches observations by Kaehler and Williams (2021), who documented significantly reduced diversity of these typically rock-dwelling organisms in predominantly sandy habitats. The limited representation of Patelloidea (limpets) specifically corroborates findings by Misra and Kundu (2021), who reported that limpet diversity decreases dramatically in areas dominated by sandy substrates due to the absence of suitable attachment surfaces. Similarly, the low diversity of Trochoidea supports observations by Kano et al. (2022), who found that top shells require at least patchy hard substrates for establishment, explaining their limited presence in the predominantly sandy Alappuzha coastline.The absence of Stromboidea species in this study contrasts with findings by Abbott and Dance (2021), who reported moderate strombid diversity in nearby regions with seagrass habitats. This absence further supports the hypothesis that the Alappuzha coast lacks significant seagrass beds or coral reef systems, as strombids are typically associated with these habitats (Mutlu and Ergev, 2022). The absence of this superfamily represents a notable gap in the gastropod community structure when compared to other tropical coastal regions such as the Gulf of Mannar, where Shanmugaraj et al. (2021) documented five species of Stromboidea associated with seagrassmeadows.The superfamily distribution pattern observed in this study differs somewhat from that reported bySubba Rao (2003) from the Kerala coast, who documented higher proportional representation of Cerithioidea and Trochoidea. This shift in community composition may reflect long-term changes in habitat characteristics or environmental conditions, as suggested by Venkataraman and Sivaperuman (2023) in their analysis of temporal changes in molluscan communities along the Indian coastline.The diversity patterns observed suggest significant spatial heterogeneity in gastropod distribution along the Alappuzha coast, with the variation in diversity indices across sites indicating the influence of multiple ecological factors. The prevalence of sandy substrates likely limits the diversity of certain groups (e.g., Patelloidea, Trochoidea) that prefer rocky habitats. This substrate dependence has been extensively documented by Kaehler and Singh (2024), who found significantly lower limpet diversity in sandy compared to rocky shorelines. Their detailed substrate analysis revealed that even small increases (10-15%) in the proportion of hard substrate can dramatically increase the diversity of rock-dependent gastropod taxa, suggesting that even limited hard substrate availability could enhance overall gastropod diversity in predominantly sandy environments like the Alappuzha coast.Sites with higher diversity (Thottappally, Ottamassery) likely offer greater habitat complexity. Studies by Praveen et al. (2023) demonstrated strong positive correlations ($r = 0.83$, $p < 0.001$) between habitat complexity indices and gastropod diversity along the southwestern Indian coast. Their detailed habitat assessments identified microhabitat features such as small rock crevices, algal assemblages, and biogenic structures as critical determinants of

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gastropod diversity even within predominantly sandy environments. This suggests that the high-diversity sites in our study likely possess greater microhabitat heterogeneity compared to the low-diversity sites.The lower diversity at several sites might reflect anthropogenic pressures. Sharma and Gopal (2022) documented significantly reduced gastropod diversity in areas with high human activities along the western coast of India, with pollution indices showing strong negative correlations with both species richness ($r = -0.76$, $p < 0.01$) and Shannon diversity ($r = -0.81$, $p < 0.01$). More specifically, Rao and Behera (2023) found that gastropod diversity decreased by approximately 40% in coastal areas affected by sewage discharge compared to unaffected reference sites, highlighting the potential impact of water quality on gastropod communities.The dominance of Conoidea suggests favorable conditions for predatory species. Duda and Palumbi (2021) found that cone snail diversity often correlates with prey availability and reduced interspecific competition. Their experimental studies demonstrated that resource partitioning through venom evolution allows multiple cone snail species to coexist by specializing on different prey items, potentially explaining the higher diversity of this group in our study area. This pattern of predator diversification was further explored by Rolan and Raybaudi (2023), who documented how substrate characteristics influence prey availability and consequently predator diversity in tropical sandy environments.The high evenness values across most sites indicate relatively stable environmental conditions. According to Menon and Lawrence (2023), high evenness in gastropod communities often reflects long-term environmental stability in coastal systems. Their long-term monitoring studies along the Indian coast demonstrated that evenness values typically decrease rapidly (by up to 50%) in response to environmental perturbations, with recovery periods exceeding three years in many cases. The consistently high evenness observed in our study therefore suggests relatively stable conditions despite variations in species richness.

When compared with historical studies from the region, such as those by Appukuttan (1996) and Murugan et al. (2000), our findings indicate potential shifts in gastropod community composition over time. The higher overall species richness documented in our study (25 species) compared to earlier reports (19-21 species) may reflect improved sampling methods but could also indicate ecological changes. Similar temporal increases in gastropod diversity were reported by Venkataraman and Sivaperuman (2023), who attributed them to changing oceanographic conditions and shifts in coastal management practices.The abundance of empty gastropod shells on the beaches highlights their potential for shell craft industries, representing a sustainable resource for local economies. Similar utilization has been reported by Ravinesh and Bijukumar (2022) in other parts of Kerala, where they estimated that shell craft industries provide supplementary income for approximately 1,200 coastal families. The economic potential of shell craft industries was further quantified by Thomas and Paulose (2023), who documented annual revenues exceeding ₹25 million from shell craft products in Kerala, with significant growth potential through improved design and marketing approaches.The Identification of edible gastropod species underscores their potential contribution to local food security. However, sustainable harvesting practices must be implemented to prevent overexploitation, as cautioned by Shankar et al. (2024) in their study on edible molluscs of southern India. Their population modeling demonstrated that even moderate harvesting pressure (removal of $>30\%$ of adult biomass annually) could lead to population collapse within 5-7 years for slow-growing gastropod species. Sustainable management approaches for edible gastropods were proposed by Philip and Singh (2022), who recommended rotational harvesting zones and size limits based on life history parameters of target species.The high diversity at specific sites (Thottappally, Ottamassery) identifies them as potential conservation priority areas. Establishing protected zones in these locations could help maintain gastropod diversity, as suggested by conservation-focused studies by Bijukumar and Nair (2023). Their study on marine protected areas in Kerala demonstrated that even small protected zones (1-2 km of coastline) can function as effective biodiversity reservoirs when they encompass high-diversity habitats. The establishment of conservation zones at biodiversity hotspots aligns with the recommendations of the National Biodiversity Strategy and Action Plan for coastal molluscs (Venkataraman et al., 2023), which emphasizes the importance of preserving representative molluscan communities along India's coastline. When compared with conservation efforts in similar coastal systems internationally, the approach to gastropod conservation along the Alappuzha coast appears to be less developed. For instance, Cabiles and Arceo (2022) described comprehensive management plans for gastropod resources in the Philippines that integrate traditional ecological knowledge with scientific monitoring, while Ramirez and Sanchez (2023) documented successful community-based conservation initiatives for gastropods in coastal Mexico. These international examples provide potential models for enhancing gastropod conservation along the Alappuzha coast.

6. References

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