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BIODIVERSITY ASSOCIATED WITH THE MUSSEL BEDS OF VIZHINJAM COAST, KERALA, INDIA

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Abstract: The survey of biodiversity associated with mussel beds (*Perna perna*) of Vizhinjam coast of India from the High Intertidal Zone (HIZ), Mid Intertidal Zone (MIZ) and Low Intertidal Zone (LIZ) recorded a total of 114 species of organisms including of Algae /sea weeds (10 species), Porifera (3 species), Cnidaria (1 species), Platyhelminthes (1 species), Bryozoa (2 species), Annelida (5 species), Nemertea (1 species), Mollusca (49 species), Arthropoda (30 species), Echinodermata (7 species) and Tunicata (2 species). The study recorded two species for the first time from the Indian coast, including *Liomera striolata* (family Xanthidae) and *Axiopsis serratifrons* (family Axiidae). Mussel beds in HIZ harboured a total of 69 species, MIZ 81 species and LIZ 65 species. The floral species diversity, abundance, Simpson concentration, Simpson diversity, Shannon diversity, Brillouin diversity, Pielou evenness and Chao-1 indices registered higher values in HIZ. The Average entropy of the faunal metacommunity was 3.288, with Shannon entropy exhibiting high diversity for LIZ (3.767) than in MIZ (3.555) and HIZ (2.824). The total α diversity recorded a very high value of 26.778; α diversity was highest in LIZ (43.230), followed by MIZ (34.979) and HIS (16.846). Hutcheson's *t*-test for α diversity showed significant variations in floral metacommunity associated with mussel beds between three intertidal zones. The β diversity, indicating the variations between three intertidal zones, recorded a value of 1.376, while the γ diversity value was 36.840. The biodiversity indices for flora and fauna recorded higher values in HIZ and MIZ, indicating that their growth was more in the zones with good light penetration. The spatial heterogeneity, light availability, degree of exposure, changes in temperature and salinity, larval transport, food supply, substrate type and biotic features may lead to the development of a characteristic zonation of species and habitats. This study showed that mussel beds in the intertidal rocky shore ecosystem of Vizhinjam support high diversity of flora and fauna and highlights the need the better understanding of the coastal biodiversity through in depth taxonomic studies.

Keywords: Rocky shore, *Perna*, *Liomera striolata*, *Axiopsis serratifrons*, alpha diversity, beta diversity, Kerala, New record

INTRODUCTION

Rocky shores are home to some of the most biologically diverse and productive communities throughout the world (Little and Kitching, 1996), and are currently used extensively as an ideal habitat to document anthropogenic impacts on the ecosystems (Coutinho *et al.*, 2016). Mussel beds distributed on hard or semi-consolidated substrata throughout most of the oceans, are one of the most prominent and well researched features of rocky shores (Seed, 1976). Mussel beds are intrinsically complex, in terms of their demography, physical structure, associated biota and interactions and are among the most common component of biodiversity of intertidal zones of rocky shores (Dayton, 1971). Mussels are such habitat modifiers (Dayton, 1972), or engineering species (Jones *et al.*, 1994), which by altering the environmental properties facilitate the presence of species that would otherwise be absent (Crooks, 1998) or inhibit or exclude other species (Commito, 1987).

The mussel shells provide secondary hard substratum, which in sedimentary habitats may be the only hard substratum available for settlement of sessile organisms and algae (Albrecht, 1998; Buschbaum *et al.*, 2008). Mussels can thus supply the associated community with 24 to 31 per cent of its energy demand (Norling and Kautsky, 2008). Mussel distribution is often extensive along coastlines, forming either dense mussel beds or patchy distributions, depending on natural factors such as wave exposure, shore level, topography, predation and recruitment rates (Paine and Levin, 1981). Their activities they modify maintain and create habitats facilitating the existence of other species (Jones *et al.*, 1994). Many microhabitats, resources and niches are thus offered by mussel beds and different species may coexist within them, contributing to the further diversification of these assemblages and promoting biocenosis. Mussels are also widely and include species that have been extensively used as biomonitors of environmental water quality (Phillips, 1985).

In India two species of mussels *Perna perna* and *P. viridis* one widely distributed along the coastal waters (Jones and Alagarswami, 1973; Kuriakose and Nair, 1976; Ravinesh and Biju Kumar, 2013). In India the production of mussels, oysters and clams formed around 84,483 tonnes during 2016 (CMFRI, 2017). Brown mussel fishery and aquaculture are well established along Kerala coast (Appukuttan and Nair, 1980; Appukuttan *et al.* 1987, 1989; Ramachandran *et al.*, 1998; Kripa *et al.*, 2001). Studies on the biodiversity associated with mussel beds along Indian coast are limited primarily to the biofouling organisms (Nair and Thampy, 1980). Pillai and Jasmine (1991) provided information on community structure of organisms associated with *Perna perna* from the intertidal rocky shores of Vizhinjam coast, while Biju Kumar and Ravinesh (2013) compared the intertidal biodiversity associated with natural rocky shore and artificial sea wall along Vizhinjam coast of India, while Baiju *et al.* (2016) documented 127 species of organisms in the mussel fishery region of Vizhinjam. Studies by Gardner *et al.* (2016) synonymized *Perna indica* Kuriakose and Nair with *Perna perna* (Linnaeus, 1758). This paper documents the biodiversity associated with the mussel (*Perna perna*) beds of Vizhinjam coast, India.

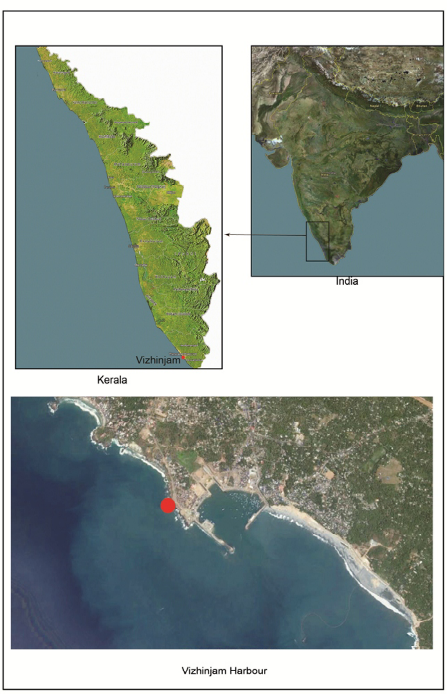

Fig. 1. Map showing the location of mussel beds at Vizhinjam, Kerala, India

MATERIALS AND METHODS

Rocky shore located at Vizhinjam, close to the fishing harbour (Fig. 1) rich in mussel beds was selected as the study site (8°22'N lat; 76° 59' E long.) to document biodiversity associated with the mussel beds. The mussel beds dominated by *Perna perna* were surveyed during December 2015 to May 2016 period. Fortnightly collections were made during early morning, at the time of low tide. To investigate the biodiversity associated with mussel beds, three zones were identified in the intertidal area, namely, (i) High Intertidal Zone (HIZ), (ii) Middle Intertidal Zone (MIZ), and Low Intertidal Zone (LIZ). Quadrats of 0.25 m^2 (50 cm x 50 cm) were used for the assessing the biodiversity (Gonor and Kemp, 1978). The quadrates were placed randomly at each of the intertidal zones identified (HIZ, MIZ and LIZ) and quadrate samples were collected bimonthly. The collection was made with the help of local mussel collectors at Vizhinjam. Statistical analyses such as diversity indices and quadrat richness were calculated using the software Paleontological Statistics Software Package for Education and Data (PAST) version 3.2.1 (Hammer *et al.*, 2001). Metacommunity analysis of three intertidal zones (HIZ, MIZ and LIZ) were compared using the software Biodiversity R

(Biodiversity R and 'vegan' R Development Core Team, 2005). Alpha diversity of the three intertidal zones was compared using Hutcheson's t-test (Zar, 1974).

RESULTS

a. Species Diversity

The study of biodiversity associated with mussel beds (*Perna perna*) of Vizhinjam coast, Kerala revealed the presence of a total of 114 species of organisms (Table 1). The recorded diversity included kingdom Plantae represented by 10 species of algae (sea weeds), kingdom Chromista with 3 species of seaweeds (phylum Phaeophyta) and kingdom Animalia with 101 species. The faunal diversity included Porifera (3 species), Cnidaria (1 species), Platyhelminthes (1 species), Bryozoa (2 species), Annelida (5 species), Nemertea (1 species), Mollusca (49 species), Arthropoda (30 species), Echinodermata (7 species) and Tunicata (2 species).

The study recorded two species for the first time from the Indian coast, *Liomera striolata* (Arthropoda, Crustacea, Brachyura, Xanthidae) (Fig. 2), and *Axiopsis serratifrons* (Arthropoda, Crustacea, Axiidea, Axiidae) (Fig. 3). One species of nudibranch (Nudibranchia, Facelinidae) *Moridilla brockii* was recorded for the first time from the west coast of India. The six species recorded first time from the Kerala coast, included *Lamellaria cf indica* (Gastropoda, Littorinimorpha,Velutinidae), *Doriopsilla miniata* (Nudibranchia, Dendrodorididae), *Vulsella vulsella* (Bivalvia, Ostereoida, Pteriidae), *Spondylus multisetosus* (Pectinida, Spondylidae), *Irus macrophylla* (Veneroida, Veneridae) and *Alpheus serenei* (Malacostraca, Decapoda, Alpheidae).

b. Spatial Variations in Biodiversity

The study also showed variations in the occurrence of species in three different intertidal zones (Fig. 4). HIZ mussel beds harboured a total of 69 species, which included 10 species of Plantae, 3 species of Chromista, and 56 species of Animalia. The species diversity in MIZ mussel beds included 81 species representing 9 species of Plantae, and 69 species of Animalia. The LIZ harboured 65 species, with one species of Chromista and 64 species of Animalia; Plantae was absent in this zone.

The floral species diversity, abundance, Simpson Concentration, Simpson Diversity, Shannon Diversity, Brillouin Diversity, Pielou Evenness and Chao-1 indices registered higher values in HIZ . The evenness index, however, was higher in LIZ, registering a value of 1.00, followed by HIZ (0.468). Menhinick Richness Index recorded higher value in MIZ (0.530) than in HIZ (0.420) and LIZ (0.333). Similarly Margalef Richness Index and Fisher's Alpha Index were also was higher in MIZ than in HIZ. Berger-Parker Dominance was higher in LIZ and MIZ than in HIZ. The values of quadrat richness recorded a value of 106.524 for flora, while the value was only 13 for the fauna associated with mussel beds of Vizhinjam coast.

Fig. 2. *Liomera striolata* collected from the mussel beds of Vizhinjam, Kerala

Fig. 3. *Axiopsis serratifrons* collected from the mussel beds of Vizhinjam, Kerala

The Average entropy of the floral metacommunity was 1.678, with Shannon entropy exhibiting high diversity for HIZ (1.805) than in MIZ (1.471); LIZ recorded a zero value.The total α diversity recorded for the floral metacommunity was 5.356; α diversity was highest in HIZ (6.079), followed by MIZ (4.352) and LIS (1). Hutcheson's t-test for á diversity showed significant variations in floral metacommunity associated with mussel beds between three intertidal zones. The β diversity, indicating the variations between three intertidal zones, recorded a value of 1.029, while the γ diversity value was 5.511. Relative homogeneity of communities was 0.943 and species turn over recorded was 0.014.

The Average entropy of the faunal metacommunity was 3.288, with Shannon entropy exhibiting high diversity for LIZ (3.767) than in MIZ (3.555) and HIZ (2.824).The total á diversity recorded a very high value of 26.778; α diversity was highest in LIZ (43.230), followed by MIZ (34.979) and HIS (16.846). Hutcheson's t-test for α diversity showed significant variations in floral metacommunity associated with mussel beds between three intertidal zones. The βdiversity, indicating the variations between three intertidal zones, recorded a value of 1.376, while the γ diversity value was 36.840. Relative homogeneity of communities was 0.584 and species turn over recorded was 0.188. The biodiversity indices for flora and fauna recorded higher values in HIZ and MIZ, indicating that their growth was more in the zones with good light penetration. Flora and fauna diversity were less in LIZ when compared to other zone, because lower littoral area under dredging activity for port construction. Each species reaches the peak of its competitive ability at a given intersection of the habitat gradients and yet its distribution is ultimately influenced by interactions with other species.

The Kingdom Plantae was represented by 10 species of algae (sea weeds) classified under 2 classes, 6 orders and 7 families. *Chaetomorpha antennina* and *Ulva* spp. were dominant during the collection period. Kingdom Chromista in the intertidal zones of Vizhinjam coast included 3 species of seaweeds represented under phylum Phaeophyta, class Phaeophyceae, two orders and two families. *Sargassum ilicifolium* was the dominant flora in the region, represented in all the intertidal zones. Kingdom Animalia contained 101 species of organisms associated with the mussel bed. The phyla represented in this category are Porifera (3 species, 1 class, 2 orders and 2 families), Cnidaria (1 species), Platyhelminthes (1 species), Bryozoa (2 species, 1 class, 1 order, 2 families), Annelida (5 species, 1 class, 5 orders, 5 families), Nemertea (1 species), Mollusca (49 species, 3 classes, 11 orders, 24 families), Arthropoda (30 species, 1 class, 4 orders, 19 families), Echinodermata (7 species, 3 class, 4 orders, 4 families) and Tunicata (2 species, 1 class, 1 order, 2 families) (Fig. 5).

The indices of biodiversity of flora (Plantae and Chromista) and fauna (Animalia) associated with the mussel beds of three zones of Vizhinjam coast is given in Tables 2 and 3.

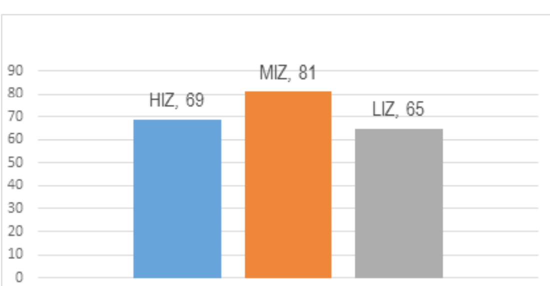

Fig. 4. Species diversity associated with mussel beds in three different intertidal zones of Vizhinjam, Kerala

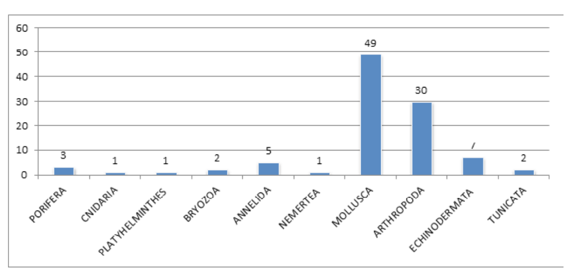

Fig. 5. Species diversity of various animal phyla associated with mussel beds of Vizhinjam coast, Kerala.

Table 1. List of species associated with mussel beds of Vizhinjam coast, Kerala

Sl. No	CLASSIFICATION	Presence in various intertidal zones			Remarks
		HIZ	MIZ	LIZ	
1.	KINGDOM: PLANTAE PHYLUM: CHLOROPHYTA Class: Ulvophyceae Order: Bryopsidales Family: Caulerpaceae Genus: *Caulerpa* *Caulerpa fastigiata* Montagne, 1837	+	+	-	
2.	Order: Cladophorales Family: Cladophoraceae Genus: *Chaetomorpha* *Chaetomorpha antennina* (Bory de Saint-Vincent) Kützing, 1847	+	+	_	
3.	Order: Ulvales Family: Ulvaceae Genus: *Ulva* *Ulva fasciata* (C.Agardh) Montagne, 1846	+	+	-	
4.	*Ulva lactuca* Linnaeus, 1753	+	+	-	
5.	*Ulva quilonensis* Sindhu & Panikkar, 1995	+	-	-	
6.	PHYLUM: RHODOPHYTA Class: Florideophyceae Order: Ceramiales Family: Rhodomelaceae Genus: *Acanthophora* *Acanthophora spicifera* (M.Vahl) Børgesen, 1910	+	+	-	
7.	Genus: *Chondrophycus* *Chondrophycus ceylanicus* (J.Agardh) M.J. Wynne, Serio, Cormaci & G. Furnari, 2005	+	+	-	
8.	Order: Gigartinales Family: Gigartinaceae Genus: *Chondracanthus* *Chondracanthus acicularis* (Roth) Fredericq, 1993	+	+	-	
9.	Family: Spyridiaceae Genus: *Spyridia* *Spyridia filamentosa* (Wulfen) Harvey, 1833	+	+	-	
10.	Order: Corallinales Family: Corallinaceae Genus: *Jania* *Jania spectabile (*Harvey ex Grunow) J.H. Kim, Guiry & H.-G. Choi, 2007	+	+	-	
11.	KINGDOM: CHROMISTA PHYLUM: PHAEOPHYTA Class: Phaeophyceae Order: Dictyotales Family: Dictyotaceae Genus: *Dictyota* *Dictyota dichotoma* (Hudson) J.V. Lamouroux, 1809	+	+	-	

12.	Order: Fucales Family: Sargassaceae Genus: *Sargassum* *Sargassum ilicifolium* (Turner) C.Agardh, 1820	+	+	+
13.	*Sargassum wightii* Greville ex J.Agardh 1848	+	+	-
14.	KINGDOM: ANIMALIA PHYLUM: PORIFERA Class: Demospongiae Order: Haplosclerida Suborder: Haplosclerina Family: Callyspongiidae Genus: *Callyspongia* *Callyspongia diffusa* Ridley, 1884	_	+	+
15.	Order: Hadromerida Family: Clionaidae Genus: *Cliona* *Cliona celata* Grant, 1826	-	+	+
16.	Genus: *Pione* *Pione vastifica* (Hancock, 1849)	+	-	+
17.	PHYLUM: CNIDARIA Class: Anthozoa Order: Actiaria Family: Actinidae Genus: *Anthopleura* *Anthopleura nigrescens* (Verrill, 1928)	+	-	+
18.	PHYLUM: PLATYHELMINTHES Class: Rhabditophora Order: Polycladida Family: Gnesiocerotidae Genus: *Styloplanocera* *Styloplanocera sp*	+	+	+
19.	PHYLUM: BRYOZOA Class: Gymnolaemata Order: Cheilostomatida Family: Bugulidae Genus: *Bugula* *Bugula neritina* (Linnaeus, 1758)	+	+	-
20.	Family: Electridae Genus: *Einhornia* *Einhornia crustulenta* (Pallas, 1766)	+	+	+
21.	PHYLUM: ANNELIDA Class: Polychaeta Order: Aciculata Family: Nereididae Genus: *Nereis* *Nereis* sp.	+	+	+
22.	Order: Spionida Family: Cirratulidae Genus: *Cirriformia* *Cirriformia tentaculata* (Montagu, 1808)	+	+	+
23.	Family: Lumbrineridae Genus: *Lumbrineris* *Lumbrineris latreilli* Audouin & Milne Edwards, 1834	+	-	+

24.	Order: Aphroditoidea Family: Polynoidae Genus: *Lepidonotus* *Lepidonotus* sp.	+	+	+
25.	Order: Terebellida Family: Terebellidae Genus: *Loimia* *Loimia medusa* Savigny (in Lamarck, 1818)	+	+	+
26.	PHYLUM: NEMERTEA Class: Anopla Family: Lineidae Genus: *Lineus* *Lineus mcintoshii* (Langerhans, 1880)	+	+	+
27.	PHYLUM: MOLLUSCA Class: Polyplacophora Order: Chitonida Family: Acanthochitonidae Genus: *Acanthochitona* *Acanthochitona mahensis* Winckworth, 1927	+	+	-
28.	Family: Mopaliidae Genus: *Plaxiphora* *Plaxiphora tricolor* Thiele, 1909	+	+	-
29.	Class: Gastropoda Order: Vatigastropoda Family: Nacellidae Genus: *Cellana* *Cellana livescens* (Reeve, 1855)	+	-	-
30.	*Cellana radiata* (Born, 1778)	+	+	-
31.	Family: Fissurellidae Genus: *Clypidina* *Clypidina notata* (Linnaeus, 1785)	+	-	-
32.	Family: Trochidae Genus: *Trochus* *Trochus radiatus* Gmelin, 1791	+	+	+
33.	Family: Childontidae Genus: *Euchelus* *Euchelus asper* (Gmelin, 1791)	-	+	+
34.	Order: Cycloneritimorpha Family: Neritidae Genus: *Nerita* *Nerita albicilla* Linnaeus, 1758	+	-	-
35.	Order: Littorinimorpha Family: Cypraeidae Genus: *Erosaria* *Erosaria erosa* (Linnaeus, 1758)	-	+	+
36.	*Erosaria ocellata* (Linnaeus, 1758)	-	+	+
37.	Genus: *Lyncina* *Lyncina carneola* (Linnaeus, 1758)	-	-	+
38.	Genus: *Mauritia* *Mauritia arabica (Linnaeus, 1758)*	-	-	+
39.	Genus: *Monetaria* *Monetaria caputserpentis* (Linnaeus, 1758)	-	+	+
40.	*Monetaria moneta* (Linnaeus, 1758)	-	-	+
41.	Genus: *Palmadusta* *Palmadusta clandestina* (Linnaeus, 1767)	-	-	+
42.	Family: Littorinidae Genus: *Littoraria* *Littoraria coccinea glabrata* (Philippi, 1846)	+	+	-

43.	*Littoraria scabra* (Linnaeus, 1758)	+	+	-	
44.	Family: Velutinidae Genus: *Lamellaria* *Lamellaria cf indica* Leach, 1867	+	-	+	New to Kerala Coast
45.	Order: Neogastropoda Family: Columbellidae Genus: *Anachis* *Anachis terpsichore* (G. B. Sowerby II, 1822)	+	+	-	
46.	Family: Muricidae Genus: *Haustellum* *Haustellum haustellum* (Linnaeus, 1758)	-	+	+	
47.	Genus: *Purpura* *Purpura bufo* Lamarck, 1822	-	-	+	
48.	Genus: *Indothais* *Indothais lacera* (Born, 1778)	-	-	+	
49.	Genus: *Maculotriton* *Maculotriton serriale* (Deshayes, 1834)	+	+	+	
50.	Genus: *Tenguella* *Tenguella granulata* (Duclos, 1832)	+	-	-	
51.	Order: Pleurobranchomorpha Family: Pleurobranchidae Genus: *Berthellina* *Berthellina delicata* (Pease, 1861)	+	-	+	
52.	Family: Dorididae Genus: *Doris* *Doris* sp.	-	+	-	
53.	Order: Nudibranchia Family: Dendrodorididae Genus: *Dendrodoris* *Dendrodoris fumata* (Rüppell & Leuckart, 1830)	-	-	+	
54.	*Dendrodoris nigra* (Stimpson, 1855)	-	-	+	
55.	Genus: *Doriopsilla* *Doriopsilla miniata* (Alder & Hancock, 1864)	-	-	+	New to Kerala Coast
56.	Family: Facelinidae Genus: *Moridilla* *Moridilla brockii* Bergh, 1888	-	-	+	New to West Coast
57.	Class: Bivalvia Order: Mytiloida Family: Mytilidae Genus: *Arcuatula* *Arcuatula senhousia* (Benson in Cantor, 1842)	+	+	-	
58.	Genus: *Brachidontes* *Brachidontes pharaonis* (P. Fischer, 1870)	+	+	-	
59.	Genus: *Modiolus* *Modiolus auriculatus* (Krauss, 1848)	+	+	+	
60.	*Modiolus* sp.	+	+	+	
61.	Genus: *Musculus* *Musculus* sp.	-	+	+	
62.	Order: Ostereoida Family: Pinnidae Genus: *Atrina* *Atrina vexillum* (Born, 1778)	-	-	+	
63.	*Pinna saccata* Linnaeus, 1758	-	-	+	
64.	Family: Ostreidae Genus: *Ostrea* *Ostrea* sp1	-	+	+	

65.	*Ostrea* sp2	-	+	+	
66.	Family: Pteriidae Genus: *Pinctada* *Pinctada imbricata fucata* (Gould, 1850)	-	+	+	
67.	*Pinctada margaritifera* (Linnaeus, 1758)	-	+	+	
68.	*Pinctada sugillata* (Reeve, 1857)	-	+	+	
69.	Genus: *Vulsella* *Vulsella vulsella* (Linnaeus, 1758)	+	+	+	New to Kerala Coast
70.	Order: Limoida Family: Limidae Genus: *Limaria* *Limaria fragilis* (Gmelin, 1791)	-	-	+	
71.	Order: Pectinoida Family: Anomidae Genus: *Monia* *Monia sp*	-	+	+	
72.	Family: Chamidae Genus: *Chama* *Chama asperella Lamarck, 1819*	-	-	+	
73.	*Chama pacifica* Broderip, 1835	-	-	+	
74.	Family: Spondylidae Genus: *Spondylus* *Spondylus multisetosus Reeve, 1856*	-	-	+	New to Kerala Coast
75.	Order: Veneroida Family: Veneridae Genus: *Irus* *Irus macrophylla (Deshayes, 1853)*	-	+	+	New to Kerala Coast
76.	PHYLUM: ARTHROPODA Class: Malacostraca Order: Isopoda Family: Anthuridae Genus : *Cyathura* *Cyathura rudloei* Kensley, 1980	+	+	-	
77.	Family: Limnoriidae Genus :*Limnoria* *Limnoria tripunctata* (Menzies, 1951)	-	+	-	
78.	Family: Corallanidae Genus : *Lanocira* *Lanocira glabra Jones, 1982*	+	+	-	
79.	Order: Amphipoda Family: Ampeliscidae Genus : *Ampelisca* *Ampelisca brevicornis* (Costa, 1853)	+	+	+	
80.	Family: Amphithoidae Genus : *Amphithoe* *Amphithoe* sp.	+	+	-	
81.	Family: Aoridae Genus : Aora *Aora typica Krøyer*, 1845	+	+	-	
82.	Family: Gammaridae Genus : *Gammarus* *Gammarus roeselii* Gervais, 1835	+	+	+	
83.	Family: Lysianassidae Genus: *Nannonyx* *Nannonyx goesii* (Boeck, 1871)	+	-	-	
84.	Family: Melitidae Genus: *Elasmopus* *Elasmopus rapax* Costa, 1853	+	+	-	

85.	Class : Crustacea Order: Decapoda Family: Porcellanidae Genus: *Pachychales* *Pachychales natalensis* Krauss,1843	+	+	+	
86.	Genus: *Petrolisthes* *Petrolisthes boscii* Audouin, 1826	+	+	-	
87.	*Petrolisthes lamarckii* (Leach, 1820)	+	+	-	
88.	Class : Crustacea Order: Decapoda Family: Leucosidae Genus: *Cryptocnemus* *Cryptocnemus* sp.	+	+	-	
89.	Genus: *Cyclodius* *Cyclodius* sp.	+	+	-	
90.	Family: Xanthidae Genus: *Liocarpilodes* *Liocarpilodes* sp.	+	+	-	
91.	*Liomera caelata* Odhner, 1925	+	+	-	
92.	*Liomera monticulosa* (A. Milne-Edwards, 1873)	+	+	-	
93.	*Liomera striolata* Odhner, 1925	-	-	+	New to Indian Coast
94.	Genus: *Macromedaeus* *Macromedaeus voeltzkowi* Lenz, 1905	-	+	+	
95.	Family: Menippidae Genus: *Menippe* *Menippe rumphii* Fabricius, 1798	+	+	-	
96.	Family: Hymenosomatidae Genus: *Elamena* *Elamena cristatipes* (Gravely, 1927)	+	+	-	
97.	Family: Pinnotheridae *Afropinnotheres ratnakara* Ng & Kumar, 2015	+	+	+	
98.	Class: Malacostraca Order: Decapoda Family: Alpheidae Genus: *Synalpheus* *Synalpheus sp. aff. tumidomanus* Paulson, 1875	+	+	+	
99.	Genus: *Alpheus* *Alpheus digitalis* De Haan, 1844 [in De Haan, 1833-1850]	-	-	+	
100.	*Alpheus pacificus* Dana, 1852	-	-	+	
101.	*Alpheus serenei* Tiwari, 1964	-	-	+	New to Kerala Coast
102.	Family: Axiidae Genus: *Axiopsis* *Axiopsis serratifrons* A. Milne-Edwards, 1878	-	+	+	New to Indian Coast
103.	Class: Maxillopoda Order: Sessilia Family: Balanidae Genus: *Amphibalanus* *Amphibalanus amphitrite* Darwin, 1854	+	+	-	
104.	Genus: *Megabalanus* *Megabalanus tintinnabulum* Linnaeus, 1758	+	+	+	
105.	Family: Platylepadidae Genus : *Platylepas* *Platylepas* sp	+	+	-	

106. Phylum: ECHINODERMATA Class: Holothuroidea Order: Aspidochirotida Family: Holothuridae Genus: *Holothuria* *Holothuria (Semperothuria) cinerascens* Brandt, 1835	-	+	-
107. Order: Dendrochirota Family: Cucumaridae Genus: *Aslia* *Aslia forbesi* Bell, 1886	-	-	+
108. Genus: *Staurothyone* *Staurothyone rosacea* Semper, 1869	-	+	+
109. Class: Echinoidea Order: Camorodonta Family: Toxopneustidae Genus: *Tripneustes* *Tripneustes gratilla* Linnaeus, 1758	-	-	+
110. Class: Ophiuroidea Order: Ophiurida Family: Ophiactidae Genus: *Ophiactis* *Ophiactis savignyi* Müller &Troschel, 1842	+	+	+
111. Family: Ophiocomidae Genus: *Ophiocoma* *Ophiocoma (Breviturma) dentata* Müller & Troschel, 1842	+	+	+
112. Genus: *Macrophiothrix* *Macrophiothrix aspidota* Müller & Troschel, 1842	+	+	-
113. Phylum: TUNICATA Class: Ascidiacea Order: Enterogona Family: Ascidiidae Genus: *Phallusia* *Phallusia nigra* Savigny, 1816	-	+	-
114. Family: Didemnidae Genus: *Diplosoma* *Diplosoma listerianum* Milne Edwards, 1841	-	+	+

c. Metacommunity partitioning in various intertidal zones

The results of diversity partitioning of floral metacommunity associated with mussel beds in various intertidal zones of Vizhinjam coast is given in Table 4 and Fig. 6. The Average entropy of the floral metacommunity was 1.678, with Shannon entropy exhibiting high diversity for HIZ (1.805) than in MIZ (1.471); LIZ recorded a zero value. The total α diversity recorded for the floral metacommunity was 5.356; α diversity was highest in HIZ (6.079), followed by MIZ (4.352) and LIS (1). Hutcheson's *t*-test for α diversity showed significant variations in floral metacommunity associated with mussel beds between three intertidal zones.

The β diversity, indicating the variations between three intertidal zones, recorded a value of 1.029, while the γ diversity value was 5.511. Relative homogeneity of communities was 0.943 and species turn over recorded was 0.014.

The results of diversity partitioning of faunal metacommunity associated with mussel beds in various intertidal zones of Vizhinjam coast is given in Table 5 and Fig. 7. The Average entropy of the faunal metacommunity was 3.288, with Shannon entropy exhibiting high diversity for LIZ (3.767) than

Table 2. Structural indices of á biodiversity of the floral (Plante and Chromista) communities of the high, mid and lower intertidal zones of Vizhinjam coast, Kerala

Index	High Intertidal Zone (HIZ)	Mid Intertidal Zone (MIZ)	Low Intertidal Zone (LIZ)
Species (S) = Richness	13	12	1
Individuals = Abundance	957	512	9
Simpson Concentration (D)@	0.241	0.31	1
Simpson Diversity (1-D)#	0.759	0.69	0
Shannon Diversity (H') (ln)	1.805	1.471	0
Evenness (corresponding to Shannon)	0.468	0.363	1
Brillouin Diversity	1.773	1.428	0
Menhinick Richness	0.42	0.53	0.333
Margalef Richness	1.748	1.763	0
Equitability (J) = Pielou Evenness	0.704	0.592	0
Fisher's alpha (Logalpha)	2.127	2.2	0.288
Berger-Parker Dominance	0.417	0.469	1
Chao-1	13	12	1

@ = Simpson's Diversity Index
# = Dominance Index = Gini-Simpson Index = Probability of Interspecific Encounter (PIE)

Table 3. Structural indices of á biodiversity of the faunal (Animalia) communities of the high, mid and lower intertidal zones of Vizhinjam coast, Kerala

Index	High Intertidal Zone (HIZ)	Mid Intertidal Zone (MIZ)	Low Intertidal Zone (LIZ)
Species (S) = Richness	58	73	66
Individuals = Abundance	1575	1214	847
Simpson Concentration (D)@	0.134	0.052	0.033
Simpson Diversity (1-D)#	0.866	0.948	0.967
Shannon Diversity (H') (ln)	2.824	3.555	3.767
Evenness (corresponding to Shannon)	0.29	0.479	0.655
Brillouin Diversity	2.752	3.438	3.616
Menhinick Richness	1.461	2.095	2.268
Margalef Richness	7.742	10.14	9.641
Equitability (J) = Pielou Evenness	0.696	0.829	0.899
Fisher's alpha (Logalpha)	11.84	17.06	16.74
Berger-Parker Dominance	0.259	0.137	0.083
Chao-1	86	73.13	66.17

@ = Simpson's Diversity Index
# = Dominance Index = Gini-Simpson Index = Probability of Interspecific Encounter (PIE)

in MIZ (3.555) and HIZ (2.824). The total α diversity recorded a very high value of 26.778; α diversity was highest in LIZ (43.230), followed by MIZ (34.979) and HIS (16.846). Hutcheson's *t*-test for α diversity showed significant variations in floral metacommunity associated with mussel beds between three intertidal zones.

The β diversity, indicating the variations between three intertidal zones, recorded a value of 1.376, while the γ diversity value was 36.840. Relative homogeneity of communities was 0.584 and species turn over recorded was 0.188.

In the present study the α-diversity is estimated as 5.356 and 26.778 for flora and fauna; for flora it was higher in the HIZ, while for fauna it was higher in the MIZ. Beta diversity as a measure of species turnover overemphasizes the role of rare species as the difference in species composition between two sites or communities is likely reflecting the presence and absence of some rare species in the assemblages.

Table 4. Results of diversity partitioning of the floral metacommunity associated with mussel beds in various intertidal zones of Vizhinjam coast

Metacommunity	**High, Mid and Low Intertidal Zones**		
Local Communities	High Intertidal Zone (HIZ)	Mid Intertidal Zone (MIZ)	Low Intertidal Zone (LIZ)
Shannon entropy	1.805	1.471	0
Average entropy of the communities*	1.678		
α diversity	6.079	4.352	1
Total α diversity	5.356		
β diversity	1.029		
γ diversity	5.511		
Relative homogeneity of communities@	0.943		
Species turnover$	0.014		

Hutcheson's *t*-test for α diversity

HIZ*MIZ	$P < 0.001$
HIZ*LIZ	$P < 0.001$
MIZ*LIZ	$P < 0.001$

* Weighted average of community entropy (Routledge,1979)
@ Species composition
$ Rate of change in species composition across H, M & L regions
Values for metacommunities are shown in bold face

Table 5. Results of diversity partitioning of the faunal metacommunity associated with mussel beds in various intertidal zones of Vizhinjam coast

Metacommunity	**High, Mid and Low Intertidal Zones**		
Local Communities	High Intertidal Zone (HIZ)	Mid Intertidal Zone (MIZ)	Low Intertidal Zone (LIZ)
Shannon entropy	2.824	3.555	3.767
Average entropy of the communities*	3.288		
α diversity	16.846	34.979	43.23
Total α diversity	26.778		
β diversity	1.376		
γ diversity	36.84		
Relative homogeneity of communities@	0.584		
Species turnover$	0.188		

Hutcheson's *t*-test for α diversity

HIZ*MIZ	$P < 0.001$
HIZ*LIZ	$P < 0.001$
MIZ*LIZ	$P < 0.001$

* Weighted average of community entropy (Routledge,1979)
@ Species composition
$ Rate of change in species composition across H, M & L regions
Values for metacommunities are shown in bold face

According to Anderson *et al.* (2006) beta diversity is positively related to environmental heterogeneity. The beta diversity values recorded for flora and fauna in the mussel beds are 1.029 and 1.376 respectively, with values of species turn over 0.014 and 0.188. This indicates no much pronounced variations of species in the three intertidal zones (HIZ, MIZ and LIZ) at Vizhinjam. β diversity curve obtained in the present study suggests that the communities are more diverse when their least (rare) common species are considered, because diversity measures of diversity order q>1 are disproportionately sensitive to common species and vice versa. However, the mussel beds in the intertidal rocky shore ecosystem in Vizhinjam support high diversity of flora and fauna; the γ-diversity values of flora and fauna are 5.511 and 36.840 respectively, indicating that the floral communities found the mussel beds as ideal habitat for settlement and colonization.

DISCUSSION

The intertidal and subtidal rocky shores harbour a rich diversity of organisms, and mussel beds are the dominant communities in many such environments, both in tropical and subtropical waters. Many mussel beds are commercially important as mussels form a marine resource with considerable demand as a rich source of protein. As the most traded bivalves in the world, mussels also form integral part of the marine capture fisheries. In the present study a total of 114 species of organisms including 10 species of algae (sea weeds), 3 species of seaweeds and 101 species of animal phyla (Porifera: 3 species; Cnidaria: 1 species; Platyhelminthes: 1 species; Bryozoa: 2 species; Annelida: 5 species: Nemertea: 1 species; Mollusca: 49 species: Arthropoda: 30 species; Echinodermata: 7 species and Tunicata: 2 species).

The study also showed variations in the occurrence of species in three different intertidal zones, High Intertidal Zone (HIZ), Mid Intertidal Zone (MIH) and Low Intertidal Zone (LIZ). HIZ mussel beds harboured a total of 69 species, which included 10 species of Plantae, 3 species of Chromista, and 56 species of Animalia. The species diversity in MIZ mussel beds included 81 species representing 9 species of Plantae, and 69 species of Animalia. The LIZ harboured 65 species, with one species of Chromista and 64 species of Animalia; plantae was absent in this zone. The biodiversity indices for flora (Plantae and Chromista), in general, recorded higher values in HIZ and MIZ, indicating that their growth was more in the zones with good light penetration. The higher values of flora in terms of quadrat richness obtained during the study also corroborate the argument.

The animal diversity recorded in HIZ, MIZ and LIZ were 56, 69 and 64 species respectively. The abundance of fauna, however, was much high in the HIZ, followed by MIZ and LIZ. This observation was also supported by metacommunity studies. In the present study Hutcheson's *t*-test for α diversity showed significant variations in floral and faunal metacommunity associated with mussel beds between three intertidal zones.

Rocky shores encompass a vast range of habitat and community characteristics over a very narrow spatial scale. An important contribution to biodiversity at the level of the physical habitat is the wide range of

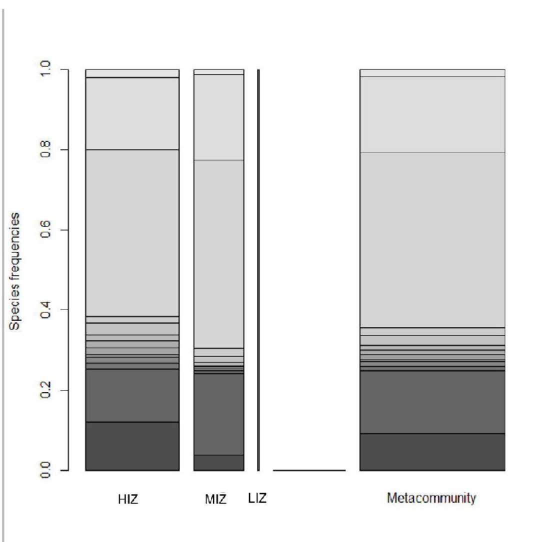

Fig. 6. Plot of the floral metacommunity in various intertidal zones (HIZ, MIZ and LIZ). Bar widths are proportional to community weights. Species abundances are represented vertically

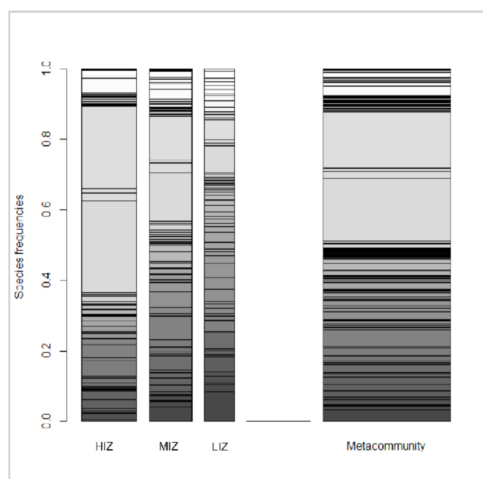

Fig. 7. Plot of the faunal metacommunity in various intertidal zones (HIZ, MIZ and LIZ). Bar widths are proportional to community weights. Species abundances are represented vertically.

biotopes found on rocky shores resulting from environmental gradients and structural complexity of the shore. Each species reaches the peak of its competitive ability at a given intersection of the habitat gradients and yet its distribution is ultimately influenced by interactions with other species. The variable physical conditions, including light availability, degree of exposure, changes in temperature and salinity, aspect, substrate type and biotic features lead to the development of a characteristic zonation of species and habitats. The presence of rock pools provides an opportunity to view many species of intertidal plants and animals in their natural habitat (Bulleri, 2005). Conditions on rocky shores are harsh; organisms have to be able to survive rapidly to changing environmental conditions and to be capable of rapid recolonisation (Dayton, 1971).

The principal causes of differences in assemblages were the wave exposure, larval transport, food supply and spatial heterogeneity (Menge, 1976). Ellis (2003) investigated on temperate intertidal rocky shore zonation and found that the fauna in temperate rocky shore present truly marine species in the low intertidal zone and semi-terrestrial species in the supratidal zones. In the present study the animals recorded from the HIZ are the ones capable of tolerating short periods of exposure. The trend of increased vertical distribution of intertidal species at areas with high wave exposure was found in the rocky shore of intertidal areas (Underwood, 1981).

The spatial heterogeneity, light availability, degree of exposure, changes in temperature and salinity, larval transport, food supply, substrate type and biotic features may lead to the development of a characteristic zonation of species and habitats. This study showed that mussel beds in the intertidal rocky shore ecosystem of Vizhinjam support high diversity of flora and fauna. The earlier studies on the communities associated with mussel beds of *Perna perna* from the Vizhinjam coast (Pillai and Jasmine, 1991) indicated the presence of algae, sponges, sea anemones, planarians, polychaetes, sipunculids, amphipods, isopods, cirripedes, crabs, gastropods and fish larvae. Ravinesh and Biju Kumar (2013) documented Intertidal regions of Kovalam and Vizhinjam rocky regions with a total of 147 species, including 32 seaweeds, 11 sponges, 6 coelenterates, 2 bryozoans, 31 molluscs, 7 annelids, 2 sipunculids, 40 arthropods, 9 echinoderms and 7 species of ascidians were recorded from the location. Baiju *et al*. (2016) documented 127 species including marine algae (8 species), sponges (7 species), cnidarians (7species), platyhelminthes (1 species), annelids (3 species), arthropods (22 species), molluscs (42 species), echinoderms (20 species), chordates (tunicates, 1 species) and fishes (15 species) from this location.

Protected microhabitats on exposed shores, such as algal turfs or deep crevices, can however support a surprising variety of species (Raffaelli and Hawkins, 1996). In the present study greater diversity and abundance of species in HIZ and MIZ corroborate this contention. A study on the community structure of *Perna perna* from the intertidal rocky shores of Vizhinjam by Pillai and Jasmine (1991) showed higher distribution of organisms on the lower intertidal zones; the study showed the major communities associated with mussel beds in Vizhinjam include cirripedes (68% by weight), molluscs (12.74%), polychaetes (7.49%), algae (4.90%), planarians (3.89%), sea anemones (1.20%), amphipods and isopods (0.71%), crabs (0.32%), sipunculids (0.25%), sponges (0.17%) and fish larvae (0.03%). In the present study also the dominant faunal elements dominated with the mussel beds are Mollusca and Arthropoda.

Dayton (1970) observed that an indirect effect of the presence of large organisms is to provide shelter for smaller ones beneath them. Many small animals live beneath mussels, which reduce water movements and trap detritus in a fashion similar to that of deep crevices. Large algae have sheltering beneath them smaller species which die back to their holdfasts if the canopy species are removed.

The presence of zonation patterns indicates that large proportions of available space are dominated by a few species, and this includes sea weeds and a few species of arthropods and molluscs. The complexity of mussel beds in terms of physical structures offers greater scope for settlement of fouling and boring organisms, besides providing microhabitats for others. Algal canopies, and holdfasts especially, support a variety of epiphytic organisms and mussel beds provide a refuge and habitat for a great number of species including representatives from most of the main invertebrate phyla. The importance of biological microhabitat provision on rocky shore diversity is well studied. Physical complexity is also important with crevices, rock pools and the underside of boulders all harbouring diverse species assemblages, including species which are restricted to these microhabitats. According to Pillai and Jasmine (1991) the surface of the shell, the byssus thread and the interspaces of mussels provide substratum and living space for both parabions and cryptobions in the community.

In ecological terms metacommunity is a set of interacting communities which are linked by the dispersal of multiple, potentially interacting species (Gilpin and Hanski, 1991; Wilson, 1992). In the present study the average entropy of the communities were 1.678 and 3.288 respectively for flora and fauna associated with mussel beds of intertidal area.

Alpha (α), beta (β) and gamma (γ) diversities are among the fundamental descriptive variables of ecology and biodiversity studies. While α-diversity represents the mean species diversity in sites or habitats at a more local scale, β-diversity is the rate of change in species composition along a gradient or between sites and γ-diversity is the total species diversity in a landscape (Whittaker, 1972; Magurran, 1988). In the present study the α-diversity is estimated as 5.356 and 26.778 for flora and fauna; for flora it was higher in the HIZ, while for fauna it was higher in the MIZ.

Beta diversity as a measure of species turnover overemphasizes the role of rare species as the difference in species composition between two sites or communities is likely reflecting the presence and absence of some rare species in the assemblages. According to Anderson *et al.* (2006) beta diversity is positively related to environmental heterogeneity. The beta diversity values recorded for flora and fauna in the mussel beds are 1.029 and 1.376 respectively, with values of species turn over 0.014 and 0.188. This indicates no much pronounced variations of species in the three intertidal zones (HIZ, MIZ and LIZ) at Vizhinjam. β diversity curve obtained in the present study suggests that the communities are more diverse when their least (rare) common species are considered, because diversity measures of diversity order $q>1$ are disproportionately sensitive to common species and vice versa.

However, the mussel beds in the intertidal rocky shore ecosystem in Vizhinjam support high diversity of flora and fauna; the γ-diversity values of flora and fauna are 5.511 and 36.840 respectively, indicating that the floral communities found the mussel beds as ideal habitat for settlement and colonization.

In general, species diversity and numbers increase with habitat complexity (Kostylev *et al.*, 1996). The abundance of any species is determined by the resources available and its ability to compete for them. Therefore, species diversity will be greatest in those shores which are rich in varied microhabitats. Mussel beds are recognised as an important source of biodiversity. The presence of biogenic microhabitats can have a negative effect of the number of individuals in a given area.

The biodiversity associated with mussel beds recorded by Pillai and Jasmine (1991) from Vizhinjam region was much lesser compared to the present study. The present study, however, recorded higher species diversity associated with the mussel beds of Vizhinjam coast of Kerala, and highlights the need the better understanding of the coastal biodiversity through in depth taxonomic studies. Such studies would ultimately form the baseline data for planning and implementing coastal development projects, biodiversity monitoring and environmental impact assessment programmes.

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