Eco. Env. & Cons. 29 (July Issue) pp. S55-S67
Copyright@ EM International
ISSN 0971–765X

Special Issue on "Int. Conf. on Impact of Clim. Change on Aq. Life and Mtgn. Measures for a Sust. Blue Economy", 23-25 Nov, 2022, PG & Res. Dept. of Zoology, FMNC, Kollam, Kerala, India.

DOI No.: http://doi.org/10.53550/EEC.2023.v29isp2.010

Intertidal Molluscan Diversity of Thirumullavaram, Kerala, India

Kanni J. Mohan, Laseetha T. G., Jisha S.* and Hari B.

Post Graduate & Research Department of Zoology,
Sree Narayana College, (Affiliated to University of Kerala), Kollam 691 301, Kerala, India

ABSTRACT

Intertidal molluscs are benthic macroinvertebrates that are integral to most intertidal ecosystems. Molluscan diversity along the coast of Thirumullavaram was surveyed for a period of one year (January to December 2021). Specimens were collected during the low tide for each month at four sampling stations through the quadrat method and random handpicking. The samples were photo-documented and preserved in 5% formalin. The collected specimens were identified and classified taxonomically using standard keys and references. A total of 27 species of molluscans were identified during the study period. 17 species were identified from Class Gastropoda, which comprised three orders and 12 families. *Littoraria scabra* was the most numerous gastropod found in all stations. Class Bivalvia was represented by eight species belonging to six families and five orders. Only two species were identified from Class Polyplacophora. 23 species were recorded from Station 1, an undisturbed area, followed by Station 2 with 20 species and station 3 with 13 species. The least was observed in Station 4 (11 species), where heavy human activities were noted. Various diversity indices were estimated for each sampling station. The Shannon-Weiner Diversity index (H′) ranged from 1.14 to 1.55 among the sampling stations. Margalef diversity index was in the higher side for Station 1 and 3 (2.97 and 2.77 respectively) when compared to Stations 3 and 4 (1.82 and 1.57 respectively). The comparative assessment of the relative abundance of the molluscan assemblage revealed that, it did not vary significantly (P>0.05) among the four sampling stations. *Littoraria scabra*, *L. undulata* and *Patella notata* were obtained throughout the study period. Intertidal molluscans play important roles in ecosystem functioning by serving as food resources, promoting intertidal seaweed-litter decomposition, and nutrient cycling. Furthermore, they are acting as ecological indicators of microhabitats, hence continuous monitoring is highly recommended for enabling the conservation of their habitat.

***Key words**: Intertidal rocky shore, Thirumullavaram, Gastropod, Polyplacophora, Molluscs*

Introduction

The intertidal zone, commonly known as the littoral zone, is the area between land and sea that is covered by water at high tide but not during low tide (Jaiswar and Kulkarni, 2001). It is part of the coast which is highly variable, and one of the diverse and most productive areas providing shelter to several intertidal faunas such as crustaceans, polychaetes, amphipods, and molluscs. Phylum Mollusca is the second largest invertebrate group after arthropods, with more than 200,000 species (Ponder and Lindberg, 2004). The littoral fauna, particularly molluscs, are a source of food for other organisms and contribute to huge amounts of biomass on the different trophic levels in ecosystems from primary consumers to top predators (Green *et al.*, 1996).

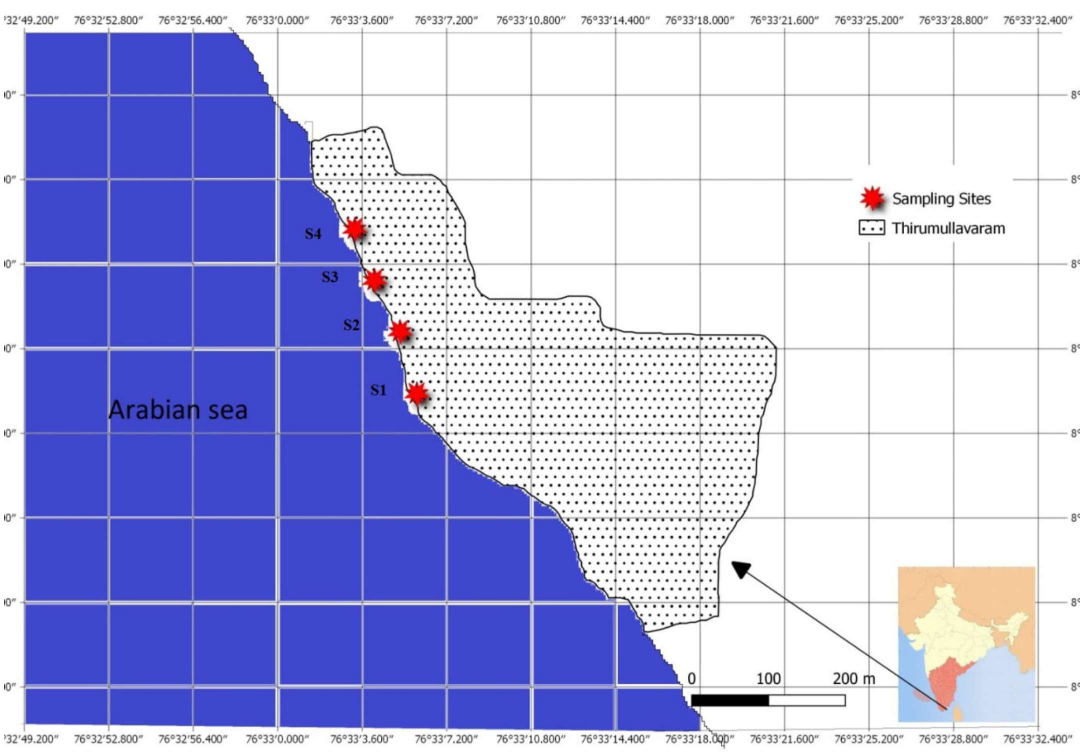
Remote sensing and GIS have been employed in mapping marine habitats, change detection, and estimation of spatial relationships among benthic macrofauna and their habitats in the coastal zones (Green *et al.*, 1996; Godet *et al.*,2009). Choi *et al.* (2011) generated macrofauna habitat potential maps for the Hwangdo tidal flat in South Korea. Molina (2015) correlated shoreline changes in Puerto Rico with the diversity of molluscs using remote sensing and GIS. Several studies have been carried out on the diversity of intertidal molluscs in India (Jaiswar and Kulkarni, 2001; Vaghela *et al.*, 2013; Paul *et al.*, 2014; Pavithran *et al.*, 2014; Monolisha and Patterson, 2015). Paul *et al.* (2016) carried out molluscan mapping based on the biomass differences during different seasons and their physical attributes. Thomas *et al.* (2011) observed that molluscan habitats could be mapped by coupling a dynamic energy budget approach with environmental data such as chlorophyll concentration and temperature extracted from satellite images.

Industrialization and ongoing developmental activities on land have led to the destruction of intertidal habitats. The effect of urbanization on shoreline molluscan communities is thus important. Studies on changes in the coastal ecosystems with respect to the land-use patterns to assess the extent of anthropogenic impacts on the population structure of faunal assemblages have been suggested (Henning *et al.*, 2007). The processes in an ecosystem can take on the diversity of the organisms that make it up. Measuring species richness and diversity across different habitats is useful for planning actions to conserve marine biodiversity (McLean, 1983). Therefore, the present study explains the species composition and diversity of the intertidal rocky shores of Thirumullavaram. The results of this study are expected to enrich the data on the species and habitat of invertebrates in Thirumullavaram, Kollam. The study targets the assessment of the diversity and distribution of molluscan fauna along the intertidal zone.

Materials and Methods

Study site

Thirumullavaram is situated on the west coast ($80^0$42'N Latitude and $76^0$34'E Longitude) of Kollam district of Kerala State (Fig. 1). The shore is partially formed of rocky substratum and sand and is subjected to heavy wave action. The shoreline can be divided into different zones depending on the tidal



S1-Station 1, S2-Station 2, S3–Station 3, S4-Station 4

Fig. 1. Map showing the sampling sites at Thirumullavaram, Kollam, Kerala

action and the type of substratum. The shore is comprised of laterite rocks and scattered granite boulders which provide excellent habitat for the luxurious growth of flora and fauna.

Four stations were selected along the coastline based on anthropogenic activities and degrees of pollution. Station 1 (S1) ($80^0$92′N Latitude and $76^0$64′E Longitude) is comparably undisturbed due to difficulty in accessibility and has a rich growth of seaweeds and epifaunal diversity. Station 2 (S2) ($80^0$91′N Latitude and $76^0$61′E Longitude) is also used as a site for waste disposal from households and fishing activities. The wastes from the Matsyafed Shrimp Hatchery also contribute to coastal pollution. The waste after fishing like the baits and damaged fishing equipment like nets can be seen at this site. Stations 1 and 2 can be characterised by the presence of both artificial rocks for building seawalls and natural rocks. These contribute to the luxuriant growth of macroalgae since they provide the substratum for seaweeds. Station 3 (S3) ($80^0$89′N Latitude and $76^0$58′E Longitude) is characterized by the dumping of waste including the wastes from adjacent shops and houses. The remaining waste of the religious rites and rituals is either dumped directly into the sea or along the shores. The plastic waste disposed of after the visit of tourists and pilgrims are littered along the shore. Station 3 is also mainly composed of artificial rocks along with scattered natural laterite rocks. Station 4 (S4) ($80^0$45′N Latitude and $76^0$55′E Longitude) is selected because it is subjected to high human activities (trampling) since it attracts national as well as international tourists and nature activities. It is also famous among the pilgrims as Thirumullavaram is a pilgrimage center. Station 4 can be distinguished by the presence of artificial rocks which forms the macroalgal bed.

Sample collection

The samples were collected for a study period of one year (January to December 2021) during the low tide (6 am.-10 am.). The methodology included random sampling with 25 cm^2 quadrats (Verma and Agarwal, 1998). The samples were also collected by handpicking. Cemented species such as Chitons were split with a scalpel. Samples were brought to the laboratory and preserved in 5% formalin. Specimens were photo-documented using Nikon D3500 and kept for identification.

Taxonomic Identification

Taxonomic determination was made by using morphological characters and authentic keys of Abbott and Dance (1982), Huber (2010), Rao (2010), and Robin (2008). The identification was also done with the help of a reliable global database (WoRMS, 2021).

Diversity and statistical analysis

The diversity was analyzed using the Shannon-Wiener diversity index, taking into account the number of specimen (individuals) as well as the number of taxa.

Shannon-Weaver diversity index (H′) = - Sum [pi x log (pi)] (Shannon and Weaver, 1949);

Where, H′ = Shannon-Weaver index, Pi = ni /N, ni = no. of individuals of a species, N = Total number of individuals.

Margalef species richness (d) = (S-1)/log (N) (Margalef, 1968);

Where, S = Total species, N = Total individuals

Pielou's evenness index (J′) = H(s)/H(max.) (Pielou, 1966);

Where, H (s) = the Shannon-Weaver information function, H (max.) = the theoretical maximum value for H(s) if all species in the sample were equally abundant

Simpson dominance index (C) = $\Sigma^{s}_{i=1}$ (ni / N)^2 (Simpson, 1949);

Where, ni = number of individuals in the 'each' species, N = total number of individuals, S = total number of species.

Station-wise relative abundance of the molluscan fauna for the study period was analysed by one-way ANOVA. The analysis was performed on the arcsine-transformed data. Statistical analysis was performed using the data analysis function of MS Excel.

Results and Discussion

Species composition

The molluscs species identified from Thirumullavaram during the study period are given in Table 1. The study recorded 27 species of intertidal molluscs belonging to three classes, 9 orders, and 19 families. The Class Gastropoda possessed the highest number of species (17) - 14 species belonging to two orders, Neogastropoda and Littorinimorha, and two species of the family Nacellidae and one

Table 1. Checklist of molluscs collected and identified from Thirumullavaram during January to December 2021

Sl. No.	Class	Order	Family	Species
1	Gastropoda	Neogastropoda	Babylonidae	*Babylonia zeylanica*
2			Conidae	*Conus figulinus*
3				*Conus betulinus*
4			Volutidae	*Harpulina lapponicaloroisi*
5			Muricidae	*Murex pectin*
6				*Thais bufo*
7		Littorinimorpha	Bursidae	*Bursa crumena*
8				*Bursa* sp.
9			Cypraeidae	*Cypraea arabica*
10			Littorinidae	*Echinolittorina leucostica*
11				*Littoraria scabra*
12				*Littoraria undulata*
13			Cassidae	*Phalium bisculatum*
14			Rostellaridae	*Tibia curta*
15		Not assigned	Patellidae	*Patella notata*
16			Nacellidae	*Cellana radiata*
17				*Cellana livescens*
18	Bivalvia	Arcida	Arcidae	*Anadara indica*
19			Glycymerididae	*Glycymeris glycymeris*
20		Carditida	Cartidae	*Cardita bicolor*
21		Cardiida	Donacidae	*Donaxa perittus*
22		Venerida	Veneridae	*Paphia textile*
23				*Venus imbricata*
24		Mytilida	Mytilidae	*Perna indica*
25				*Perna viridis*
26	Polyplacophora	Chitonida	Mopaliidae	*Plaxiphora tricolor*
27		Lepidopleuridae	Leptochitonidae	*Leptochiton asellus*

species of the family Patellidae. Four families (Babylonidae, Conidae, Volutidae, and Muricidae) were recorded in the Order Neogatropoda. Bursidae, Cypraeidae, Littorinidae, Cassidae, and Rostellaridae were the five families observed in the Order Littorinimorpha. The family Littorinidae was observed to have the highest number of species (3).

The Class Bivalvia recorded 8 species belonging to five orders (Arcida, Carditida, Cardiida, Venerida, and Mytilida) and six families. The Order Arcida consisted of two families – Arcidae and Glycymerididae. Class Polyplacophora recorded two species belonging to two orders (Chitonida and Lepidopleuridae) and two families (Mopaliidae and Leptochitonidae).

D'Souza *et al.* (2022) recorded 20 species of molluscs on the Dakshina Kannada coast and reported that their abundance varied between the sites. The study conducted by Michel *et al.* (2007) from the Gulf of California revealed that the highest density of molluscs was shown by Class Gastropoda (1,528 species) from the coastal line which agrees with the result of the present study where Class Gastropoda recorded 17 species. Similar results were obtained from the Chennai coast by Venkataraman *et al.* (2012). 26 species of gastropods and 21 species of bivalves were recorded by them. Paul *et al.* (2014) reported 63 marine molluscs from the coastal cities of northeast India, where 32 species of bivalves were recorded, followed by 31 species of gastropods. Molina (2015) recorded the species of bivalves to be high on the Peurto Rico coast, similar to a study conducted on the Dakshina Kannada coast (D'Souza *et al.*, 2022) where the erosion favoured the presence of bivalves in intertidal zones. The Class Polyplacophora recorded only two species belonging to two orders and two families. Conditions like water availability increased feeding time and decreased water and air temperature determine the occurrence of molluscs in intertidal regions (Jaiswar and Kulkarni, 2001).

Spatial and temporal variation of molluscan fauna and diversity indices

A spatial comparison of the mollusc species collected and identified from Thirumullavaram during the study period is shown in Table 2. Six species of molluscs (*Conus figulinus*, *C. betulinus*, *Echinolittorina leucosticta*, *Littoraria scabra,* L. *undulata*, *Patella notata*, *P. indica, P. viridis* and *Plaxiphora tricolor*) were recorded in all the four stations. *Babylonia zeylanica, Harpulina lapponica loroisi, Cypraea arabica, Phalium bisculatum, Anadara indica, Venus imbricata* and *Leptochiton ascellus* were only observed in Station 1. The species *Murex pectin*, *Donax aperittus,* and *Paphia textile* were observed only in Station 2.

The relative abundance of the molluscan fauna is provided in Table 3 and the one-way ANOVA of the relative abundance revealed that there exists no significant (P>0.05) difference aiming the four different sampling stations. Station 1 was recorded with 23 species as it is an undisturbed area with fewer human activities compared to the other selected stations (Table 4). The Margalef diversity index (Species richness) of four stations was estimated (Table 4) and higher values were recorded for Station 1 (2.97) followed by Station 2 (2.77) and lowest at station 4 (1.57). Station 1 is characterised by the presence of natural laterite rocks, harbouring a rich variety of microhabitats such as rock pools, holes, and crevices, which could be the reason for a higher diversity of species (Gosling, 1992). Ravinesh and Bijukumar (2012) reported 73 species from the intertidal area of a sea wall, while the natural rocky shore harboured 128 species, indicating a preference of organisms to the natural substratum. Twenty molluscan species were recorded from Station 2 and 13 from Station 3. The least number of species was recorded in Station 4 (11). This could be attributed to the waves that break directly in the intertidal zone which carries the intertidal fauna to the supralittoral zones, where burrowing becomes difficult (McLachlan, 2005). The station-wise population count of molluscs collected and identified from Thirumullavaram from January to December 2021 showed that (Table 4), Station 1 was recorded with the highest number of molluscs (1,170) followed by

Table 2. Spatial variation of molluscs collected and identified from Thirumullavaram from January to December 2021

Species	Station 1	Station 2	Station 3	Station 4
Babylonia zeylanica	+	-	-	-
Conus figulinus	+	+	+	+
Conus betulinus	+	+	+	+
Harpulina lapponica loroisi	+	-	-	-
Murex pectin	-	+	-	-
Thais bufo	+	+	-	-
Bursa crumena	+	+	+	-
Bursa sp.	+	+	+	-
Cypraea arabica	+	-	-	-
Echinolittorina leucosticta	+	+	+	+
Littoraria scabra	+	+	+	+
Littoraria undulata	+	+	+	+
Phaliumbis culatum	+	-	-	-
Tibia curta	+	+	-	-
Patella notata	+	+	+	+
Cellana radiata	-	+	+	+
Cellana livescens	+	-	+	+
Anadara indica	+	-	-	-
Glycymeris glycymeris	+	+	-	-
Cardita bicolor	+	+	-	-
Donax aperittus	-	+	-	-
Paphia textile	-	+	-	-
Venus imbricata	+	-	-	-
Perna indica	+	+	+	+
Perna viridis	+	+	+	+
Plaxiphora tricolor	+	+	+	+
Leptochiton asellus	+	-	-	-

" +"- Present; "-"- Absent

Station 2 (953) and Station 3 (733). The least number of molluscs was recorded in Station 4 (575).

The Shannon-Weiner diversity index (H') value denotes the diversity: H'<1=low, 1<H'<3= moderate, H' >3= high. In the present study, the Shannon-Weiner index (H') values of the four sampling stations were in the range of 1.14 to 1.55. The lowest and highest values were recorded in Station 2 (1.14) and Station 3 (1.55), respectively. These values denote that the molluscan species diversity (Shannon-Weiner diversity index) in Thirumullavaram intertidal area was in a moderate level. Simpson's diversity index (1-D) was 0.79 at station 3 and 1 at Station 4. The Pielous species evenness index (H'/Hmax) was highest at station 3 (0.6) followed by station 4 (0.58) and the lowest was recorded in station 2 (0.38). Susintowati *et al*. (2019) who estimated the gastropod diversity and taxa distribution in Alas Purwo National Park, East Java, Indonesia reported the highest value of H' of 3.271, in a rocky shore and this means that, of all the sampled sites, the rocky beach has the highest gastropod diversity when compared to mangrove area where H' = 1.499. Shannon-Weiner diversity index in the range of 1.14 to

Table 3. Relative abundance (%) of molluscs collected from Thirumullavaram from January to December 2021

Species	Station1	Station 2	Station 3	Station 4
Babylonia zeylanica	0.1	0.0	0.0	0.0
Conus figulinus	0.2	0.1	0.1	0.2
Conus betulinus	0.1	0.1	0.1	0.2
Harpulina lapponica loroisi	0.1	0.0	0.0	0.0
Murex pectin	0.0	0.2	0.0	0.0
Thais bufo	0.8	0.5	0.0	0.0
Bursa crumena	1.2	0.8	1.4	0.0
Bursa sp.	1.0	1.3	1.1	0.0
Cypraea arabica	0.2	0.0	0.0	0.0
Echinolittorina leucosticta	2.7	3.1	3.7	3.0
Littoraria scabra	3.4	3.8	3.5	3.5
Littoraria undulata	3.1	3.4	2.9	3.5
Phalium bisculatum	0.1	0.0	0.0	0.0
Tibia curta	0.1	0.1	0.0	0.0
Patella notata	2.7	2.9	2.7	2.8
Cellana radiata	0.0	1.9	1.9	1.6
Cellana livescens	1.9	0.0	2.6	1.7
Anadara indica	0.1	0.0	0.0	0.0
Glycymeris glycymeris	0.1	0.1	0.0	0.0
Cardita bicolour	0.1	0.1	0.0	0.0
Donax aperittus	0.0	0.1	0.0	0.0
Paphia textile	0.0	0.2	0.0	0.0
Venus imbricata	0.1	0.1	0.0	0.0
Perna indica	38.5	40.5	39.8	44.0
Perna viridis	41.8	39.2	38.1	38.3
Plaxiphora tricolor	1.6	1.4	2.0	1.4
Leptochiton asellus	0.1	0.0	0.0	0.0

Table 4. Total number of molluscans collected and identified from Thirumullavaram and their diversity indices from the four sampling stations during the sampling period (January 2021 to December 2021)

	Station 1	Station 2	Station3	Station 4
Total number of molluscan faunas sampled	1170	953	733	575
Total number of molluscan species reported from each sampling station	22	20	13	11
Shannon-Wiener Diversity Index (H')	1.51	1.14	1.55	1.38
Effective No. of Species (ENS)	5	3	5	4
Simpson's Index of Diversity (1-D)	0.67	0.68	0.79	1.00
Pielous Species Evenness Index (H'/H_{max})	0.48	0.38	0.60	0.58
Margalef diversity index (Species richness)	3.11	2.77	1.82	1.57

1.55 in the present study has an equivalent diversity as a community containing equally-common species of exp(H′) which only in the range of 3-5. In the present study, even though 22 and 20 species were recorded from the stations 1 and 2, respectively the effective no of species (ENS) were very low (5 in Station 1 and 3 in Station 2, respectively). Furthermore, the Shannon-Weiner diversity index estimated in the present study (1.14 to 1.55) fell in the range of 1-3 category of H′ which clearly indicated that the study area was moderately polluted (Das *et al*., 2012).

A monthly occurrence of molluscs collected from Thirumullavaram from January to December 2021 is given in Table 5. *Littoraria scabra, L. undulata* and *Patella notata* were recorded throughout the study period. The highest number of species was recorded in the months of May and December (15). The least was recorded in the months of June and July (4 species).

Station-wise count of gastropods, bivalves, and polyplacophorans collected and identified from Thirumullavaram from January to December 2021 is represented in Fig. 2. Bivalves were the dominant class at all four stations and recorded highest in Station 1 (943). *P.viridis* was the most numerous molluscans in Station 1 (489). *P. indica* was the most numerous bivalves in Station 4 (253). 621 molluscs were obtained in Class Gastropoda from all stations. Sta-

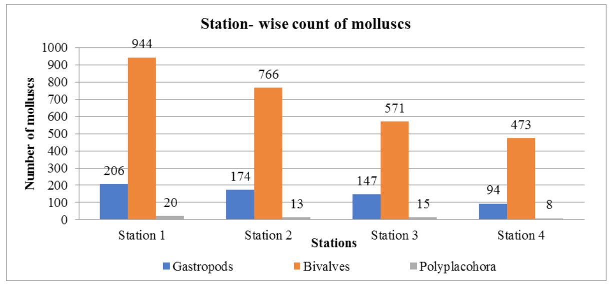


Fig. 2. Station-wise counts of molluscs collected and identified from Thirumulllavaram from January to December 2021

Table 5. Comparative analysis of molluscs collected and identified from Thirumullavaram during January to December 2021

Name of species	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Babylonia zeylanica	-	-	-	+	-	-	-	-	-	-	-	-
Conus figulinus	+	+	-	-	+	-	-	+	-	-	-	-
Conus betulinus	-	-	+	-	+	-	-	-	+	-	-	+
Harpulina lapponica loroisi	-	-	-	-	-	-	-	-	-	-	-	+
Murex pectin	-	-	+	-	-	-	-	-	-	-	-	-
Thais bufo	-	-	-	+	+	-	-	-	-	-	+	+
Bursa crumena	+	-	-	+	+	-	-	+	-	+	-	+
Bursa sp.	-	+	+	+	+	-	-	-	-	+	+	+
Cypraea arabica	-	-	-	+	+	-	-	-	-	-	-	-
Echinolittorina leucosticta	+	+	+	+	+	-	-	+	+	+	+	+
Littoraria scabra	+	+	+	+	+	+	+	+	+	+	+	+
Littoraria undulata	+	+	+	+	+	+	+	+	+	+	+	+
Phalium bisculatum	-	-	-	-	-	-	-	-	-	+	-	-
Tibia curta	-	-	-	-	-	-	-	-	-	-	-	+
Patella notata	+	+	+	+	+	+	+	+	+	+	+	+
Cellana radiata	-	+	+	-	+	-	-	+	-	+	+	+
Cellana livescens	+	-	+	+	+	-	-	+	+	+	+	+
Anadara indica	-	-	+	-	-	-	-	-	-	-	-	-
Glycymeris glycymeris	-	-	-	-	-	+	-	-	-	-	-	-
Cardita bicolor	-	-	-	-	+	-	-	-	-	-	-	-
Donax aperittus	-	-	-	-	-	-	+	-	-	-	-	-
Paphia textile	-	-	-	-	-	-	-	-	+	-	-	-
Venus imbricata	-	-	-	-	-	-	-	-	-	-	+	-
Perna indica	+	+	+	+	+	-	-	+	+	+	+	+
Perna viridis	+	+	+	+	+	-	-	+	+	+	+	+
Plaxiphora tricolor	+	+	+	+	-	-	-	-	-	+	+	+
Leptochiton asellus	-	-	-	-	-	-	-	-	-	-	+	-

"+"- Present; "-"- Absent

tion 1 recorded 206 gastropods while only 94 were reported from Station 4. Only 56 molluscs were recorded in Class Polyplacophora and the highest number was reported from Station 1 (20).

The monthly count of molluscs collected and identified from Thirumullavaram from January to December 2021 is shown in Fig. 3. The highest number of molluscs was recorded in the month of November (454), followed by December (446). The least number of molluscs were observed in July (27).

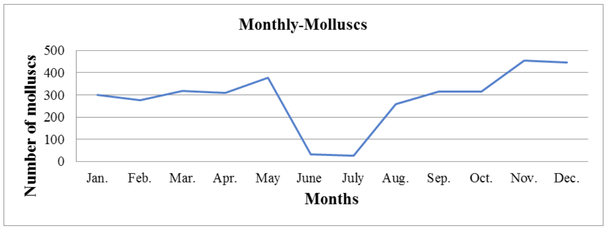


Fig. 3. Monthly counts of molluscs collected and identified from Thirumullavaram from January to December 2021

The Order Neogastropoda recorded only 27 individuals during the study period (Fig. 4). The species *Thais bufo* recorded the highest with 14 individuals. The highest number of molluscs of Order Neogastropoda was recorded in April 2021 (7).

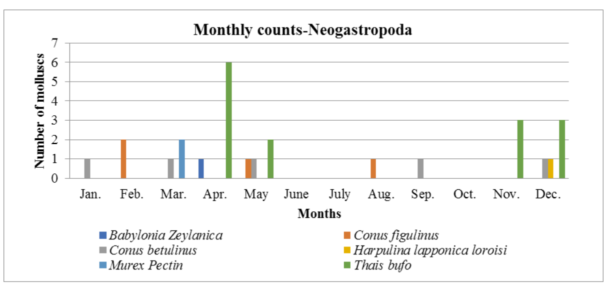


Fig. 4. Monthly counts of molluscs of the Order Neogastropoda collected and identified from Thirumullavaram from January to December 2021

The Order Littorinimorpha recorded 406 individuals during the study period. The species *Littoraria scabra* recorded the highest with 122 individuals (Fig. 5). The highest number of molluscs of Order Littorinimorpha was recorded in August 2021.

The gastropods *Patella notata*, *Cellana radiata*, and *C. livescens* are not assigned to any orders (WoRMS, 2021). The species *P. notata* recorded the highest number (96) during the study period and was noted as highest in the month of August 2021 (11) (Fig 6).

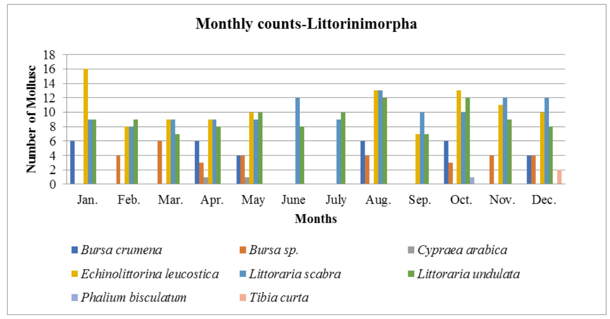


Fig. 5. Monthly counts of molluscs of the Order Littorinimorpha collected and identified from Thirumullavaram from January to December 2021

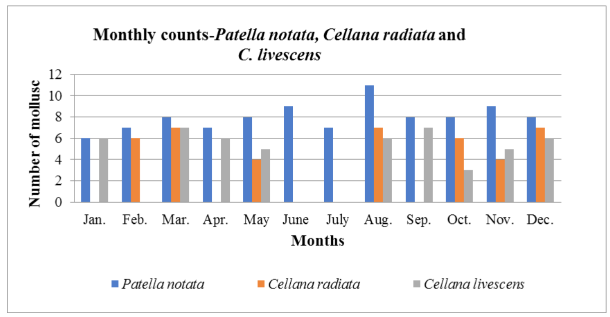


Fig. 6. Monthly counts of molluscs *Patella notata*, *Cellana radiata*, and *C. livescens* collected and identified from Thirumullavaram from January to December 2021

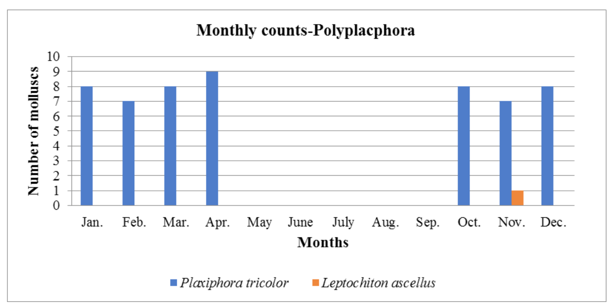


Fig. 7. Monthly counts of bivalves collected and identified from Thirumullavaram from January to December 2021

Bivalves were the dominant class with the most representatives (2,753) during the study period out of which, the highest recorded species was *Perna indica* (1,382) (Fig. 7). They were recorded highest in the month of November 2021 (389).

Class Polyplacophora recorded only 56 individuals during the study period (Fig. 8). *Leptochiton asellus* was observed only in November and represented by a single individual. *Plaxiphora tricolor* was the most represented polyplacophoran (55).

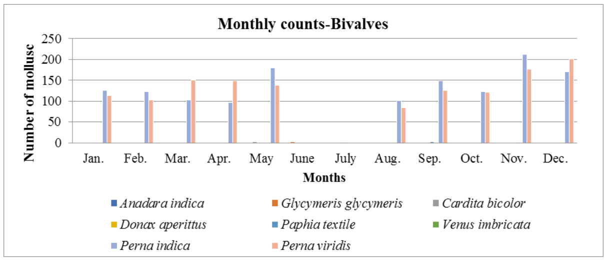


Fig. 8. Monthly counts of molluscs of Class Polyplacophora collected and identified from Thirumullavaram from January to December 2021

Commercial importance

The molluscs have been used throughout human history for food, tool, decoration, exchange currency, etc. (Maurer, 2006; Bar-Yosef *et al.*, 2010; Çakirlar, 2011). Many species are cultivated and harvested, and used commercially (Cooley *et al.*, 2012). There are several economically important species of gastropods present in Thirumullavaram such as *B. zeylanica*, *Thais bufo*, *Bursa* sp., *Littoraria* sp., and *Tibia curta*. In India, during time immemorial the usage of gastropods is common for food and commercial purpose. Philip and Appukuttan (1997) described the heavy landings of *Babylonia* sp. of Kollam. The meat and operculum of *B. zeylanica* are commercially important (Anjana, 2007) and in the present study, it is obtained from Station 1 of Thirumullavaram. Ayyakkanuu (1994) reported that at Annappanpettai landing center along the Porto Novo coast, fishing for *B. spirata* was carried out using special traps with the help of catamarans and dried octopus as bait. The genus Littorina is abundant in Thirumullavaram as it is present in all stations and present throughout the study period. Natarajan *et al.* (1988) reported that species of the following genera are collected and their shells were used by ornamental industry: *Littorina*, *Tibia*, *Conus*, *Murex*, *Babylonia*, *Bursa*, *Phalium*, and *Thais*. *P. indica* and *P. viridis* are the most numerous bivalves present in Thirumullavaram and can be found in all stations. The clam, *Donax aperittus* obtained from Station 2 is also cultured for food. Clams and mussels are commercially cultured as well as exploited for food (Kripa and Appukuttan, 2003). The tremendous potential value of molluscan resources can be associated with sustainable molluscan fisheries and can fuel prosperous India (Mohammed and Venkatesan, 2017).

Ecological importance

Molluscs can be highly sensitive to environmental change being used as indicators (e.g., "Mussel Watch Program", one of the most successful biomonitoring programs ever (Kimbrough *et al.*, 2008). These molluscans can be used as biological filters also (Gutiérrez *et al.*, 2003; Jackson *et al.*, 2008). The rocky substratum and luxurious macroalgal vegetation at Thirumullavarm provide a habitat for the excellent growth of *P. indica* and *P. viridis.* Mussels are among the best-studied organisms probably due to their high economic value but also because of their high invasiveness capabilities (Michaelidis *et al.*, 2005; Kurihara *et al.*, 2008; Gazeau *et al.*, 2010). Biomedical investigations can make utilise some molluscan species (Olivera and Teichert, 2007; Safavi-Hemamia *et al.*, 2015). Many of them are hosts of parasites, pests, and invasive species (Lowe *et al.*, 2000; Barker, 2002; Caron *et al.*, 2014). Shells and their aggregations are important components of benthic ecosystems, providing complex and heterogeneous habitats influencing processes like colonization and settlement, and supporting a rich species diversity (McLean, 1983; Coen and Grizzle, 2007; Commito *et al.*, 2008). Bivalves can be considered excellent ecosystem engineers in aquatic environment (Crooks and Khim, 1999; Gutiérrez and Iribarne, 1999; Vaughn and Spooner, 2006; Buschbaum *et al.*, 2009). Intertidal habitats are today at risk from increased anthropogenic impact due to over exploitation, habitat destruction, climate change, and its consequences (Coleman and Williams, 2002; Lydeard *et al.*, 2004; Galbraith *et al.*, 2010; Gazeau *et al.*, 2013, Atkinson and Vaughn, 2015).

Conservation measures

The land-use patterns indicate the anthropogenic changes along the coast which alter the coastal geomorphology by shifting the shorelines, thus affecting the diversity of molluscs inhabiting these sites (D'souza *et al.*, 2022). Intertidal habitats are facing a threat due to the shifting of residential land uses toward coastlines (Rumahlatlu and Leikawabessy, 2017). Global climate change, population growth, and sea-level rise increase anthropogenic pressures, which in turn causes unusual impacts on coastal ecosystems (Dafeo, 2009). Recent studies have shown that anthropogenic disturbances influence mollus can species richness and evenness (D'Souza and Shenoy, 2018). Habitat disturbance due to anthropogenic activities is a major source of biodiversity loss, especially in Intertidal rocky shores (Worm *et al.,* 2006). The Coast of Kerala is a famous tourist attraction and a paradise for nature activists also the anthropogenic activities like the construction of buildings by impinging the shores and religious activities performed at pilgrimage sites like Varkala, Kovalam, etc. constitute the heavy plastic pollution along the shoreline (Palanisamy and Yadav, 2015). Station 1 is rich in molluscs owing to its inaccessibility and presence of macroalgae which provides habitat, shelter and food. Since Thirumullavaram is a famous pilgrimage site, the dumping of plastic and organic waste resulting in heavy pollution poses a serious issue in all the stations, especially in 2, 3, and 4. It is of great importance to identify and monitor information regarding the local fauna to understand the impacts on the ecosystem and to formulate successful conservation strategies for the habitat as well as the diversity (Meirless *et al.,* 2006). Hence, immediate priority should be given to avoid developmental activities as well as plastic pollution at Thirumullavaram intertidal rocky shores, which are impacted by receding shorelines. Then, the intertidal zone can be recovered as a habitat for the molluscs.

Conclusion

Intertidal molluscs are benthic macroinvertebrates that are integral to most intertidal ecosystems. A total of 27 species and 3,430 molluscs were identified during the study period. 17 species were identified from Class Gastropoda, which comprised two orders and 12 families. Class Bivalvia was represented by eight species belonging to six families and five orders. Only two species were identified from Class Polyplacophora. *Perna indica* was the highest-recorded mollusc from Thirumullavaram. *Littoraria scabra* was the most numerous gastropods found in all stations. 23 species were recorded from Station 1. Only 11 species were recorded from Station 4 owing to the anthropogenic activities going on there. Margalef diversity index was on higher side for Stations 1and 3 (2.97 and 2.77, respectively) when compared to Stations 3 and 4 (1.82 and 1.57, respectively). The Shannon-Weiner Diversity index (H') ranged from 1.14 to 1.55 among the sampling stations and it denotes that Thirumullavram intertidal area support only moderate molluscan diversity. The comparative assessment of the relative abundance of the molluscan assemblage revealed it did not vary significantly ($P>0.05$) among the four sampling stations. Acquiring data on the diversity of molluscs can help monitor the shoreline changes and to understand the distribution of molluscan species along the coast. Thirumullavaram coast is facing a threat due to changes in land-use patterns, as well as waste disposals. The present study stresses the need for minimizing anthropogenic activities such as the modernization of beaches for recreation, pilgrimage activities, and plastic pollution in order to protect the habitats of molluscs.

Acknowledgement

The authors are grateful to The Principal, Sree Narayana College, Kollam for providing the facility for carrying out the study. The authors are also acknowledging the research facility provided by DST-FIST (2018-2021) and DBT- Star College Scheme. The first author acknowledges CSIR for JRF fellowship for pursuing her Ph.D. Programme and University of Kerala for her Ph.D. Registration.

Conflicts of Interest

The authors declare that they have no conflict of interest.

References

Abbott, R.T. and Dance, S.P. 1982. Marine Gastropods. In: EP Dutton (Eds.). *Compendium of Seashells*. Odysey Publications, New York. 320-411

Anjana, M. 2007. *Eco-biology and fisheries of the whelk, Babylonia spirata (Linnaeus, 1758) and Babylonia zeylanica (Bruguiere, 1789) along Kerala coast, India. Doctoral Thesis.* Central Marine Fisheries Research Institute, Kochi, India. 115-125.

Atkinson, C. L. and Vaughn, C.C. 2015. Biogeochemical hotspots: Temporal and spatial scaling of freshwater mussels on ecosystem function. *Freshwater Biology.* 60 : 563-574.

Ayyakkannu, K. 1994. Fishery status of *Babylonia spirata* at Porto Novo, southeast coast of India. *Phuket Marine Biological Center Special Publication.* 13: 53-56.

Barker, G. M. 2002. Gastropods as Pests in New Zealand Pastoral Agriculture, with Emphasis on Agrilomacidae, Arionidae and Milacidae. In: Barker, G.M. (Eds.). *Molluscs as Crop Pests*. CABI Publications, Wallingford, Oxfordshire, United Kingdom. 361-424.

Bar-Yosef, M.D. E., Gümüs¸ D. A. and Islamoglu, Y. 2010. Fossil hunting in the Neolithic: Shells from the Taurus Mountains at Çatalhöyük, Turkey. *Geoarchaeology*. 25: 375-392.

Buschbaum, C., Dittmann, S., Hong, J.S., Hwang, I.S., Strasser, M., Thiel, M., Valdivia, N., Yoon, S.P. and Reise, K. 2009. Mytilid mussels: Global habitat engineers in coastal sediments. *Helgoland Marine Research.* 63: 47-58.

Çakirlar, C. 2011. Archaeomalacology Revisited: Non-dietary use of molluscs in archaeological settings. *Archaeomalacology Revisited*. 1-104.

Caron, Y., Martens, K., Lempereur, L., Saegerman, C. and Losson, B. 2014. New insight in lymnaeid snails (Mollusca, Gastropoda) as intermediate hosts of *Fasciola hepatica* (Trematoda, Digenea) in Belgium and Luxembourg. *Parasites & Vectors.* 7: 66-75.

Choi, J.K., Oh, H. J., Koo, B. J., Lee, S. and Ryu, J. H. 2011. Macrobenthos habitat mapping in a tidal flat using remotely sensed data and a GIS-based probabilistic model. *Mar. Pollut. Bull*. 62: 564-572; https://doi.org/1010.1016/j.marpolbul.2010.11.028.

Coen, L.D. and Grizzle, R. 2007. Ecosystem services related to oyster restoration. *Marine Ecology Progress Series.* 341: 303-307.

Coleman, F. C. and Williams, S.L. 2002. Over exploiting marine ecosystem engineers: Potential consequences for biodiversity. *Trends in Ecology Evolution.* 17: 40-44.

Commito, J. A., Como, S., Grupe, B. M. and Dow, W. E. 2008. Species diversity in the soft-bottom intertidal zone: Biogenic structure, sediment, and macrofauna across mussel bed spatial scales. *Journal Experimental Marine Biology Ecology.* 366: 70-81.

Cooley, S.R., Lucey, N., Kite-Powell, H. L. and Doney, S.C. 2012. Nutrition and income from molluscs today imply vulnerability to ocean acidification tomorrow. *Fish and Fisheries.* 13: 182-215.

Crooks, J. A. and Khim, H.S. 1999. Architectural vs biological effects of a habitat altering, exotic mussel, *Musculista senhousia*. *Journal Experimental Marine Biology Ecology*. 240: 53-75.

D'Souza, S. L., Bhatt, G. H and Shenoy, K. B. 2022. Study of intertidal molluscan diversity of the Dakshina Kannada coast, India using remote sensing and GIS techniques. *Current Science*. 122(12): 1426-1440.

D'Souza, S.L. and Shenoy, K.B. 2018. Intertidal molluscan diversity of Mangalore coast. *Perspectives on Biodiversity of India*. 3: 173-175.

Dafeo, O. 2009. Threats to sandy beach ecosystems: A review. *Estuarine, Coastal and Shelf Science.* 81(1): 1-12.

Das P., Joshi S., Rout J. and Upreti D.K. 2012. Shannon Diversity Index (H) as an Ecological Indicator of Environmental Pollution - A GIS Approach. *Journal of Functional and Environmental Botany* 2(1): 22-26. doi:10.5958/j.2231-1742.2.1.003.

Galbraith, H. S., Spooner, D. E. and Vaughn, C. C. 2010. Synergistic effects of regional climate patterns and local water management on freshwater mussel communities. *Biological Conservation.* 143: 1175-1183.

Gazeau, F., Gattuso, J. P., Dawber, C., Pronker, A., Peene, F., Peene, J., Heip, C. and Middelburg, J. 2010. Effect of ocean acidification on the early life stages of the blue mussel, *Mytilus edulis. Biogeoscience.* 7: 2051-2060.

Gazeau, F., Parker, L. M., Comeau, S., Gattuso, J. P., O'Connor, W. A., Martin, S., Pörtner, H. O. and Ross, P. M. 2013. Impacts of ocean acidification on marine shelled mollusks. *Marine Biology.* 160: 2207-2245.

Godet, L., Fournier, F., Toupoint, N. and Olivier, F. 2009. Mapping and monitoring intertidal benthic habitats: A review of techniques and a proposal for a new visual methodology for the European coasts. *Progress in Physical Geography.* 33(3) : 378-402; https://doi.org/10.1177/ 0309133309342650.

Gosling, E. M. 1992. Systematics and geographic distribution of *Mytilus*. *Developments in Aquaculture and Fisheries Science.* 25: 1-20.

Green, E. P., Mumby, P. J., Edwards, A. J. and Clark, C. D. 1996. A review of remote sensing for the assessment and management of tropical coastal resources. *Coastal Management*. 24: 1-40; https://doi.org/10.1080/0892759609362279.

Gutierrez, J. L. and Iribarne, O. O. 1999. Role of Holocene beds of the stout razor clam *Tagelus plebeius* in structuring present benthic communities. *Marine Ecology Progress Series.* 185: 213-228.

Gutierrez, J. L., Jones, C. G., Strayer, D. L. and Iribarne, O. O. 2003. Mollusks as ecosystem engineers: The role of shell production in aquatic habitats. *Oikos*. 101: 79-90.

Hennig, B. D., Cogan, C. and Bartsch, I. 2007. Hyperspectral remote sensing and analysis of intertidal zones – A contribution to monitor coastal biodiversity. In: Car, A., Griesebner, G. and Strobl, J. (Eds). *Geospatial Crossroads. Proceedings of the First Geoinformatics Forum*, Wichmann Publishers. 62-73.

Huber, M. 2010. *Compendium of bivalves - A Full-Color Guide to 3300 of the World's Marine Bivalves.* Hackenheim (Eds.), Conch Books, Germany. 344-421.

Jackson, A., Chapman, M. and Underwood, A. 2008. Ecological interactions in the provision of habitat by urban development: Whelks and engineering by oysters on artificial seawalls. *Austral Ecology.* 33: 307-316.

Jaiswar, A. K. and Kulkarni, B. G. 2001. Vertical distribution of molluscs in intertidal area in and around Mumbai, India. *Journal of Indian Fisheries Association.* 28: 93-100.

Kimbrough, K. L., Johnson, W. E., Lauenstein, G. G., Christensen, J. D. and Apeti, D. A. 2008. An assessment of two decades of contaminant monitoring in the nation's coastal zone, Silver Spring, Maryland. *NOAA Technical Memorandum*. 74: 15-105.

Kripa, V. and Appukuttan K.K. 2003. Marine Bivalves. In: Joseph, M.M. and Jayaprakash, A.A. (Eds). *Status of Exploited Marine Fishery Resources of India*. Central Marine Fisheries Research Institute, Cochin, India. 211-220.

Kurihara, H., Asai, T., Kato, S. and Ishimatsu, A. 2008. Effects of elevated pCO_2 on early development in the mussel, *Mytilus galloprovincialis*. *Aquatic Biology*. 4: 225-233.

Lowe, S., Browne, M. and Boudjelas, S. 2000.100 of the World's Worst Invasive Alien Species - A Selection from the Global Invasive Species Database. In: *The Invasive Species Specialist Group (ISSG)* (Eds.). *Aliens* 12. Auckland, New Zealand. 1-12.

Lydeard, C., Cowie, R.H., Ponder, W.F., Bogan, A.E., Bouchet, P., Clark, S.A., Cummings, K.S., Frest, T.J., Gargominy, O., Herbert, D.G. and Hershler, R. 2004. The global decline of nonmarine mollusks. *Bio Science*. 54(4): 321-330.

MacLachlan, A. and Dorvlo, A.S. 2005. Global patterns in sandy macrobenthic communities. *Journal of Coastal Research*. 21(4) : 674-687; https://doi.org/10.2112/04-0408.1.

Margalef, R. 1968. *Perspectives in Ecological Theory.* Chicago: University of Chicago Press

Maurer, B. 2006. The anthropology of money. *Annual Review Anthropology.* 35: 15-36.

McLean, R. 1983. Gastropod shells: A dynamic resource that helps shape benthic community structure. *Journal Experimental Marine Biology Ecology.* 69: 151-174.

Meireless, A. L., Terossi, M., Biagi, R. and Mantelatto, F. L. 2006. Spatial and seasonal distribution of the Hermit Crabs *Pagurusexilis* (Benedict, 1892) (Decapoda: Paguridae) in the southwestern coast of Brazil. *Revista de Biologia Marina y Oceanografia.* 41(1): 87-95.

Michaelidis, B., Ouzounis, C., Paleras, A. and Pörtner, H.-O. 2005. Effects of long-term moderate hypercapnia on acid-base balance and growth rate in marine mussels, *Mytilus galloprovincialis. Marine Ecology Progress Series.* 293 : 109-118.

Michel, E.H., Richard, C.B., Mercedes, C. and German, R.R. 2007. Marine and brackish-water molluscan biodiversity in the Gulf of California, Mexico. *Scientia Marina*. 71(4) : 637-647.

Mohamed, K.S. and Venkatesan, V. 2017. Marine molluscan diversity in India–Exploitation, conservation. *Summer School on Advanced Methods for Fish Stock Assessment and Fisheries Management.* 6: 56-81.

Molina, D.C. 2015. Shoreline changes in the west coast of Puerto Rico as determined by remote sensing techniques and their correlation to changes in the diversity of shell molluscs. *Dissertations*, University of Puerto Rico, Mayaguez (Puerto Rico). 33-77.

Monolisha, S. and Patterson, E.J.K. 2015. Biodiversity of marine molluscs from selected locations of Andhra Pradesh coast, southeastern India. *Indian Journal of Geo-Marine Sciences.* 44(6) : 842-845.

Natarajan, P., Ramadoss, K., Sivalingam, D. and Thillairajan, P. 1988. Ornamental shell industry of Ramanathapuram coast. *Bull. Cent. Mar. Fish. Res. Inst.* 42(1) : 106-110.

Olivera, B. M. and Teichert, R. W. 2007. Diversity of the neurotoxic *Conus* peptides: A model for concerted pharmacological discovery. *Molecular Interventions.* 7: 51-260.

Palanisamy, M. and Yadav, S.K. 2015. Distribution, diversity and conservation of seaweeds of Thiruvananthapuram coast, Kerala. In: Rajendran, A. and Aravindhan, V. (Eds.). *Biodiversity Conservation: Aspects and Prospects.* Lambert Academic Publishing, Germany. 52-62.

Paul, P., Panigrahi, A. K. and Tripathy, B. 2014. A study on marine molluscs with respect to their diversity, relative abundance and species richness in northeast coast of India. *Indian Journal of Applied Research.* 4(12) : 538-541.

Paul, T.T., Dennis, A. and George, G. 2016. A review of remote sensing techniques for the visualization of mangroves, reefs, fishing grounds, and molluscan settling areas in tropical waters. *Seafloor Mapping along Continental Shelves*. 105-123.

Pavithran, A. and Nandan, B. 2014. Distribution and diversity of intertidal macrofauna of Dharmadam beach, south west coast of India. *International Journal of Marine Sciences*. 4(23): 210–218; doi:10.5376/ijms.2014. 04.0023.

Philip, M.B. and Appukuttan, K.K. 1997. A check-list of gastropods landed at Sakthikulangara-Neendakara area. *Marine Fisheries Information Service.* 138: 9-10.

Pielou, E.C. 1966. The Measurement of Diversity in Different Types of Biological Collections. *Journal of Theoretical Biology*. 13 : 131-144.

Ponder, W. F. and Lindberg, D. R. 2004. Phylogeny of the molluscs - World Congress of Malacology. In: Ponder, W.F., Lindberg, D.R. and Ponder, J.M., (Eds). *Biology and Evolution of the Mollusca.* CRC Press, New York. 509-606.

Rao, D.V. 2010. Field guide to corals and coral associates of Andaman and Nicobar Islands. *Zoological Survey of India.* 159-160.

Ravinesh, R. and Bijukumar, A. 2012. Comparison of intertidal biodiversity associated with natural rocky shore and sea wall: A case study from the Kerala coast, India. *Indian Journal of Geo-Marine Sciences*. 42(2): 223-235.

Robin, A. 2008. *Encyclopedia of Marine Gastropods.* Paris and Hackenheim (Eds). ConchBooks, Germany. pp. 480.

Rumahlatu, D. and Leiwakabessy, F. 2017. Biodiversity of gastropoda in the coastal waters of Ambon

Island,Indonesia. *Aquaculture, Aquarium, Conservation and Legislation – International Journal of the Bioflux Society*. 10(2): 285-296.

Safavi-Hemami, H., Gajewiak, J., Karanth, S., Robinson, S.D., Ueberheide, B., Douglass, A.D., Schlegel, A., Imperial, J.S., Watkins, M., Bandyopadhyay, P.K. and Yandell, M. 2015. Specialized insulin is used for chemical warfare by fish-hunting cone snails. *Proceedings of the National Academy of Sciences*. 112(6): 1743-1748.

Shannon, C.E. and Weaver W.J. 1949. *The Mathematical Theory of Communication.* University of Illinois Press, Urbana, pp. 117

Simpson, E.H. 1949. Measurement of diversity. *Nature*. 163: 688.

Susintowati, Nyoman P., Erny P., Niken Satuti Nur H. , Suwarno H. 2019. The intertidal gastropods (Gastropoda: Mollusca) diversity and taxa distribution in Alas Purwo National Park, East Java, Indonesia. *Biodiversitas.* 20 (7): 2016-2027.doi: 10.13057/biodiv/d200731.

Thomas, Y., Mazurié, J., Alunno-Bruscia, M., Bacher, C., Bouget, J.F., Gohin, F., Pouvreau, S. and Struski, C. 2011. Modelling spatio-temporal variability of *Mytilus edulis* (L.) growth by forcing a dynamic energy budget model with satellite-derived environmental data. *Journal of Sea Research*. 66(4): 308-317.

Vadher, P., Gadhvil, R., Parekh, H. and Dabhi, J. 2014. Occurrence of marine molluscs along the Chorwad coast, Gujarat, India. *Advances in Applied Science Research.* 5(5): 24-28.

Vaghela, A., Bhadja, P. and Kunder, R. 2013. Diversity and distribution of intertidal molluscs at Sourashtra coast of Arabian Sea. *Global Journal of Bioscience and Biotechnology*. 2(2): 154-158.

Vaughn, C. C. and Spooner, D. E. 2006. Unionid mussels influence macroinvertebrate assemblage structure in streams. *Journal North American Benthological Society.* 25: 691-700.

Venkataraman, K., Raghunathan, C., Raghuraman, R. and Sreeraj, C.R. 2012. Marine Biodiversity of India. *Zoological Survey of India*. 73-102.

Worm, B., Barbier, E. B., Beaumont, N. and Duffy, J. E. 2006. Impacts of biodiversity loss on ocean ecosystem services. *Science*. 314: 787-790.

WoRMS, 2021. World Register of Marine Species, accessed on 23rd September 2021; https://www.marinespecies.org.