

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

185,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.  
For more information visit [www.intechopen.com](http://www.intechopen.com)



---

# Diversity and Distribution of Polychaetes in Mangroves of East Coast of India

---

Perumal Murugesan, Palanivel Partha Sarathy,  
Samikkannu Muthuvelu and Gopalan Mahadevan

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.78332>

---

## Abstract

This research article reports an exhaustive account on the mangrove-associated polychaetes. Polychaetes are an important component in marine benthic communities and they play a major ecological role in mangrove ecosystem. This article gives an overview of polychaete diversity associated to five major mangrove forests of east coast of India (Muthupettai, Pichavaram, Coringa, Bhitarkanika and Sundarban). The results of this survey indicated that the physicochemical parameters did not vary much except a few parameters that showed only marginal variations. With regard to the macrobenthic organisms, the polychaetes topped the list. Crustaceans were found to be the next dominant group in the order of abundance and followed by gastropods and bivalves of the total benthic organisms collected. The results of the statistical analysis revealed that the parameters such as salinity, pH, silt, clay, total organic carbon (TOC), total nitrogen (TN) and total phosphate (TP) were manifested as best match in determining benthic fauna distributions followed by TOC, slit, clay and TP. The maximum number of polychaete species was recorded from Sundarban mangroves (68 species) and minimum in Muthupettai mangroves (39 species).

**Keywords:** environmental factors, macrofauna, population density, statistical analyses, southeast coast of India

---

## 1. Introduction

Mangroves are unique coastal ecosystem contributing as a rich store house of biodiversity. Mangrove forests are extremely important coastal resources [1] which play a pivotal role in socio-economic development. It also plays a major role as nursery ground for juveniles of a plethora of fin and shell fishes. A total of 54 mangrove species belonging to 20 genera and

16 families are reported globally [2]. The most dominant families among mangroves are Avicenniaceae, comprised of one genus and eight species and the Rhizophoraceae having 16 genera and approximately 120 accepted species [3–5]. According to FAO [6] the mangrove area worldwide is estimated to cover from 12 to 20 million hectares. According to Giri *et al.* [7], the mangroves are found in Asia (42%), Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%). In India, the total area under mangrove cover is 4,445km<sup>2</sup>, of which about 60% is found on the east coast, 23% on the west coast and the remaining 17% in Andaman & Nicobar Islands [8]. Three types of mangroves habitats, namely deltaic, backwater- estuarine and insular are reported to occur in India. The deltaic mangroves are luxuriantly present on the east coast (Bay of Bengal) where the gigantic rivers make mighty deltas such as the Gangetic, the Mahanadi, the Godavari and Cauvery deltas. The backwater-estuarine types of mangroves exist along the west coast (Arabian Sea), and are characterized by typical funnel-shaped estuarine system of major rivers (Indus, Narmada, Tapti, etc.) or occur in the backwaters, creeks, and neritic inlets. The insular mangroves are present in Andaman and Nicobar Islands, wherein many tidal estuaries, small rivers, neritic inlets, and lagoons support a rich mangrove flora. The mangroves in east coast are large and widespread owing to the nutrient-rich alluvial soil formed by the rivers-Ganga, Brahmaputra, Mahanadi, Godavari, Krishna and Cauvery- and a perennial supply of fresh-water along the deltaic coast coupled with smooth and gradual slope which provides larger for colonization of mangroves [9].

Annually, mangroves approximately sequester 22.8 million metric tons of carbon, covering 0.1% of the earth's forests, which is accounting for 11% of terrestrial carbon into the ocean [10] and 10% of the terrestrial dissolved organic carbon exported to the ocean [11]. Despite its enormous benefits, which biodiversity commands, the mangroves have always been given least importance from the point of view of benthic biodiversity by the scientific community.

Benthic communities are either epibenthic or infaunal invertebrates [12, 13] that occur at the soil surface or at the surface of bottom entities, and within the substrate, respectively (Encyclopedia Britannica, Inc. 2015). Benthic fauna are divided into two major groups namely macrofauna and meiofauna. The macrofauna are those organisms which are in the size range of more than 0.5 mm or 500 micron and the meiofauna are the fauna which are less than 0.5 mm but greater than 0.062 mm or 62 microns [12]. They are an important component that influences the productivity of the habitat, and thereby helps in recycling of nutrients and in turn promotes primary productivity [14]. Macro-benthos also help in decomposition and the breakdown of particulate organic material by exposing them to microbes and their waste materials contain rich nutrients forming food for other consumers. Of the various macro benthic taxa, polychaetes constitute the most dominant group constituting about 80% of the total macro benthic community and their diet include microbial, meiobial, and organic substances [15]. Polychaetes are secondary producers of mangroves subsoil habitat production, which is essential for tracing the biotic stability of the area from fisheries point of view [16]. For example, decomposition, the fundamental process wherein the dead organic matter and leaf litter is broken down into CO<sub>2</sub> and simple inorganic molecules which take place through polychaetes in the benthic environment. Added to the utilities stated above, polychaetes are also used as most veritable marine organisms for the

detection of pollution and are considered as the taxonomic group with the highest level of sensitivity to perturbation of the soft substrata [17].

No comprehensive study has been undertaken so far on benthic biodiversity in general and polychaete taxonomy in particular in the mangroves of east coast of India. Taking cognizance of the facts stated above, a case study on the diversity and distribution pattern of polychaetes in five major mangroves of east coast of India is posted in this article.

## 2. Material and methods

### 2.1. Study area

For the present investigation, survey was conducted in five different mangrove ecosystems of east coast of India. The description of the study area is detailed in the following section (Table 1 & Figure 1).

The water, sediment and macrofaunal samples were collected seasonally from five major mangrove ecosystem of east coast of India during 2013–2014. In each mangrove, three stations representing i) Land ward zone, ii) core mangrove, and iii) Seaward zone, were fixed and thus altogether 15 stations were sampled:

Name of the mangroves	Station code	Locations	
		Latitude (N)	Longitude (E)
Muthupettai	MUT-1 (LW)	10° 18' 4.96" N	79° 22' 27.59" E
	MUT-2 (CM)	10° 18' 10.27" N	79° 22' 26.51" E
	MUT-3 (SW)	10° 18' 14.64" N	79° 22' 25.28" E
Pichavaram	PIC-1 (LW)	11° 26' 0.49" N	79° 48' 29.06" E
	PIC-2 (CM)	11° 25' 46.06" N	79° 48' 2.05" E
	PIC-3 (SW)	11° 25' 56.45" N	79° 48' 16.14" E
Coringa	COR-1 (LW)	16° 49' 29.16" N	82° 20' 44.74" E
	COR-2 (CM)	16° 47' 42.17" N	82° 20' 11.73" E
	COR-3 (SW)	16° 45' 7.86" N	82° 19' 58.86" E
Bhitarkanika	BIT-1 (LW)	20° 42' 0.96" N	87° 0' 56.96" E
	BIT-2 (CM)	20° 44' 40.07" N	86° 53' 35.99" E
	BIT-3 (SW)	20° 42' 43.98" N	86° 52' 39.13" E
Sundarbans	SUN-1 (LW)	21° 44' 53.02" N	89° 9' 29.38" E
	SUN-2 (CM)	21° 50' 55.37" N	89° 5' 12.46" E
	SUN-3(SW)	22° 3' 27.36" N	89° 2' 23.73" E

LW = Landward zone, CM = Core mangrove zone, SW = Seaward zone.

**Table 1.** Geographical location of sampling stations in various mangrove ecosystems covered.

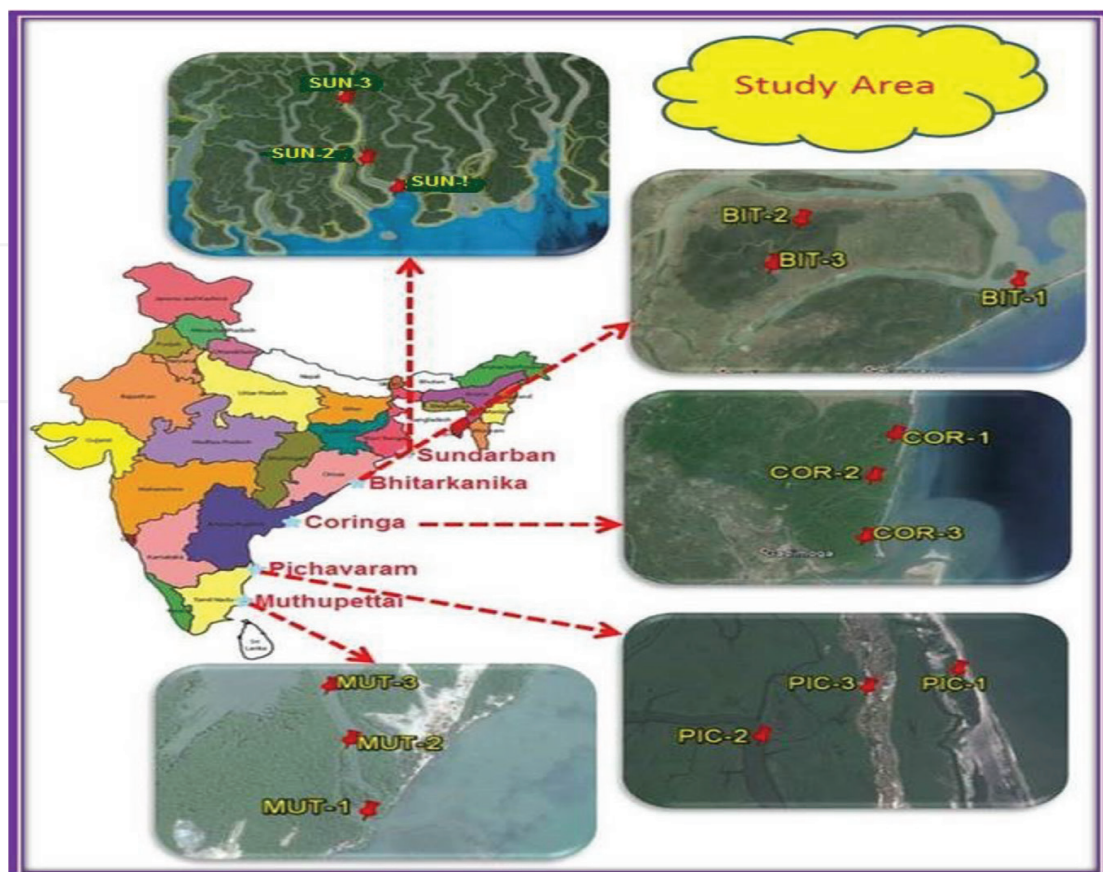


Figure 1. Map showing the various mangrove ecosystems studied in or around east coast of India.

The major mangrove forests selected for the present study are the following:

- i) Muthupettai mangroves (Lat.  $10^{\circ}18'N$ ; Long.  $79^{\circ}49'E$ ) are located on a lagoon environment. They are situated 400 km south of Chennai and lie on the southern part of Cauvery deltaic region along the southeast coast of India. Mangroves spread to an area of about 6800 ha, in which *Avicennia marina* is the single dominant mangrove species accounting for about 95% of the vegetative cover.
- ii) Pichavaram mangroves (Lat.  $11^{\circ}27'N$ ; Long.  $79^{\circ}47'E$ ) are situated amidst the Vellar estuary in the north and the Coleroon estuary in the south. These are a repository of rare, endemic and endangered species of mangroves. In this mangrove, about 81 species belonging to 41 families have been recorded.
- iii) Coringa mangroves (Lat.  $16^{\circ}44'$  to  $16^{\circ}53'N$  and Long.  $82^{\circ}14'$  to  $82^{\circ}22'E$ ) are located south of Kakinada Bay, Andhra Pradesh state, India. Coringa mangroves receive freshwater from Coringa and Gaderu rivers, distributaries of Gautami Godavari River, and neritic waters from Kakinada bay.
- iv) Bhitarkanika mangroves cover an area of 650 km<sup>2</sup> in the river delta of the Brahmani and Baitarani rivers of Odisha state. Next to Sundarbans, Bhitarkanika (Lat.  $20^{\circ}4'$  to  $20^{\circ}8'N$ ;  $86^{\circ}45'$  to  $87^{\circ}50'E$ ) is the second largest viable mangrove ecosystem in India harboring more than 70 species of mangrove and its associates.



- v) Sundarban is one among the world's largest delta covering 10,200 sq.km of mangrove forest, spread over India (4200 sq. km of Reserved Forest) and Bangladesh (6000 sq.km approx. of Reserved Forest). The total area of Sundarban region in India is 9600 sq. km, which constitutes the Sundarban Biosphere Reserve, West Bengal. India.

## 2.2. Collection of water and sediment samples

The environmental parameters such as pH, salinity, temperature and dissolved oxygen (DO) was measured following the modified Winkler's method [18] in the site itself. The sediment nutrient parameters such as total nitrogen (TN) was estimated by following the method of Strickland and Parsons [18], total phosphorous (TP) by following the method of Menzel and Corwin [19]; and total organic carbon (TOC) by following the standard method of El Wakeel and Riley [20].

## 2.3. Biological sample (field and lab routines)

In each station, three replicate samples were collected using Peterson grab. This type of grab is considered to be the most efficient gear in obtaining the good penetrative samples in shallow water environments. The grab employed was found to take a sample covering an area of 0.1m<sup>2</sup>. The procedure adopted for sampling was following the method of Mackie [21]. After collecting the samples, they were emptied into a plastic tray. The larger organisms were handpicked immediately from the sediments and then sieved through 0.5 mm mesh screen. The organisms retained by the sieve were placed in a labeled container and fixed in 5–7% formalin. Subsequently, the organisms were stained with Rose Bengal solution (0.1 g in 100 ml of distilled water) for greater visibility during sorting. All the species were sorted, enumerated and identified to the advanced possible level with the consultation of available literature. The works of Fauvel [22] and Day [23] and <http://www.marinespecies.org/polychaeta/> were referred for identification.

## 2.4. Statistical analyses

The data were approached to various statistical methods namely univariate, graphical/distributional and multivariate methods available in PRIMER (Ver. 7.) statistical software [24]. The data were analyzed for diversity index (H') using the method of Shannon – Wiener's formula [25]; for species richness (d) using the formula of Margalef [26] and species evenness (J') using Pielou [27].

Cluster analysis was done to find out the similarities between the samples/stations/regions. The most commonly used clustering technique is the hierarchical agglomerative method. MDS (non - metric Multi-Dimensional Scaling) [28, 29], was used to find out the similarities (or dissimilarities) between each pair of entities to produce a 'map', which would ideally show the interrelationships of all.

The principal component analysis-Bi-plot (PCA-Bi-plot), a multivariate procedure capable of providing a data reduction and easy visualization through the Pearson correlation between the physicochemical parameters and sampling stations were performed using XLSTAT-Pro version 5.1.4. Canonical Correspondence Analysis (CCA) was also done to relate the abundance of benthic species with linear combination of environmental variables [30, 31].

Canonical Correspondence Analysis (CCA) allows to obtaining a simultaneous representation of the sites, the objects, and the variables in two or three dimensions that is optimal for a variance criterion [30]. To confirm the results obtained through CCA, BIO-ENV procedure [32] was also employed. A weighted Spearman rank correlation coefficient ( $\rho_w$ ) was used to determine the harmonic rank correlation between the biological variable and all possible combinations of the environmental variables.

## 2.5. Results

### 2.5.1. Environmental variables

The mean values of physicochemical parameters recorded at each sampling station are summarized in **Table 2**. The temperature ranged between 20.43°C and 33.67°C with maximum at Muthupettai and minimum at Sundarbans; salinity values varied between 12.3 psu and 33.12 psu with maximum at Muthupettai and minimum at Sundarbans; pH values fluctuated between 7.10 and 8.23 with maximum at Pichavaram and minimum at Sundarbans; Dissolved Oxygen ranged between 3.80 and 8.23 mg/l with maximum at Bhitarkanika and minimum at Pichavaram. Total nitrogen value ranged between 3.48 and 5.98  $\mu\text{g/g}$  with maximum at Muthupettai and minimum at Sundarbans; Total phosphate value ranged between 0.88 and 1.74  $\mu\text{g/g}$  with maximum at Coringa and minimum at Bhitarkanika; TOC (Total organic carbon) in sediment ranged between 6.45 and 16.52  $\mu\text{g/g}$  with maximum at Sundarbans and minimum at Coringa mangroves. The level of sand in sediment ranged between 47.9% and 78.64% with maximum at Pichavaram and minimum at Sundarban mangroves; Silt in sediment ranged between 10.1 and 31.4% with maximum at Sundarbans and minimum at Bhitarkanika mangroves and the clay content ranged between 6.5 and 23.8% with maximum at Sundarbans and minimum at Pichavaram mangroves.

### 2.5.2. Principal component analysis

The PCA was performed using physicochemical parameters to set a well defined distinction between the stations and the parameters. The PCA drawn for five mangroves showed 85.67% variance of the total axis wherein the first axis (F1) explained up to 62.47% of the total variance and F2 axis explained only 23.20% of the total variance. When the results were viewed, the parameters such as salinity, pH, Silt, Clay, TN, TP and TOC got positively correlated with MUT-1, PIC-1, BIT-2, PIC-2, SUN-2 and SUN-3 and MUT-1 while water temperature, DO and sand were negatively correlated with stations MUT-3, PIC-3, BIT-1, BIT-3, SUN-1, COR-1, COR-2 and COR-3 (**Figure 2**).

### 2.5.3. Biological entities

#### 2.5.3.1. Species composition of macrofauna

In the present study, organisms of the following five groups were recorded in the benthic samples collected: 1. polychaetes, 2. crustaceans, 3. bivalves, 4. gastropods and 5. 'others.' As many as 97 species of macrofauna were recorded from 5 mangrove ecosystems of the present

Parameters	Muthupettai		Pichavaram		Coringa		Bhitarkanika		Sundarbans	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Temperature °C	26 ± 0.02	33.67 ± 0.41	26.33 ± 0.23	30.50 ± 0.52	22.5 ± 0.21	29.17 ± 0.29	23.5 ± 0.32	29.33 ± 0.40	20.43 ± 0.31	31.17 ± 0.29
Salinity (psu)	29.34 ± 0.19	33.12 ± 0.68	18.80 ± 0.43	30.33 ± 0.32	17.5 ± 0.17	29.40 ± 0.31	12.5 ± 0.21	21.77 ± 0.7	12.3 ± 0.45	27.07 ± 0.73
pH	7.13 ± 0.35	7.85 ± 0.47	7.33 ± 0.21	8.23 ± 0.15	7.18 ± 0.32	7.67 ± 0.28	7.2 ± 0.09	7.47 ± 0.14	7.10 ± 0.23	7.7 ± 0.21
DO mg/l	5.34 ± 0.86	6.37 ± 0.41	3.80 ± 0.53	5.23 ± 0.10	4.06 ± 0.18	6.45 ± 0.05	4.33 ± 0.18	7.27 ± 0.34	4.06 ± 0.63	6.33 ± 0.42
TN µg/g	4.69 ± 0.52	5.98 ± 0.78	4.78 ± 0.24	5.03 ± 0.46	4.22 ± 0.78	4.75 ± 0.15	3.76 ± 0.26	5.01 ± 0.09	3.48 ± 0.21	5.41 ± 0.34
TP µg/g	1.12 ± 0.17	1.45 ± 0.28	1.30 ± 0.24	1.62 ± 0.09	0.95 ± 0.05	1.74 ± 0.14	0.88 ± 0.03	1.32 ± 0.08	1.02 ± 0.19	1.47 ± 0.15
TOC mgC/g	9.86 ± 0.07	16.36 ± 0.43	9.98 ± 0.90	16.36 ± 0.22	6.45 ± 0.35	14.4 ± 0.51	7.5 ± 0.07	15.54 ± 0.42	6.55 ± 0.41	16.52 ± 0.13
Sand %	56.4 ± 0.36	67.18 ± 0.05	63.55 ± 0.41	78.64 ± 0.45	64.01 ± 0.28	70.45 ± 0.32	67.6 ± 0.27	75.41 ± 0.09	47.9 ± 0.98	52.1 ± 0.29
Silt %	22.99 ± 0.51	33.22 ± 0.54	14.08 ± 0.64	29.83 ± 0.21	12.34 ± 0.78	21.35 ± 0.17	10.1 ± 0.43	12.32 ± 0.24	26.1 ± 0.29	31.4 ± 0.46
Clay %	9.01 ± 0.86	12 ± 0.02	6.5 ± 0.56	10.5 ± 0.09	12.21 ± 0.45	18.2 ± 0.27	14.34 ± 0.74	20.78 ± 0.15	18.2 ± 0.32	23.8 ± 0.19

**Table 2.** Physicochemical parameters recorded in five different mangroves ecosystem of east coast of India.



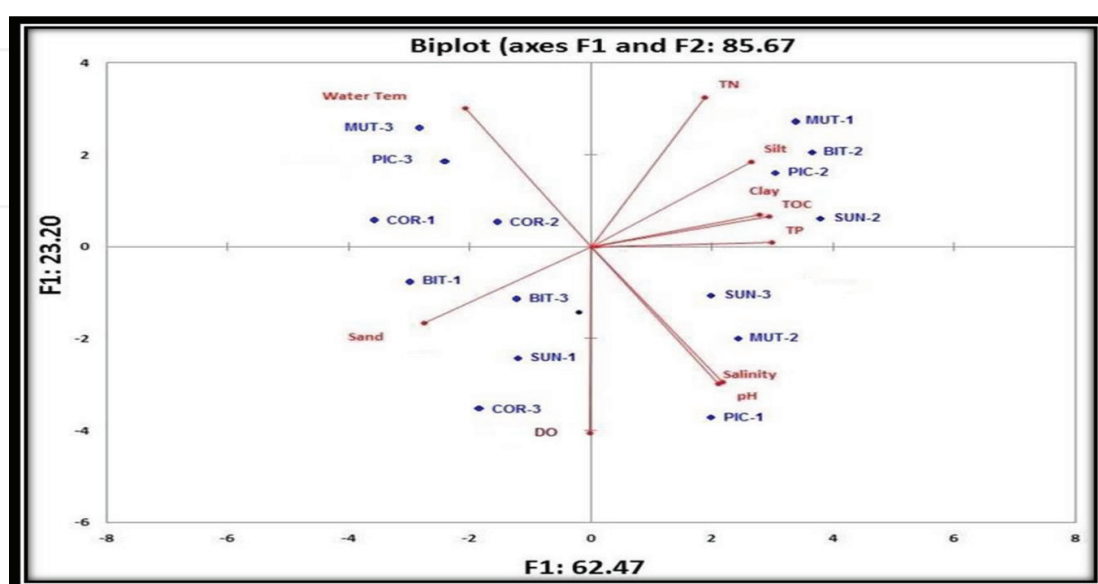
study. Of these species, polychaetes were found to be the largest component in the collection with 68 species. Crustaceans emerged as next dominant group in the order of abundance with 11 species. The bivalves and gastropods came next in the order with 8 and 6 species respectively and the group 'others' came last in the order with 4 species.

In Muthupettai mangroves, a total of 69 species were recorded. Among these, 39 species belonged to polychaetes, 10 species to crustaceans, 8 species each to bivalves and gastropods and 4 species to group 'others.' With respect to Pichavaram mangroves, a total of 88 species of macrofauna were recorded. Among these, there were 59 species of polychaetes, 10 species were crustaceans, 8 and 7 species were bivalves and gastropods respectively and 4 species of 'others.'

Regarding Coringa, 77 species of macrofauna were found. Among these, 50 species of polychaetes, 9 species of crustaceans and 8 and 7 species of bivalves and gastropods and 3 species of 'others' were recorded. Coming to Bhitarkanika mangroves, 81 species of macrofauna were found. Among these, 54 species of polychaetes, 10 species of crustaceans and 7 species each of bivalves and gastropods and 3 species of 'others' were recorded.

Coming to Sundarban mangroves, 97 species of macrofauna were found. Of these, 68 species of polychaetes, 11 species of crustaceans and 8 and 6 species of bivalves and gastropods respectively, and 4 species of 'Others' were recorded.

Among the polychaetes, *Amphinome* sp., *Ancistrosyllis* sp., *Brada villosa*, *Capitella capitata*, *Chone collaris*, *Cossura coasta*, *Eunice* sp., *Euclymene* sp., *Glycera unicornis*, *Goniada* sp., *Hyboscolex longiseta*, *Notomastus aberans*, *Perinereis* sp., *Phylo* sp., *Pherusa monroi*, *Pista cristata*, *Polydora capensis*, *Cirratulus* sp., *Laonice cirrata*, *Maldane sarsi*, *Magelona cincta*, *Malacoceros indicus*, *Nephtys dibranchis*, *Nereis diversicolor*, *Prionospio pinnata*, *Prionospio sexoculata*, *Sabella* sp., *Spio filicornis*, *Sternaspis scutata* and *Syllis gracilis* were found to be the commonly occurring species in the samples collected in five mangrove ecosystems. With respect to crustaceans, *Apseudes* sp., *Grandidierella* sp., *Gammarus* sp., *Urothoe* sp., *Angeliara* sp., *Mirocerberus* sp. and *Campylaspis* sp. showed consistency



**Figure 2.** Principle component analysis – Biplot drawn for the relation between physico chemical parameters and stations in five mangrove ecosystems.

S. No	Polychaetes	S-1	S-2	S-3	S-4	S-5	S. No	Polychaetes	S-1	S-2	S-3	S-4	S-5
1.	<i>Amphinome</i> sp.	*	*	*	—	*	35.	<i>Nereis diversicolor</i>	*	*	*	—	*
2.	<i>Ancistrosyllis</i> sp.	*	*	*	*	*	36.	<i>Nereis</i> sp.	*	*	*	*	*
3.	<i>Boccardia polybranchia</i>	*	—	*	*	—	37.	<i>Notomastus aberans</i>	*	*	*	*	*
4.	<i>Brada villosa</i> ,	*	—	*	*	*	38.	<i>Notomastus latericeus</i>	—	—	*	—	*
5.	<i>Capitella capitata</i>	*	*	*	*	*	39.	<i>Notoproctus pacificus</i>	*	—	*	*	*
6.	<i>Chone collaris</i>	*	*	*	—	*	40.	<i>Orbinia angrapequensis</i>	*	*	*	*	—
7.	<i>Chone letterstedti</i>	*	—	*	*	*	41.	<i>Paraonidea</i> sp	*	*	*	—	*
8.	<i>Cirratulus</i> sp.	*	*	*	—	—	42.	<i>Paraonis</i> sp.	*	*	*	*	—
9.	<i>Cirrophorus branchiatus</i>	*	*	*	*	*	43.	<i>Perinereis</i> sp.	*	*	*	*	*
10.	<i>Cossura coasta</i>	*	—	*	*	*	44.	<i>Perinereis falsovariegata</i>	*	—	*	*	*
11.	<i>Dendronereis arborifera</i>	—	*	*	*	*	45.	<i>Pherusa monroi</i>	*	—	*	*	*
12.	<i>Euclymene .oerstedii</i>	*	—	*	—	—	46.	<i>Phylo</i> sp.	*	*	*	*	—
13.	<i>Euclymene</i> sp.	*	*	*	—	*	47.	<i>Pista cristata</i>	*	—	*	*	*
14.	<i>Eunice</i> sp	*	*	*	*	*	48.	<i>Platynereis dumerilii</i>	*	—	*	*	*
15.	<i>Eurythoe complanata</i>	*	*	*	*	*	49.	<i>Polydora</i> sp.	*	*	*	*	*
16.	<i>Eurythoe parvocarunculata</i>	*	—	*	*	—	50.	<i>Polyphysia crassa</i>	*	—	*	—	*
17.	<i>Exogone clavator</i>	—	*	*	*	*	51.	<i>Prionospio cirrifera</i>	*	*	*	*	*
18.	<i>Fabrica filamentosa</i>	*	—	*	—	*	52.	<i>Prionospio pinnata</i>	*	*	*	*	*
19.	<i>Glycera benguellana</i>	*	—	*	*	*	53.	<i>Prionospio sexoculata</i>	*	—	*	*	*
20.	<i>Glycera longipinnis</i>	*	*	*	—	*	54.	<i>Prionospio</i> sp	*	—	*	—	—
21.	<i>Glycera unicornis</i>	—	*	*	—	*	55.	<i>Prionospio cirrobranchiata</i>	*	*	*	*	*
22.	<i>Goniada emerita</i>	*	*	*	*	*	56.	<i>Prionospio pinnata</i>	*	—	*	—	—
23.	<i>Hyalinoecia tubicola</i>	—	—	*	*	*	57.	<i>Prionospio saldanha</i>	*	*	*	*	*
24.	<i>Hyboscolex longiseta</i>	*	—	*	*	—	58.	<i>Sabella</i> sp.	*	*	*	*	*
25.	<i>Laonice cirrata</i>	*	*	*	*	*	59.	<i>Sabellaria intoshi</i>	*	*	*	*	*
26.	<i>Lumbrineris albidentata</i>	—	—	*	*	*	60.	<i>Scolecopsis squamata</i>	*	—	*	*	—
27.	<i>Magelona cincta</i>	*	*	*	—	—	61.	<i>Spio filicornis</i>	*	*	*	*	*
28.	<i>Malacoceros indica</i>	*	*	*	*	*	62.	<i>Spiophomianes soderstromi</i>	*	—	*	*	—
29.	<i>Maldane sarsi</i>	*	—	*	—	*	63.	<i>Sternaspis scutata</i>	*	*	*	*	*
30.	<i>Megalomma quadrioculatum</i>	—	—	*	*	*	64.	<i>Streblosoma persia</i>	*	—	*	—	*
31.	<i>Megaloma</i> sp.	—	*	*	*	*	65.	<i>Syllis benguellana</i>	*	*	*	*	*
32.	<i>Minuspia cirrifera</i>	*	—	*	—	—	66.	<i>Syllis gracilis</i>	*	*	*	*	*
33.	<i>Neanthes</i> sp.	*	*	*	*	*	67.	<i>Syllis</i> sp.	*	*	*	*	*
34.	<i>Nephtys dibranchis</i>	—	—	*	*	*	68.	<i>Terebellides stroemi</i>	*	—	*	*	*

\*presence

—absence

S-1, Pichavaram; S-2, Muthupettai; S-3, Sundarban; S-4, Coringa; S-5, Bhitarkanika

**Table 3.** Distribution and diversity of polychaete in different mangrove ecosystems of east coast of India.

in their occurrence in the entire mangrove ecosystem. With respect to bivalves, *Anadara rhombea*, *Crassostrea madrasensis*, *Katelysia opima*, *Meretrix meretrix*, *Meretrix casta*, *Perna indica*, and similarly among gastropods, *Cerithidea cingulata*, *Nassarius stollatus*, *Turritella acutangula* and *Murex trapa* were recorded frequently. Group “others” constitute fish larvae, sea urchins, crab and foraminiferans. The common macro benthic species recorded in various stations of five mangrove ecosystems is shown in **Table 3** & **Figure 3**.

#### 2.5.3.2. Population density of macrofauna

The results of population density recorded in five mangroves are given in the following section: In Muthupettai mangroves, the population density of benthic macrofauna varied from 417 to 3545 nos/m<sup>2</sup> with the maximum was noticed during summer and minimum during monsoon. Coming to Pichavaram mangroves, the density of benthic organisms varied between 451 and 5645 nos/m<sup>2</sup> with during summer and minimum during monsoon. Regarding Coringa mangroves, the density of benthic organisms ranged from 386 to 4262 nos/m<sup>2</sup> with maximum during summer and minimum during monsoon. Coming to Bhitarkanika mangroves, the density of benthic organisms varied between 433 and 4862 nos/m<sup>2</sup> with maximum during summer and minimum during monsoon. With respect to Sundarban mangroves, the density of organisms varied from 511 to 6845 nos/m<sup>2</sup>. The minimum density was recorded monsoon and maximum during summer. Among the mangroves, the maximum density of macrofauna was recorded in Sundarbans (6845 nos/m<sup>2</sup>) during summer and minimum in Muthupettai (3545 nos/m<sup>2</sup>) during monsoon (**Figure 4**).



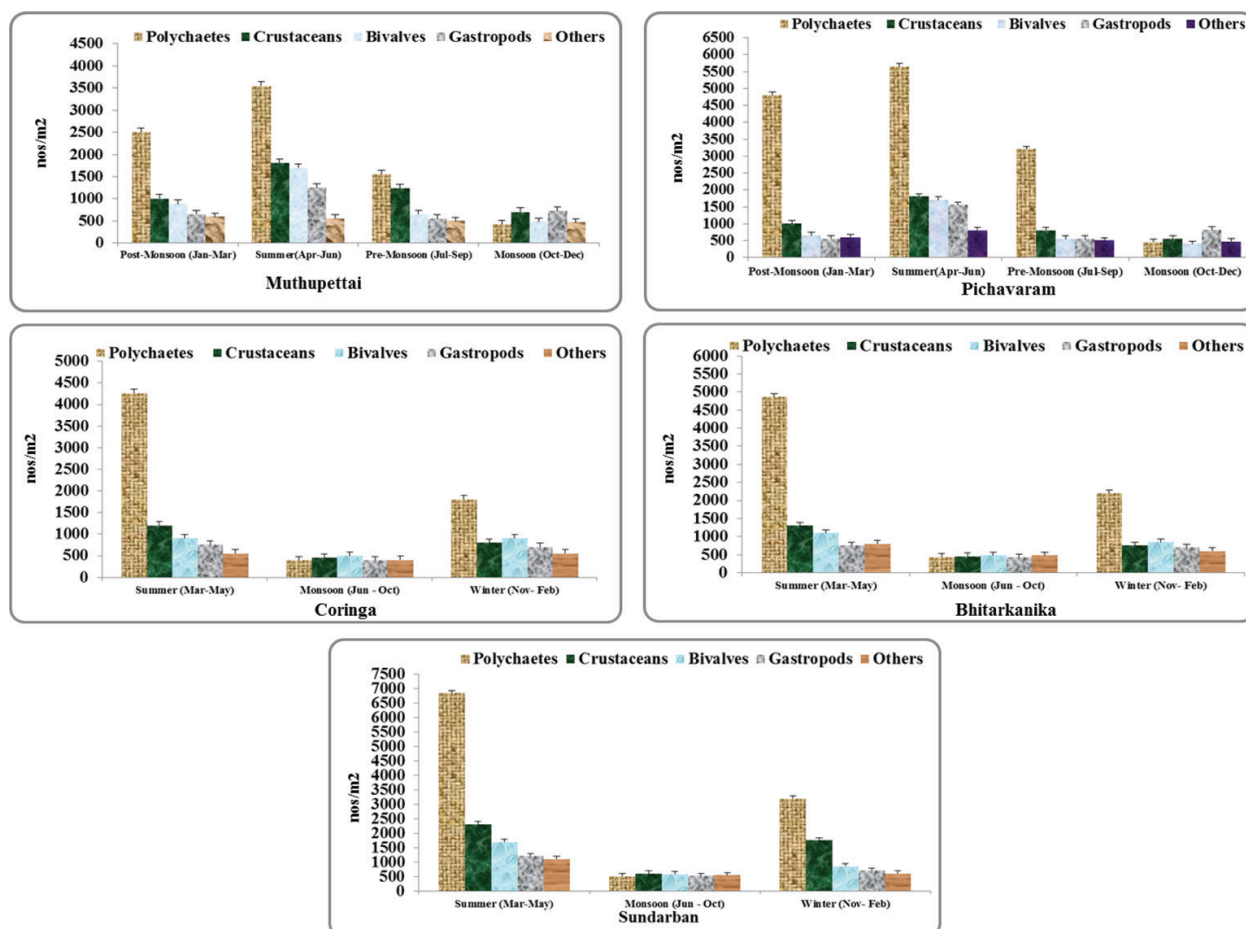
**Figure 3.** Polychaete species recorded in five different mangroves ecosystem from east coast of India.

### 2.5.3.3. Percentage composition of benthos

The percentage composition of macrofauna recorded in five different mangroves ecosystems are given below:

In Muthupettai, when the results of percentage composition of benthic fauna were viewed, polychaetes constituted the maximum with 54% of the total benthic organisms followed by crustaceans with 14%, bivalves with 12%, gastropods with 13% each and group 'others' with 7% to the samples collected in Muthupettai mangroves. With respect to Pichavaram mangroves, polychaetes continued to emerge as the dominant group in terms of abundance with a percentage occurrence of 56%. Crustaceans ranked second with a percentage contribution of 15%. Gastropods, bivalves contributed 11%, 12% respectively and 'others' with 6% to the total benthic organisms recorded.

Regarding Coringa, as in other mangroves, polychaetes continued to be the dominant group with 61%, followed by crustaceans, bivalves, gastropods and 'others' with 13%, 12%, 9% and 5% respectively. Coming to Bhitarkanika mangroves, polychaetes remained as the dominant group with a percentage contribution of 53%. Crustaceans were found to be the next dominant group with a percentage contribution of 13%. Gastropods, bivalves and 'others' contributed 8%, 11% and 5% respectively to the total benthic organisms collected. In Sundarban mangroves, polychaetes topped the list in terms of abundance with a percentage of 62%. Crustaceans



**Figure 4.** Population density of benthic faunal groups recorded in five different mangroves ecosystems of east coast of India.



formed second dominant group with a percentage contribution of 15%. Gastropods, bivalves contributed with 7% and 10% respectively and 'others' with 6% of the total benthic organisms (Figure 5).

#### 2.5.3.4. Diversity indices

The Diversity indices (mean value) recorded at each sampling station is summarized in Table 4. The species diversity varied from 3.018 to 4.476 with maximum in Sundarbans and minimum in Muthupettai mangroves; species richness fluctuated from 3.216 to 4.194 with maximum in Sundarbans and minimum in Coringa mangroves; with respect to Pielou's evenness, it varied from 0.852 to 0.991 with maximum in Bhitarkanika and minimum in Coringa mangroves.

#### 2.5.3.5. Cluster analysis

The seaward stations (MUT-1, PIC-1, COR-1, BIT-1 and SUN-1) in all the mangroves got grouped at the highest level of similarity followed by stations of core mangrove zone (MUT-2, PIC-2, COR-2, BIT-2 & SUN-2) and stations of landward zone (MUT-3, PIC-3, COR-3, BIT-3 & SUN-3) got grouped to form cluster based on the species composition with the exception of a few outliers (stations), which might be due to the species commonality between zones. This

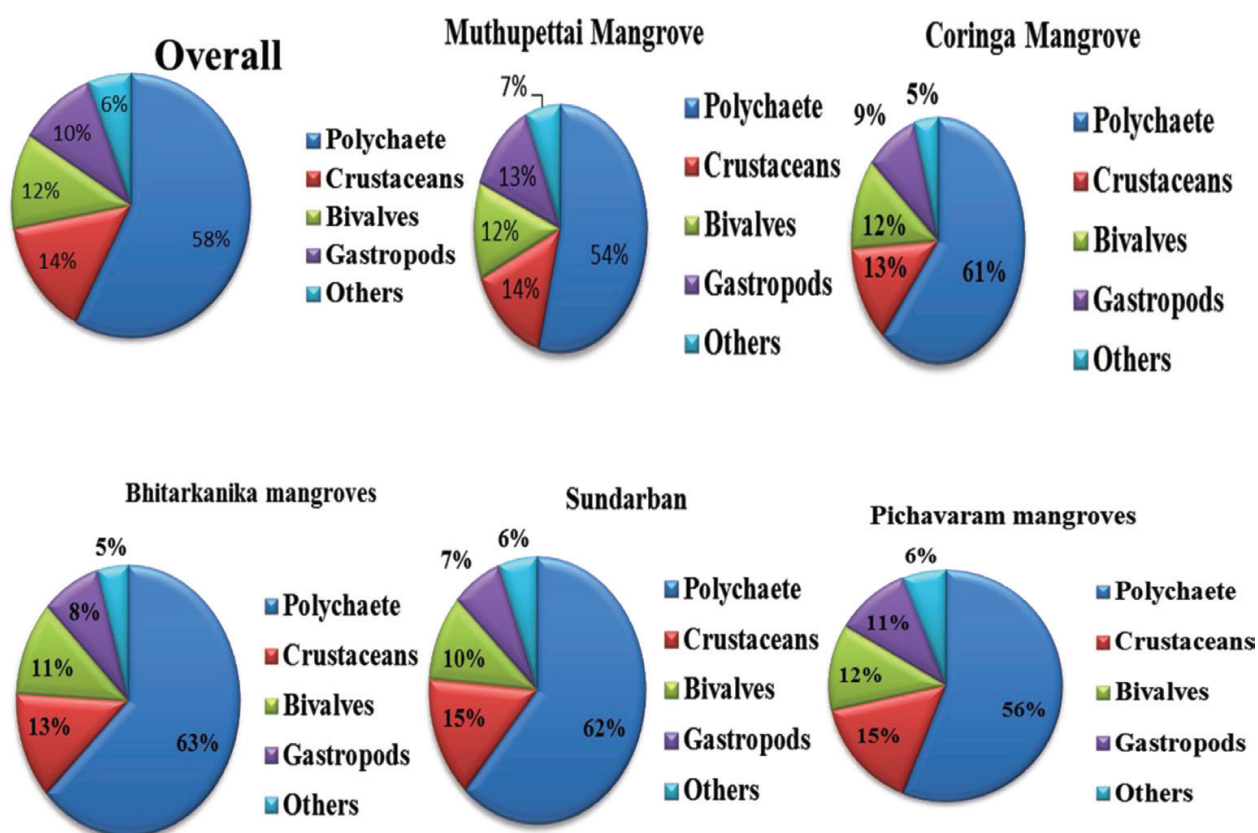


Figure 5. Percentage composition of benthic faunal groups recorded in five different mangroves ecosystem from east coast of India.



Stations	Diversity ( $H'$ )		Richness ( $S$ )		Evenness ( $J'$ )	
	Min	Max	Min	Max	Min	Max
Muthupettai	3.018	4.193	3.564	4.094	0.872	0.969
Pichavaram	3.214	4.414	3.487	4.182	0.854	0.976
Coringa	3.364	4.279	3.216	4.105	0.852	0.965
Bhitarkanika	3.214	4.389	3.314	4.216	0.854	0.991
Sundarbans	3.386	4.476	3.316	4.194	0.872	0.981

**Table 4.** Diversity indices recorded in five different mangrove ecosystems from east coast of India.

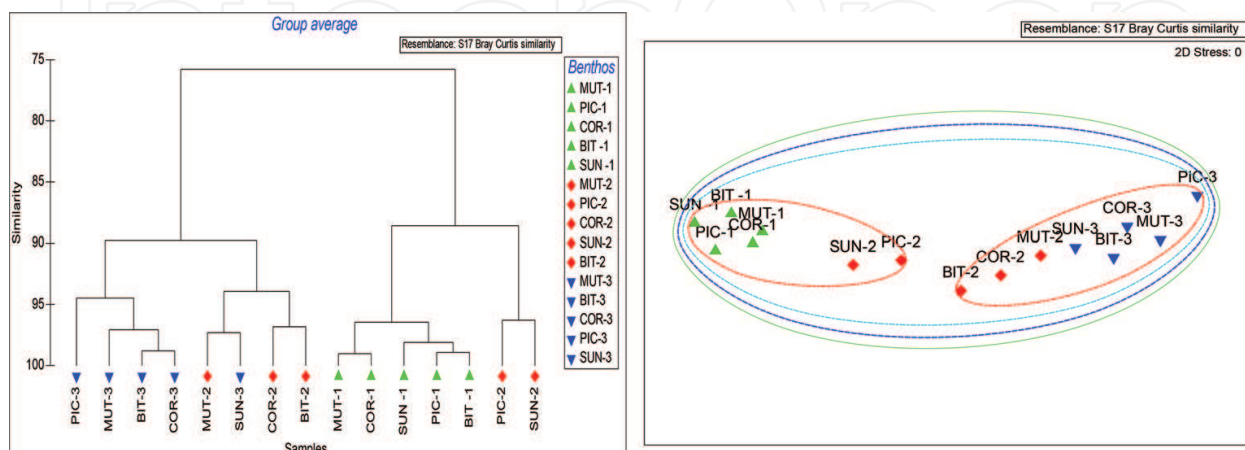
fact was further confirmed through MDS, and the results also revealed the same pattern of groupings as recognized in cluster analysis (**Figure 6**).

#### 2.5.3.6. Canonical correspondence analysis (CCA)

Canonical correspondence analysis (CCA) was done to ascertain the relationship between the physicochemical parameters and benthic faunal density. The CCA drawn for five mangrove ecosystem showed 91.43% variance of the total axis wherein the F1 axis showed 74.56% and F2 axis 16.87% of the total variance. The environmental parameters such as salinity, Silt, Clay, TOC, TP and TN were showing strong correlation with the benthic faunal diversity, while other parameters like water temperature, depth, sand and DO had weak correlation with the benthic faunal distribution (**Figure 7**).

#### 2.5.3.7. BIO-ENV (biota-environment matching)

In the BIO-ENV procedure, which was employed to measure the agreement between the rank correlations of the biological (Bray–Curtis similarity) and environmental (Euclidean distance) matrices, ten environmental variables were allowed to match the biota. The results of best



**Figure 6.** Dendrogram and MDS for the benthic faunal data collected in various mangrove ecosystems during 2013–2014.

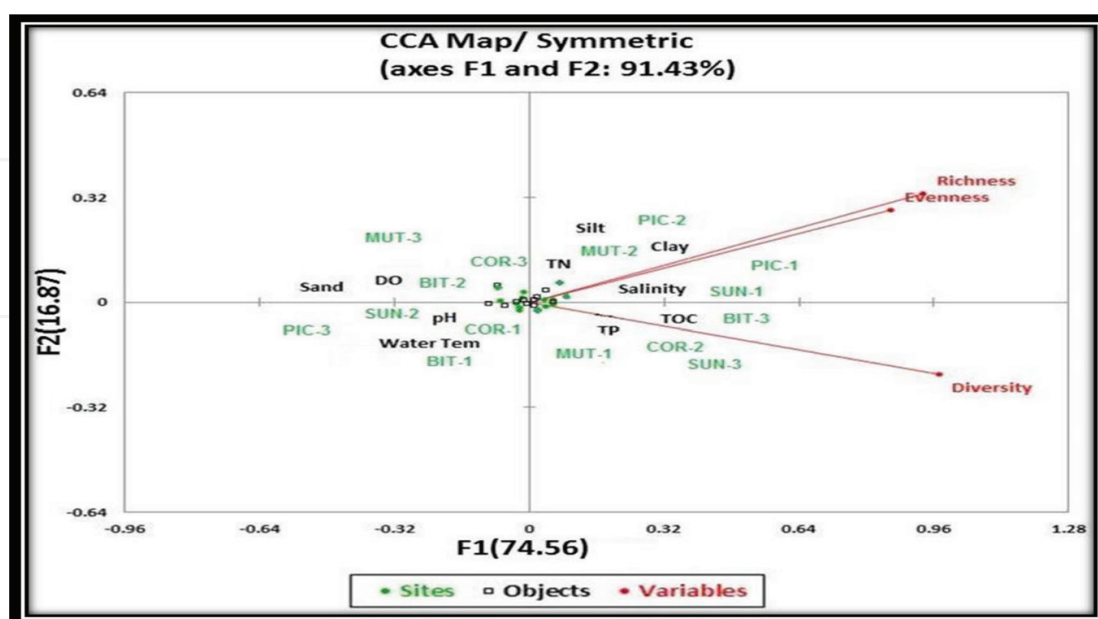
combinations are given in **Table 5**. In this case, as evidenced in CCA plot, salinity, silt, clay, TOC, total nitrogen and total phosphorous were featured as the major variables explaining the best match (0.90) with faunal distributions followed by pH, TOC and total nitrogen were also got manifested in the second best variable combinations in determining the faunal distribution in the mangrove ecosystems.

## 2.6. Discussion

Composition of benthic communities and their role varies from one habitat to another depending upon the water and sediment characteristics of the mangroves. The distribution of mangrove fauna in relation to water quality has been described quantitatively [33]. Among the five mangroves, the maximum temperature was recorded at Muthupettai during summer and minimum in Sundarbans, which could be ascribed to the effect of atmospheric cooling. Similar conclusion was also drawn earlier by Bolam *et al.* [34] in UK continental shelf waters and in shelf waters of southeast coast of India [35]. The temperature levels recorded presently are comparable with the study made by Kathiresan [36] who reported the temperature range of 28–31°C.

The high salinity values observed during summer compared to other seasons is might be due to low rain fall and the rise in atmospheric temperature resulting in high evaporation rate of the surface water. Similar seasonal variations were observed by Manokaran [35] in the inshore waters of Parangipettai and Cuddalore; by Murugesan *et al.* [37] in Tuticorin coastal waters and Rahaman *et al.* [38] in Sundarbans mangroves; Sivaraj *et al.* [39] in Vellar-Coleroon estuarine system.

In the present study, the maximum pH of 8.23 was recorded during summer and minimum of 7.1 was recorded during wet season. Hydrogen-ion concentration was found to vary among



**Figure 7.** Canonical correspondence analysis drawn for the correlation between benthic faunal composition and environmental variables in five mangrove ecosystems.

S. No.	No. of variables	Best variable combinations	Correlation ( $\rho_w$ )
1.	6	Salinity–Silt–Clay–TOC–Total Nitrogen–Total Phosphorous	0.90
2.	5	Sand–Clay–pH–TOC–Total Nitrogen	0.89
3.	5	Sand–Silt–Clay–Total Phosphorous–TOC	0.88
4.	5	Silt–Clay–DO–Salinity–Total Phosphorous	0.76
5.	4	Temperature–Salinity–Clay–Silt	0.70

**Table 5.** Harmonic rank correlations ( $\rho_w$ ) between faunal and environmental similarity matrices in various stations (mangroves).

the five mangroves and was alkaline throughout the study period. Higher pH observed in summer season could be attributed to the removal of  $\text{CO}_2$  by the photosynthetic organisms and the lower pH during monsoon season could be due to the dilution of saline water with fresh-water inflow from nearby sources as has been reported by Murugesan *et al.* [37].

Coming to dissolved oxygen, (DO) it varied from 3.80 to 7.27 mg/l with the maximum (7.27) during wet season and minimum 3.80 was recorded during dry season. All the stations of various mangroves showed the similar seasonal pattern in the distribution of dissolved oxygen with minimum value during dry months and maximum during wetter months. The relatively low DO values observed in the summer are attributed to the entry of high saline waters in to the mangroves, as well as fluctuations in temperature and salinity, which in turn affect the dissolution of oxygen [40]. This fact is in close agreement with earlier studies done elsewhere [38, 41].

Mangrove ecosystems are able to store large amounts of organic carbon [42]. In the present study, the maximum TOC of 16.52mgC/g was recorded at SUN-12 during dry season and minimum of 6.45mgC/g was recorded at COR-13 during wet season. As noticed in temperature and salinity, all the stations showed similar seasonal pattern in the distribution of organic carbon content with maximum value during dry months and minimum during wet months. Similarly, Hasrizal *et al.* [43] studied the seasonal changes of organic carbon content in the surface sediments of the Terengganu near shore coastal area of Malaysia with maximum value during postmonsoon and summer seasons and they also opined that the sediment characteristics and the organic carbon concentration are largely influenced by southwest and northeast monsoons.

In the present study, total nitrogen content showed striking seasonal variation with maximum TN (5.98  $\mu\text{g/g}$ ) was recorded during monsoon and minimum (3.48  $\mu\text{g/g}$ ) during dry season. Likewise, the maximum TP (1.73  $\mu\text{g/g}$ ) was recorded during wet season and minimum (0.88  $\mu\text{g/g}$ ) was recorded during dry season. The maximum values in wet season might be attributed to the higher amount of rainfall and river runoff as has been reported earlier by Sreedevi [44]. Similarly Kamykowski and Zentoura [45] also opined that the accumulation of nitrite in the near bottom samples depends on diffusion from sediments as well as mechanisms such as nitrification near the sediment and water interface. Similar observation was made by Gouda and Panigrahy [46] in Rushikulya estuary, Orissa, east coast of India. Manikoth and Salih [47] recorded high nitrogen concentration during monsoon season in the Vembanad estuarine complex, southwest coast of India. Joshi and Ghose [48] studied nutrient

characteristics of Sundarban mangroves. Martin *et al.* [49] studied on the benthic fauna in a tropical estuary of Cochin backwaters and Sekar *et al.* [50] in Pichavaram and Muthupettai mangroves in relation to nutrient characteristics.

Studies on the sediment composition are of paramount importance in benthic ecology. The comprehensive knowledge on the sediment composition is a pre-requisite and inevitable one to understand the benthic ecology [51]. The nature of the substratum has a profound effect on the bottom fauna and conversely, the benthos can influence the sediment characteristics. Gray and Snelgrove and Butman [52, 53] posted the information regarding the relationship between sediments and benthic organisms. They also pointed out that the grain size distribution of the sediments is of great importance in determining the distribution of benthos. Snelgrove and Butman [53] also concluded that the relationship was a complex interaction of the seabed flow and sediment characteristics and that could explain the distribution of organisms across all sedimentary habitats.

The correlation between the physicochemical parameters and benthic faunal density for the surveyed five mangrove ecosystem showed that the environmental parameters such as salinity, Silt, Clay, TOC, TP and TN were showing strong correlation with the benthic faunal diversity, while other parameters like water temperature, depth, sand and DO had weak correlation with the benthic faunal distribution. Similar variables combination were reported earlier by Sundaray *et al.* in Mahanadi River [54]; Satheeshkumar *et al.* [55] in Pondicherry coast; Sivaraj *et al.* [56] in Nandgoan coastal waters; Sivaraj *et al.* [41] in Vellar-Coleroon estuarine system.

Percentage contribution of benthic species composition of the present study showed in the order of polychaetes, crustaceans, bivalves, gastropods and groups 'others'. The dominance of polychaetes in terms of density and species composition in diverse ecological niche is due to their high degree of adaptability to a wide range of environmental factors. Similar preponderance of polychaetes has been observed earlier by Kumar [32] in Cochin backwaters; Prabha Devi [57] in Coleroon estuary, and Ansari *et al.* [58], in Mandovi estuary. Athalye and Gokhale [59] reported the dominance of polychaetes followed by gastropods, bivalves, and hermit crabs in Thane creek, Mumbai. The dominance of polychaetes might be due to the fact that firm substrate provided by roots and dense canopy of the mangroves which also provide protection against desiccation [60]. Similar dominance of polychaetes was also reported in other tropical waters [61, 62].

In a study conducted by Harkantra and Parulekar [63], polychaetes outnumbered the other faunal groups where the substratum was mainly composed of mud. Bhat and Neelakandan [64] also observed maximum number of polychaetes in the clayey-silty substratum, the fine particles of mud and clay substratum, which retains more water than coarse particles (sand and gravel). Such fine deposits or particles are commonly composed of decomposable organic constituents. As the organic content represents an important direct or indirect food source for benthic organisms, elevated organic matter may result in an enhancement of benthic faunal diversity [52, 65]. Therefore, it is clear that polychaetes abound in finer sediments as noticed by the above referred researchers. This fact also corroborates the results of present study. The population density of



macrofauna is governed by various environmental variables such as temperature, salinity, sediment type, organic carbon level in the sediments besides tidal action [66]. Monsoon months registered low density followed by gradual increase in postmonsoon and peaked during summer season, which are in agreement with the results of Sekar *et al.* [38, 50].

The population density recorded presently is comparable with the following studies made in the back waters along the east and west coasts of India: Harkantra *et al.* [66] (50–3175 nos. m<sup>2</sup>); Jegadeesan [67] (158–4138 nos. m<sup>2</sup>) in Coleroon estuary; Murugan [68] (80–3142 nos. m<sup>2</sup>) in Uppanar backwaters; Thangaraj [69] (50–2172 nos/m<sup>2</sup>) and Murugesan [70] (635–5125 nos. m<sup>2</sup>) in Vellar estuary; Muthuvelu [71] (40–8028 and 40–8328) in Parangipettai and Cuddalore coastal waters; Sekar *et al.* [50] (78–119 ind./1 cm<sup>2</sup>) in Pichavaram and Muthupettai mangroves; Sivaraj [41] (254 to 6124 nos. m<sup>2</sup> and 654 and 7845 nos. m<sup>2</sup>) in Vellar and Coleroon estuary.

In the present study, a marked seasonal variation in the Shannon diversity was found with minimum diversity value (3.018) in Muthupettai mangroves during monsoon and maximum (4.476) in Sundarbans mangroves during dry season. Similar range of diversity values was recorded earlier in Vellar estuary [71]. Shillabeer and Tapp [72] stated that the estuarine and mangrove environment is far more dynamic than the fully marine and therefore, there may be a wide range of variations in the benthic diversity of an estuary.

As in the species diversity, species richness values were also low during wet season and high during dry season, which might be due to adaptability to high salinities at high temperatures than at low temperatures [73], as a result more marine forms are able to flourish in tropical waters [74]. The trend with respect to richness values of the present study is evident in the studies made by Raveenthiranath Nehru [14] in Coleroon estuary and Sebastin Raja [14] in Sunnambar estuary; Palanisamy and Anisa [51] in Pondicherry coastal waters. With respect to evenness (*J'*), it largely followed the trend of species diversity.

With respect to classification and ordination techniques, the stations of marine zone (seaward) grouped at the highest level of similarity followed by stations of core mangrove zone and stations of fresh water zone (landward zone) grouped to form clusters based on the species composition. The physicochemical parameters such as salinity, Silt, Clay, TOC, TP and TN in landward zone and core mangrove were found relatively similar and it highly influenced the benthic faunal diversity, while in seaward zone the trends of the same parameters varied significantly and it didn't affect the distribution and diversity of the benthic fauna. The MDS results also largely followed the trend of dendrogram. Investigation similar to this was carried out by Sivaraj *et al.* [41] who made a comparative study of Vellar-Coleroon estuarine system using macrobenthic communities through cluster analysis. The stress value observed in MDS plot is comparable with the studies [75–77].

Canonical Correspondence Analysis (CCA) was done to ascertain the relationship between the physicochemical parameters and benthic faunal density. Similar combinations of environmental variables influencing benthic faunal distribution was reported in Nandgaon coastal waters, Maharashtra, India [56]; Sivaraj *et al.* [41] in Vellar-Coleroon estuarine



system. This fact was further confirmed through BIO-ENV, which yielded the combinations of six environmental entities (salinity–silt–clay–TOC–TN–TP) as best match ‘defining’ the faunal distributions. The associated coefficient of environmental to biotic similarity was 0.90. True to this, studies [39, 71] reported the similar combinations of environmental variables influencing the benthic faunal distribution. Clarke and Ainsworth [62] also reported the organic carbon-sediment particle size, to constitute the best match explaining the distribution of meiobenthic organisms. Similarly, Mackie *et al.* [78, 79] reported the combination as silt-clay-organic carbon forming the best match in explaining the faunal distribution. The combinations recognized in the above referred studies corroborate the results of the present study.

Comparing our own data with the studies made elsewhere in mangroves of other Asian countries, a few inferences could be drawn. In our study, as many as 68 species of polychaetes were recorded from 5 mangrove ecosystems of the present study. The density and number of species recorded presently is comparable with the works carried out in mangroves of other Asian countries barring a few variations in their density and diversity which might be due to the dynamic nature of the mangrove environment. Shillabeer and Tapp [72] stated that the mangrove environment is far more dynamic than the fully marine and therefore, there is every possibility in the variations in the occurrence of species. Similarly, there was no pronounced variation with respect to commonality in the species occurrence between our data and data of others. With regard to representation of polychaete families, by and large the representatives from Errant polychaetes were found to outnumber compared to sedentary counterparts. The similar dominance of errant polychaetes could be seen invariably in the works done in the mangroves of other Asian countries.

### 3. Conclusion

Based on the foregoing account, it is concluded that the present study yielded quite a good amount of information on the benthic biodiversity in general and polychaete taxonomy in particular in the mangroves of east coast of India. As there was no comprehensive report on the polychaetes of mangroves of east coast of India, comparison was done only based on the available sporadic reports and thus a clear –cut inference could not be drawn.

On the other hand, studies related to taxonomy of benthic fauna is limited as the researchers worldwide did not evince much interest in this line besides the enrolment of a new generation of benthic taxonomists has also been poor in the recent past. There are several reasons for this: (i) indifferent attitudes, both in society and educational systems, and (ii) organisms that are “invisible” from the perspective of immediate economic and medical interest to man and more importantly poor funding from the Government. To achieve this, an intensive collaboration of benthic researchers among the Asian countries is need of the hour, as it will throw an important beam of light on the Polychaete taxonomy in the mangroves with a view to formulate management strategies and also to arrive at meaningful conclusions for the policy makers.

## Acknowledgements

The authors are thankful to the Director and Dean, CAS in Marine Biology, Annamalai University, for encouragement and facilities provided. We gratefully acknowledge the Ministry of Environment Forests & Climate Change, Govt. of India, for financial support as this work forms a part of an MoEF & CC funded project.

## Author details

Perumal Murugesan\*, Palanivel Partha Sarathy, Samikkannu Muthuvelu and Gopalan Mahadevan

\*Address all correspondence to: [pmurugesaan74@gmail.com](mailto:pmurugesaan74@gmail.com)

Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai, Tamil Nadu, India

## References

- [1] Kathiresan K, Bingham BL. Biology of mangroves and mangrove ecosystems. *Advances in marine biology*. 2001;**40**:81-251. DOI: 10.1016/S0065-2881(01)40003-4
- [2] Tomlinson PB. Handbook of the botany of mangroves. Cambridge Tropical Biology Series. Cambridge, New York, USA: Cambridge University Press; 1986. 413 p
- [3] Hogarth PJ. Handbook of the Biology of Mangroves and Seagrasses. 2nd ed. United Kingdom: Oxford University Press; 2007. 978-0-19-856870-4
- [4] Prance GT. Neotropical Rhizophoraceae. In: Milliken W, Klitgård B, Baracat A, editors. (2009 Onwards), Neotropikey Interactive Key and Information Resources for Flowering Plants of the Neotropics. 2009. <[www.kew.org/neotropikey](http://www.kew.org/neotropikey)>
- [5] Spalding M, Kainume M, Collins L. Handbook on world atlas of mangroves. The Nature Conservancy. International Society for Mangrove Ecosystems. 2010:1-304
- [6] FAO. Coastal protection in the aftermath of the Indian Ocean tsunami: What role for forests and trees? In: Proceedings of the Regional Workshop; 28-31 August 2006; Khao Lak. Thailand: 2007. p. 213
- [7] Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Duke N. Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*. 2011;**20**(1):154-159

- [8] Mathew G, Jeyabaskaran R, Prema D. Mangrove ecosystems in India and their conservation. In: Coastal Fishery Resources in India-Conservation and Sustainable Utilization. 2010. pp. 186-196
- [9] Gopal B, Krishnamurthy K. Handbook on wetlands of South Asia. In: Wetlands of the World: Inventory, Ecology and Management. Vol. I. Netherlands: Springer; 1993. pp. 345-414
- [10] Jennerjahn TC, Ittekkot V. Relevance of mangroves for the production and deposition of organic matter along tropical continental margins. *Die Naturwissenschaften*. 2002;**89**(1): 23-30
- [11] Dittmar T, Hertkorn N, Kattner G, Lara RJ. Mangroves, a major source of dissolved organic carbon to the oceans. *Global Biogeochemical Cycles*. 2006;**20**(1):1-7
- [12] Dittmann S. Abundance and distribution of small infauna in mangroves of Missionary Bay, North Queensland, Australia. *Revista de Biología Tropical*. 2001;**49**(2):535-544
- [13] Kathiresan K, Rajendran N. Mangrove ecosystems of the Indian Ocean region. *Indian Journal of Marine Sciences*. 2005;**34**(1):104-113
- [14] Raveenthiranath N. Ecology of Macrobenthos in and around Mahandrapalli Region of Coleroon Estuary, Southeast Coast of India [Thesis]. India: Annamalai University; 1990
- [15] Shou L, Huang Y, Zeng J, Gao A, Liao Y, Chen Q. Seasonal changes of macro-benthos distribution and diversity in Zhoushan Sea area. *Aquatic Ecosystem Health & Management*. 2009;**12**(1):110-115
- [16] Kumar RS. Biomass, horizontal zonation and vertical stratification of polychaete fauna in the littoral sediment of cochin estuarine mangrove habitat, south west coast of India. *Indian Journal of Marine Sciences*. 2002;**31**(2):100-107
- [17] Markert BA, Breure AM. In: Zechmeister HG, editor. *Bioindicators & Biomonitors*. 2nd ed. Oxford, UK: Elsevier; 2004. p. 997
- [18] Strickland JDH, Parsons TR. A practical handbook of seawater analysis. In: *The Journal of the Fisheries Research Board of Canada*, Ottawa, Ontario. 2nd ed. Vol. 167. 1986. 310 p
- [19] Menzel DW, Corwin N. The measurement of total phosphorus in seawater based on the liberation of organically bound fractions by persulfate oxidation. *Limnology and Oceanography*. 1965;**10**(2):280-282
- [20] El Wakeel SK, Riley JP. The determination of organic carbon in marine muds. *ICES Journal of Marine Science*. 1956;**22**:180-183
- [21] Mackie ASY. *Adercodon pleijeli* gen. Et sp. nov. (Polychaeta, Ampharetidae) from the Mediterranean Sea. *Mémoires du Muséum national D'histoire naturelle*. 1994;**162**:243-250
- [22] Fauvel P. The Fauna of India Including Pakistan, Ceylon, Burma and Malaya. *Annelida: Polychaeta*. Allahabad: The Indian Press, Ltd.; 1953. p. 507
- [23] Day JH. A Monograph on the Polychaeta of Southern Africa. Part II Sedentaria. London: British Museum of Natural History; 1967. pp. 459-878

- [24] Clark KR, Gorley RN. Primer v7: User Mannual/Tutorial. Plymouth: Primer-E; 2006. p. 182
- [25] Shannon CE, Wiener W. The Mathematical Theory of Communication. Urbana: University of Ilinois. Press; 1949
- [26] Margalef R. Information theory in ecology. *International Journal of General Systems*. 1958;**3**:36-71
- [27] Pielou EC. The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*. 1966;**13**:131-144
- [28] Shepard RN. The analysis of proximities: Multidimensional scaling with an unknown distance function. *Phychometrika*. 1962;**27**:125-140
- [29] Kruskal JB. Multidimensional scaling by optimising goodness of fit to a nonmetric hypothesis. *Pscyhometrika*. 1964;**29**:1-27
- [30] TerBraak CJF. Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. *Ecology*. 1986;**67**:1167-1179
- [31] Leps J, Šmilauer P. *Multivariate Analysis of Ecological Data Using Canoco*. Cambridge: Cambridge University Press; 2003
- [32] Kumar RS. Macro benthos in the mangrove ecosystem of cochin backwaters, Kerala (southwest coast of India). *Indian Journal of Marine Science*. 1995;**24**:56-61
- [33] Guerreiro J, Freitas S, Pereira PJ, Paula MA. Sediment macrobenthos of mangrove flats at Inhaca Island, Mozambique. *Cahiers de Biologie Marine*. 1996;**37**:309-327
- [34] Bolam SG, Barrio-Frojan CRS, Eggleton JD. Macrofaunal production along the U. K continental shelf. *Journal of Sea Research*. 2010;**64**:166-179
- [35] Manokaran S. Diversity and Trophic Relationship of Shelf Macrobenthos of Southeast Coast of India [Thesis]. India: Annamalai University; 2011
- [36] Kathiresan K. A review of studies on Pichavaram mangrove, Southeast India. *Hydrobiologia*. 2000;**430**(1-3):185-205
- [37] Murugesan P, Muniasamy M, Muthuvelu S, Vijayalakshmi S, Balasubramanian T. Utility of benthic diversity in assessing the health of an ecosystem. *Indian Journal of Marine Science*. 2011;**40**:783-793
- [38] Rahaman SH, Lipton S, Rahaman M, Ghosh AK, Islam S. Nutrient dynamics in the Sundarbans mangrove estuarine system of Bangladesh under different weather and tidal cycles. *Ecological Processes*. 2013;**2**:29. DOI: 10.1186/2192-1709-2-29
- [39] Sivaraj S. *Studies on Polychaetes of Vellar-Coleroon Estuarine Complex: Biodiversity, Molecular Taxonomy and Ecological Assessment (AMBI Indices)* [Thesis]. India: Annamalai University; 2014
- [40] Vijayakumar S, Rajesh KM, Mridula RM, Hariharan V. Seasonal distribution and behavior of nutrients with reference to tidal rhythm in the Mulki estuary, southwest coast of India. *Journal of the Marine Biological Association of India*. 2000;**42**:21-31

- [41] Sivaraj S, Murugesan P, Silambarasan A, Preetha Mini Jose HM, Bharathidasan V. AMBI indices and multivariate approach to assess the ecological health of Vellar-Coleroon estuarine system undergoing various human activities. *Marine Pollution Bulletin*. 2015;**100**(1):334-343. DOI: 10.1016/j.marpolbul.2015.08.028
- [42] Nagelkerken IS, Blaber JM, Boullin S, Green P, Haywood M, Kirton LG, Meynecke JO, Pawlik J, Penrose HM, Sasikumar A, Somerfield PJ. The habitat function of mangroves for terrestrial and marine fauna: A review. *Aquatic Botany*. 2008;**89**:155-185
- [43] Hasrizal SB, Kamaruzzaman Y, Sakri I, Ong MC, Noor Azharm MS. Seasonal distribution of organic carbon in the surface sediments of the Terengganu near shore coastal area. *American Journal of Environmental Science*. 2009;**5**(1):111-115
- [44] Sreedevi C. Impact of Bottom Trawling on Benthic Ecology along the Coastal Waters of Kerala with Special Reference to Meiofauna [Thesis]. India: Kerala University; 2008. pp. 1-324
- [45] Kamykowski D, Zentoura S. Spatio-temporal and process oriented views of nitrite in the world ocean as recorded in the historical data set. *Deep-Sea Research*. 1991;**38**(4):445-464
- [46] Gouda R, Panigrahy RC. Seasonal distribution and behavior of nitrite and phosphate in Rushikulya estuary, east coast of India. *Indian Journal of Marine Science*. 1995;**24**:233-235
- [47] Manikoth S, Salih KYM. Distribution characteristics of nutrients in the estuarine complex of cochin. *Indian Journal of Marine Science*. 1974;**3**:125-130
- [48] Joshi H, Ghose M. Forest structure and species distribution along soil salinity and pH gradient in mangrove swamps of the Sundarbans. *Tropical Ecology*. 2003;**44**(2):195-204
- [49] Martin GD, Nisha PA, Balachandran KK, Madhu NV, Nair M, Shaiju P, Joseph T, Srinivas K, Gupta GVM. Eutrophication induced changes in benthic community structure of a flow-restricted tropical estuary (Cochin backwaters), India. *Environmental Monitoring and Assessment*. 2011;**176**(1-4):427-438
- [50] Sekar V, Prithiviraj N, Savarimuthu A, Rajasekaran R. Macrofaunal assemblage on two mangrove ecosystems, southeast coast of India. *International Journal of Recent Scientific Research*. 2013;**4**(5):530-535
- [51] Sebastin RS. Studies on the Ecology of Benthos in Sunnambar Estuary, Pondicherry, Southeast Coast of India [Thesis]. India: Annamalai University; 1990
- [52] Gray JS. The ecology of marine sediment. In: *An Introduction to the Structure and Function of Benthic Communities*. Cambridge: Cambridge University Press; 1981
- [53] Snelgrove PVR, Butman CA. Animal-sediment relationships revisited: Cause versus effects. *Oceanography and Marine Biology: an Annual Review*. 1994;**32**:111-177
- [54] Sundaray SK, Panda UC, Nayak BB, Bhatta D. Multivariate statistical techniques for the evaluation of spatial and temporal variation in water quality of the Mahanadi River-estuarine system (India)-a case study. *Environmental Geochemistry and Health*. 2006; **28**(4):317-330



- [55] Satheeshkumar P, Manjusha U, Pillai NGK. Conservation of mangrove forest covers in Kochi coast. *Current Science*. 2011;**101**(11):1400
- [56] Sivaraj S, Murugesan P, Muthuvelu S, Vivekanandan KE, Vijayalakshmi S. AMBI and M-AMBI indices as a robust tool for assessing the effluent stressed ecosystem in Nandgaon coastal waters, Maharashtra, India. *Estuarine, Coastal and Shelf Science*. 2014;**146**:60-67
- [57] Prabha DL. Environmental Inventory of Tidal and Gradient Zones of Coleroon Estuary, Southeast Coast of India [Thesis]. India: Annamalai University; 1994
- [58] Ansari ZA, Ingole BS, Parulekar AH. Effect of high organic enrichment of benthic polychaete population in an estuary. *Marine Pollution Bulletin*. 1986;**17**(8):361-365
- [59] Athalye RP, Gokhale KS. Macrobenthos from the mudflats of thane creek, Maharashtra, India. *Journal-Bombay Natural History Society*. 1998;**95**:258-266
- [60] Raveenthiranaath R. Ecology of Macrobenthos in and around Mahendrapalli Region of Coleroon Estuary, Southeast Coast of India [Thesis]. India: Annamalai University; 1990
- [61] Kumar RS. Biodiversity and affinity of polychaetous annelids within the mangrove ecosystem of indo-Pacific region. *Journal of the Marine Biological Association of India*. 2001;**43**(1-2):206-213
- [62] Muthuvelu S, Murugesan P, Muniasamy M, Vijayalakshmi S, Balasubramanian T. Changes in benthic macrofaunal assemblages in relation to bottom trawling in Cuddalore and Parangipettai coastal waters, southeast coast of India. *Ocean Science Journal*. 2013;**48**(2): 183-195
- [63] Harkantra SN, Parulekar AH. Benthos off cochin, southwest coast of India. *Indian Journal of Marine Science*. 1987;**16**:57-59
- [64] Bhat UG, Neelakantan B. Environmental impact on the macrobenthos distribution of Kali estuary, Karwar, central west coast of India. *Indian Journal of Marine Science*. 1988;**17**: 134-142
- [65] Meksumpun C, Meksumpun S. Polychaete-sediment relations in Rayong, Thailand. *Environmental Pollution*. 1999;**105**(3):447-456
- [66] Maurer DL, Keck RT, Tinsman JC, Leathem WA, Wethe CA. Vertical migration of benthos in simulated dredged material overburdens. In: *Marine Benthos*. Vol. I. Delaware Univ Lewes Coll Of Marine Studies; Tech Report D-78-35. US Army Engineer Water-ways Experiment Station; 1978. <http://www.dtic.mil/dtic/tr/fulltext/u2/a058725.pdf>
- [67] Jegadeesan P. Studies on Environmental Inventory of the Marine Zone of Coleroon Estuary and Inshore Waters of Pazhayar, Southeast Coast of India[Thesis]. India: Annamalai University; 1986
- [68] Murugan A. Ecobiology of Cuddalore, Uppanar Backwaters, Southeast Coast of India [Thesis]. India: Annamali Universtiy; 1989

- [69] Thangaraja GS. Ecobiology of the Marine Zone of the Vellar Estuary [Thesis]. India: Annamalai University; 1984
- [70] Murugesan P. Benthic Biodiversity in the Marine Zone of Vellar Estuary (Southeast Coast of India) [Thesis]. India: Annamalai University; 2002
- [71] Muthuvelu S. Impact of Bottom Trawling on Infaunal Communities of Inshore Waters of Parangipettai and Cuddalore, Southeast Coast of India [Thesis]. India: Annamalai University; 2013
- [72] Shillabeer N, Tapp JF. Improvements in the benthic fauna of the Vellar estuary after a period of reduced pollution loadings. *Marine Pollution Bulletin*. 1989;**20**:119-123
- [73] Sanders HL. Marine benthic diversity: A comparative study. *The American Naturalist*. 1968;**102**(925):243-282
- [74] Panikkar NK. Influence of temperature on osmotic behaviour of some crustacea and its bearing on problems of animal distribution. *Nature*. 1940;**146**:366
- [75] Palanisamy SK, Anisa BK. The distribution and diversity of benthic macroinvertebrate fauna in Pondicherry mangroves. India. *Aquatic Biosystems*. 2013;**9**:15
- [76] Ajmal Khan S, Raffi SM, Lyla PS. Brachyuran crab diversity in natural (Pichavaram) and artificially developed mangroves (Vellar estuary). *Current Science*. 2005;**88**(8):1316-1324
- [77] Tolhurst TJ, Chapman MG. Patterns in biogeochemical properties of sediments and benthic animals among different habitats in mangrove forests. *Austral Ecology*. 2007;**32**: 775-788
- [78] Mackie ASY, Oliver PG, Rees EIS. Benthic biodiversity in the southern Irish Sea. *Studies in marine biodiversity and systematics from the National Museum of Wales. BIOMOR Reports*. 1995;**1**:263
- [79] Mackie ASY, Parmiter C, Tong. Distribution and diversity of polychaeta in the southern Irish sea. *Bulletin Marine Science*. 1997;**60**(2):467-481