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Assessment of Effluent Stressed Ecosystem of Cuddalore Coastal Waters – a Bio-Indicator Approach

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Abstract

The recent focus of scientific communities relay on assessing marine environment using different bio-indicators. The Cuddalore coastal water receives different effluents from SIPCOT industrial area through the Uppanar estuary. In this background, the present study deals with the hypothesis that polychetes can be a bio-indicator for assessing environmental conditions of Cuddalore coastal waters. The result revealed that Cluster and MDS plots showed that stations I, II and III, IV grouped together in respect to species composition. Abundance Biomass Curve (ABC) indicates stations I and II are polluted because of the dominance of indicator species of an ecological group (EG-IV & V). These stations (I & II) has been fixed at the confluence point of fishing harbor and Uppanar back waters while other stations (III & IV) in off-shore of the coastal waters. Thus, this study proved that polychaetes having the great potential for assessing the nature of the ecosystem receiving industrial effluents.

Keywords Polychaetes · Indicator species · Diversity · K-dominance · ABC curve

Introduction

Globally, coastal and marine ecosystems are significantly disturbed by a variety of human activities. As far as Indian coastal line significant impacts from nearby industrial effluents and assessment of these coastal environments are essential (Sivaraj et al. 2014). Scientific communities used various indicator species to assess the coastal waters (Abhiroop and Subodh Kumar 2016) with the view of protecting the healthiness of an ecosystem. Polychaetes are one among them and they constitute the most abundant taxon in macrobenthic communities in terms of number and abundance. Unlike nektonic or crawling organisms, the polychaetes are usually live within the sediments or attached to the hard substrate, and their immobility facilitates chronic exposure to any pollutants in the environment rather than free-moving organisms. Therefore, any changes in the environment it seems to be evident through the polychaetes community (Papageorgiou et al. 2006; Belan 2003; Omena and Creed 2004; Tomassetti and Porrello 2005).

Regional Terms: Cuddalore Coastal waters; India

Geographical Co-ordinates: 11° 42' 354″ N; 79° 47' 310" E

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The coastal waters might be polluted through sewage and effluent runoff in terms of the input of organic matter and it's broken down, the oxygen levels may be reduced in the benthic realm leading to anoxic conditions. The species composition and population density may vary in that ecosystem. As proved by Pearson and Rosenberg (1978) described a model of macrobenthic successional change in benthic communities due to organic matter increases in the environment. In this model showed that the high organic community made up of a few resistant species such as *Capitella capitata* and *Malacoceros fuliginosus* present in high abundance whereas intermediate zone with reduced organic input characterized by moderate pollution tolerant species like *Nereis caudate* and *Cirriformia tentaculata* (Méndez 2006; Harlan 2008). The point away from the source of organic input would be found species usually present in the non-polluted region. Based on this observation a list of species was categorized in terms of highly resistant, tolerant and sensitive species (Ait Alla et al. 2006; Granberg et al. 2008). Besides, they have both k-selected and r-selected species with the gradient from very pristine to polluted habitats and used as bioassay/pollution indicators at species, population and community levels (Elias et al. 2003; Surugiu 2005; Joydas et al. 2011).

The utility of polychaetes in bio-monitoring studies having special value; they are extremely responsive to changes in environmental conditions over spatial and temporal scales. Especially, the mass proliferation of certain polychaete families provides a good 'snapshot' of the health of the benthic habitats. As evidence, some polychaetes families Capitellidae (e.g. *Capitella capitata*) and Spionidae (e.g. *Polydora cornuta*, *Streblospio benedicti*, *Prionospio cirrobranchiata, Malacoceros fuliginosa* etc.,) have been widely accepted as indicators of organic pollution (Levin 2000; Vallarino et al. 2002; Ajmal Khan et al. 2004; Sivadas 2009). Based on the above said credential, many biotic tools are available using polychaetes enabling better assessment of the health of an ecosystem (Borja et al. 2000; Adams 2002; Borja 2005; Salas et al. 2006; Labrune et al. 2006; Sivaraj et al. 2015).

Owing to their acute sensitivity to environmental changes, many studies had been conducted using polychaetes in environmental impact assessment studies elsewhere (Harlan 2008; Feebarani and Damodaran 2014; Thamer et al. 2018). The reasons are; (a) they constitute more than half of total benthic population, which are readily available and easier to sample (b) they include a great diversity of reproductive/rejuvenate strategies and (c) they respond to disturbance induced by different kinds of pollution exhibiting detectable changes in the community structure of benthic biodiversity (Murugesan et al. 2011). From the credential point of view, this study tries to ascertain the impact of effluents on Cuddalore coastal waters using polychaetes as a bio-indicator.

Materials and Methods

The State Industries Promotion Corporation of Tamil Nadu Limited (SIPCOT) is located on the northern bank of Uppanar estuary covering an area of 520 acres with 44 industries, dealing with chemicals, petrochemicals, fertilizers, pharmaceuticals, dyes, soap, detergents, packing materials, resins, beverages, pesticides, drugs, antibiotics, etc. The untreated effluents from the

Fig. 1 Map showing the study area

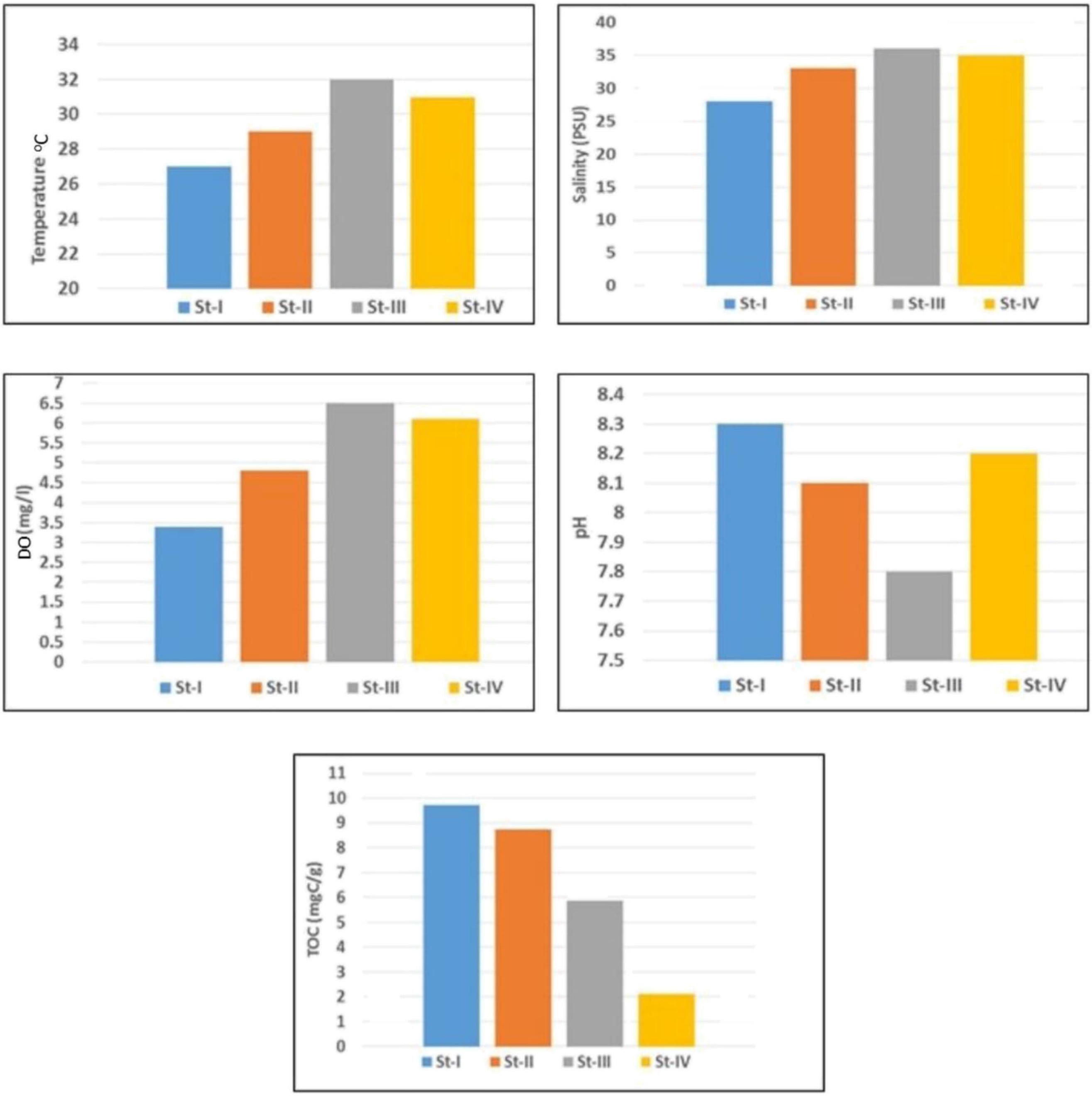

Fig. 2 Physico-chemical parameter for Temperature (°C); Salinity (psu); DO (mg/l); pH and TOC (mgC/g) of Cuddlore coastal waters

SIPCOT industrial complex are direct discharges into the Uppanar estuary for many years. Hence, it is considered as high polluted estuary ran along the southeast coast of India. During monsoonal seasons, the anthropogenic wastes enter into the estuary and they disposed into coastal waters along with industrial effluents. In this backdrop, four stations were selected in the inshore waters of Cuddalore, southeast coast of India. Stations I was fixed near the inner harbour (mouth of the estuary) while other stations (St-II, III & IV) were fixed moving towards the coastal waters with 500 m intervals between the stations (Fig. 1). Monthly sampling was made from February 2015 to January 2017. For the sake of interpretation of data, the monthly data were pooled for seasons-wise (Postmonsoon, Summer, Premonsoon and Monsoon).

Sample Collection

Three replicate sediment samples were collected at each station using van Veen grab, which covered an area of 0.1 m^2. The larger organisms were handpicked immediately from the sediments and then sieved through 0.5 mm mesh screen. The methodology adopted for benthic sample

Table 1 Overall numerical abundance of polychaetes (nos. m^{-2}) recorded from 2015 to 2017 in the study area

Family & Species	Ecological Groups	St. I	St. II	St. III	St. IV
Amphinomidae					
Amphinome rostrata	I	–	62	83	–
Amphinome sp.	I	51	80	–	52
Pisionidae					
Pisione sp.	I	–	–	46	40
Syllidae					
Sphaerosyllis capensis	II	56	–	45	47
Syllis anops	II	–	–	61	–
S. gracilis	II	87	24	89	39
S. longissima	II	–	80	–	–
Exogone clavator	II	201	174	120	54
Nereidae					
Nereis sp.	III	304	402	–	–
Nephtyidae					
Nephtys dibranchis	II	45	–	120	201
N. hombergi	II	–	84	–	–
Glyceridae					
Glycera benguellana	II	–	87	–	41
G. longipennis	II	80	82	46	–
G. unicornis	II	–		54	87
Glycera sp.	II	21	–	159	50
Goniada sp.	II	80	48	46	85
Eunicidae					
Lumbrineris aberrans	II	–	40	78	40
L. albidentata	II	–	–	94	48
Eunice sp.	II	132	41	40	63
Spionidae					
Prionospio ehlersi	IV	–	–	131	–
P. malmgreni	IV	–	40	–	–
P. sexoculata	IV	231	287	88	162
Prionospio sp.	IV	498	297	–	–
Polydora capensis	IV	–	–	46	40
Pilargidae					
Ancistrocillis parva	III	154	80	–	–
Cirratuladae					
Cirratulus cirratulus	IV	354	268	45	–
C. filiformis	III	–	–	86	–
Cirriformia tentaculata	IV	223	301	64	–
Orbiniidae					
Phylo capensis	I	–	–	97	66
Phylo sp.	I	–	80	51	56
Ophelidae					
Polyphthalmus pictus	I	–		61	80
Ophelina acuminata	III	–	–	80	80
Ophelia sp.	I	–	159	80	80
Capitellidae					
Capitella capitata	V	745	689	199	199
Pulliella armata	II	–	–	80	40
Maldanidae					
Euclymene annandalei	I	–	–	80	80
Euclymene sp.	I	48	41	120	120
Maldane sarsi	I	52	–	120	120
Flabelligeridae					
Pherusa monroi	I	–	80	80	–
Pectinariidae					
Pectinaria sp.	I	80	120	120	–
Terebellidae					
Thelepus sp.	II	–	199	–	163
Pista cristata	I	–	–	163	151
P. macrolobata	I	–	21	80	50
P. quadrilobata	I	–	–	120	–
Cossuridae					
Cossura coasta	IV	709	806	–	–
Sabellidae					
Sabella sp.	I	120	80	120	100
Potamilla reniformis	II	–	98	–	–
Fabrica filamentosa	II	–	–	80	120
Branchiomma sp.	I	74	–	–	–

Table 1 (continued)

Family & Species	Ecological Groups	St. I	St. II	St. III	St. IV
Chone collaris	II	98	102	70	55
Serpulidae					
Vermiliopsis sp.	II	–	98	–	59
Serpula vermicularis	I	–	–	55	65
Sabellaridae					
Sabellaria intoshi	I	–	–	65	80
Sternaspidae					
Sternaspis scutata	III	478	234	40	–
Total		4921	5284	3502	2813
Biomass wet weight (ww/g^{-2})		42.8 g	53.4 g	80.2 g	65.8 g

collection by Mackie (1994) and identification using Day (1967). Physico-chemical parameters such as temperature was measured in-situ using thermometer with ±0.5^0 C accuracy; salinity by Hand Refractometer (Atago co. Ltd., Japan with ±0.2%); pH by pH pen (±0.2) (Eutech Instruments, Singapore), and total organic carbon (TOC) by El Wakeel and Riley (1956) and dissolved oxygen (DO) using Winkler's method (Strickland and Parsons 1972). The percentage composition of sand, silt, and clay was analyzed standard methodology proposed by Krumbein and Pettijohn (1938).

Statistical Analysis

Physical/biological data were treated with various statistical methods namely Shannon-Wiener index, Margalef index, and Pielou's index. k – dominance curve was originally described by Warwick (1986) which involves the plotting of separate k - dominance curves (Lambshead et al. 1983) for species abundance (species diversity) of various stations on the same graph and making a comparison of these curves. The species are ranked in order of importance in terms of abundance on the X axis (logarithmic scale) with percentage dominance on the Y axis (cumulative scale). The cumulative plot is often referred to as a k - dominance curve.

Abundance Biomass Curve – plot containing both abundance and biomass curves. The plot interpreted an 'undisturbed' community indicating the biomass curve is above the abundance curve, 'gross disturbance' the abundance curve lies above the biomass curve and 'moderate disturbance' the two curves largely intersect. This is based on the observation of soft-sediment macrobenthos, the biomass dominants are large-bodied with low abundance, and are amongst the more susceptible species to environmental impact classified as undisturbed whereas gross disturbance (especially from organic enrichment) is often characterized by large numbers of individuals of a few, small-bodied 'opportunist' species.

Cluster and MDS analysis were done to find out the similarities between the samples collected in various stations. The most commonly used clustering technique is the hierarchical agglomerative method. The results are represented by a tree diagram or dendrogram with the x-axis representing the full set of samples and the y-axis defining the similarity level at which the samples or groups are fused. Bray – Curtis coefficient (Bray and Curtis 1957) was used to produce the dendrogram. MDS method was used to find out the similarities (or dissimilarities) between each pair of entities to produce a map.

BIO-ENV procedure (biota-environmental variables matching) was in order to ascertain the relationship between biological and environmental variables (Clark and Ainsworth 1993). The basic principle behind this is to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices. A weighted Spearman rank correlation coefficient ($\rho\omega$) was used to determine the harmonic rank correlation between the biological matrix and all possible combinations of the environmental variables: Further, the species belong to the Ecological Groups (EG) can be classified based on the very sensitive to opportunistic species through AMBI indices followed by Borja et al. (2000).

Results

Environmental Variables

Temperature varied from 27 to 32 °C (28.9 ± 2.9) with higher during summer (May) at station III and lower during monsoon (November) at station I. Salinity from 28 to 36 psu (32.6 ± 2.8) with lower during monsoon (December) at station I and higher in summer (May) at station III; Dissolved oxygen varied from 3.4 to 6.5 mg/l (5.1 ± 1.1) with higher during monsoon (November) at station III and lower during summer (May) at station I. pH values were from 7.8 to 8.3 (8.2 ± 0.2) with lower during monsoon (December) at station III and higher in

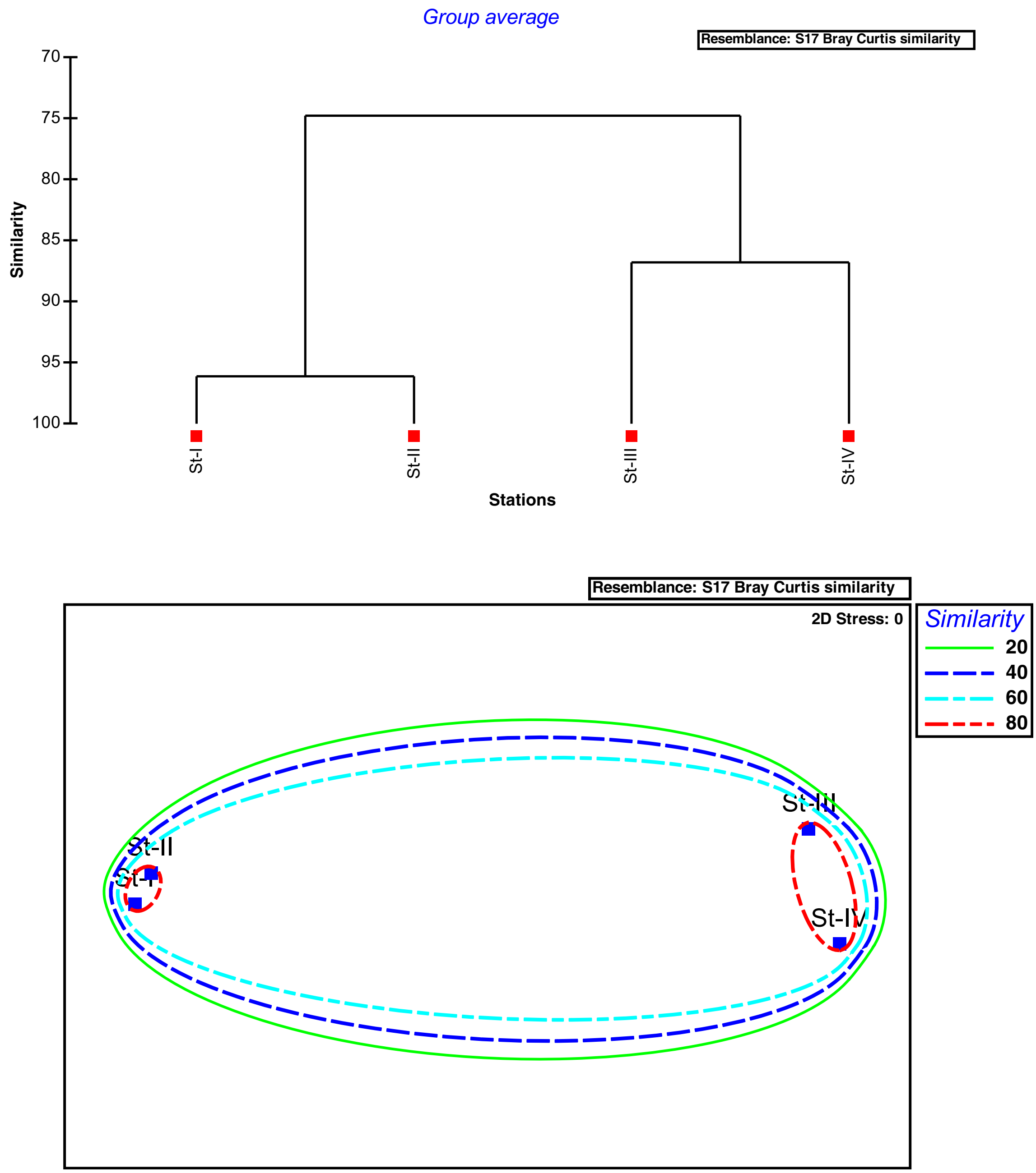

Fig. 3 Cluster and MDS analysis based on species abundance in Cuddalore coastal waters

summer (May) at station I. Total organic carbon varied from 2.11 to 9.72mgC/g (6.4 ± 2.4) with higher value during monsoon (October) at station I and lower during summer (May) at station IV (Fig. 2). Two-way ANOVA showed significant seasonal variations in temperature, salinity, DO and TOC ($P < 0.05$) and the variations between stations were also found to be significant. The sediment textural characteristic in the study stations were broadly classified into sand, silt and clay. The result revealed that sediment texture were significantly varied between the stations and also in different seasons.

Benthic Assemblages

As regards benthic fauna, as many as 54 species belonging to 22 families were recorded (Table 1). Species composition and density showed pronounced variation among the sampling stations. Based on AMBI classifications, out of 54 polychaetes, 19 species (35.19%) was fit into EG-I (very sensitive to disturbance), 21 species (38.89%) into EG-II (indifferent to disturbance), 5 species (9.26%) into EG-III (tolerant to disturbance), 8 species (14.81%) to EG-IV (second order opportunistic species) and one species (1.85%) to EG-V (first order

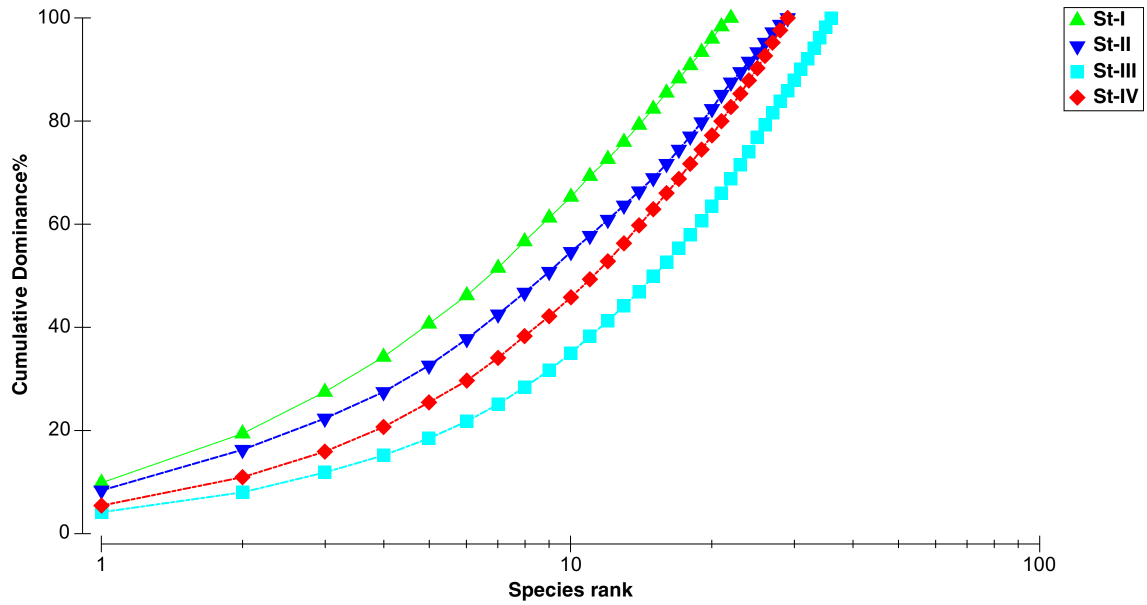

Fig. 4 *k*- Dominance curves of Cuddalore coastal waters

opportunistic species). The abundance of polychaetes varied from 2769 to 6228 nos/m^{-2} with the minimum at a station IV during monsoon and maximum at the station I during premonsoon. Among the total species, top ten bio-indicator species (Plate 1) were selected based on the predominant occurrence like *C. capitata* (199 to 1832 nos/m^{-2}), *Sternaspis scutata* (40 to 752 nos/m^{-2}), *Cossura coasta* (709 to 1515 nos/m^{-2}), *Prionospio sexoculata* (88 to 768 nos/m^{-2}), *Ancistrocillis parva* (80 to 234 nos/m^{-2}), *Cirratulus cirratus* (45 to 667 nos/m^{-2}), *Nereis* sp. (304 to 706 nos/m^{-2}), *Glycera longipinnis* (46 to 208 nos/m^{-2}), *Cirriformia tentaculata* (64 to 588 nos/m^{-2}) and *Exogone clavator* (54 to 549 nos/m^{-2}). With regard to biomass (wet weight), minimum (42.8 ww/g^{-2}) was recorded at the station I dominated by mostly opportunistic species (very short lifespan; species too small; many reproductive stages per year) and maximum (80.2 ww/g^{-2}) at station III having conservative species (long lifespan; species larger in size; one reproductive stages per year). Seasonally, maximum biomass was recorded during premonsoon and minimum in monsoon. Two-way ANOVA calculated for the differences in polychaetes biomass were found to be significant between seasons ($P < 0.05$) and not between stations.

Table 2 Harmonic rank correlations between faunal and environmental similarity matrices in various stations

No. of variables	Best variable combinations	Correlation (ρω)
5	salinity – DO – silt – clay – TOC –	0.94
5	DO - sand – Temperature – pH - TOC	0.92
4	Sand – silt – clay –TOC	0.87
4	silt – clay – DO – salinity	0.77
3	salinity – clay - silt	0.70

Multivariate Results

Shannon diversity index showed lower (2.16) at station II during monsoon and higher (3.86) at station III during summer. Margalef's species richness showed higher (5.29) at station II in summer and lower (2.95) at station I in monsoon. Species evenness varied between 0.85 and 0.92 with higher at station III during summer and lower at station II during postmonsoon. Dominance index ranged from 0.67 to 0.89 with the maximum in the station I during summer and minimum in station IV during monsoon. The results of Two-way ANOVA calculated for the differences in Shannon-Wiener diversity were found to be significant ($P < 0.025$) between seasons and not between stations and also species richness and evenness ($P > 0.05$).

Cluster/MDS Analysis/ BIO-ENV

The dendrogram showed that the stations I, II and III, IV formed separate groups. Among the stations, I and II got linked at the highest level of similarity (96%) compared to stations III and IV. This fact was confirmed through MDS which was also revealed the same pattern of groupings as observed in cluster analysis was formed (Fig. 3). Biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices were allowed to match the biota. The results showed (salinity, DO, silt, clay, and TOC) were featured as the major variables explaining the best match (0.94) with faunal distributions (Table 2).

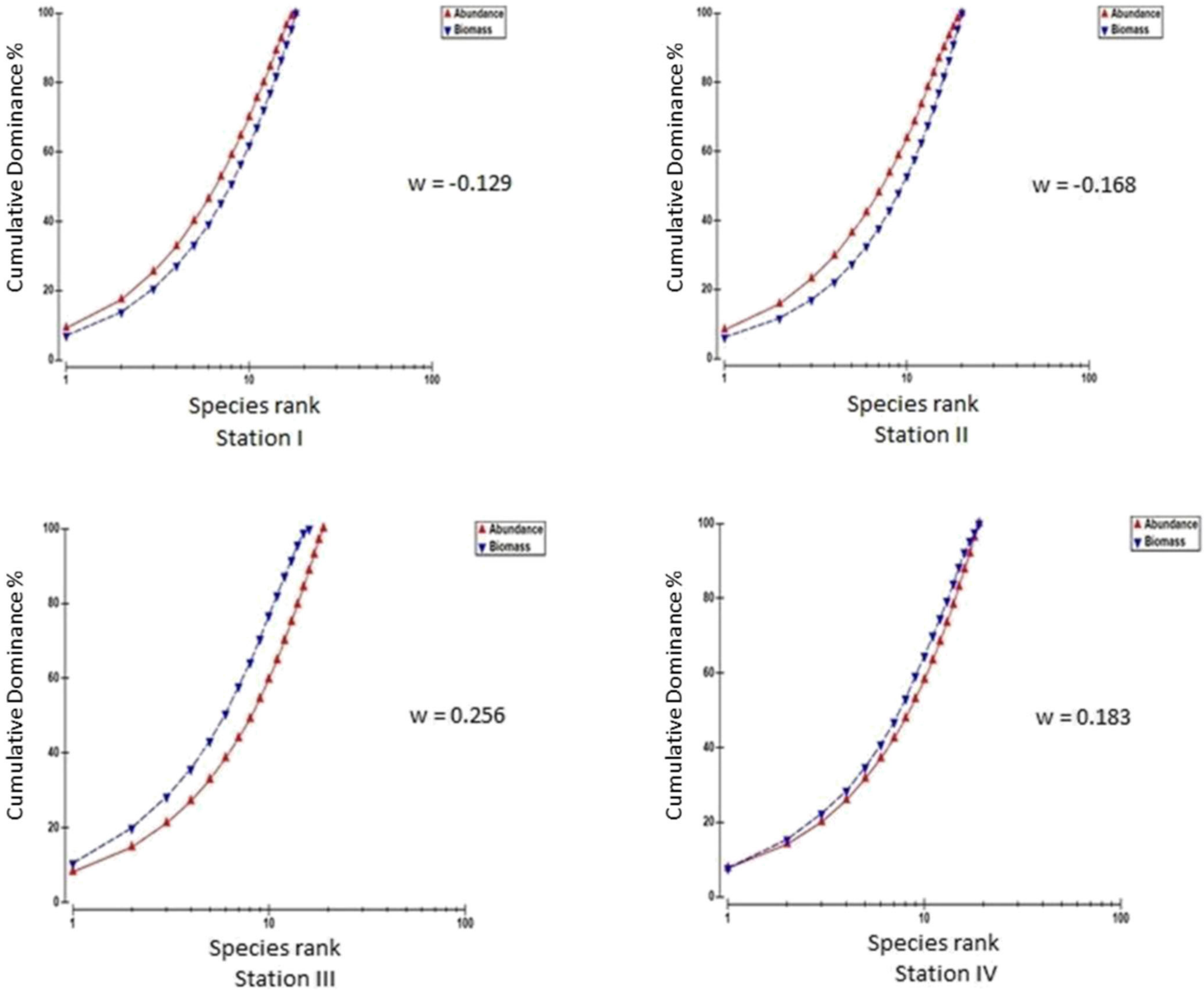

Fig. 5 The station wise ABC plot for Cuddalore coastal waters

K-Dominance Plot

This plot was drawn in order to confirm the trend observed in the diversity indices, curves of stations III and IV were found to lie lower than the other curves which indicate higher diversity whereas stations I and II lie above the curves of stations III and IV due to the greater abundance of a few species. Thus, this plot also proved the rich diversity in the stations III and IV compared to stations I and II (Fig. 4).

ABC Plot

The basic principles of this plot interpreted 'undisturbed' community indicating the biomass curve lies above the abundance curve, 'gross disturbance' the abundance curve lies above the biomass curve. Based on the principles, curves of stations I and II were found to lie above the biomass curve indicating polluted nature owing to opportunistic species (very short lifespan; species too small; many reproductive stages per year). The curves of stations III and IV were found to lies above the abundance curve (Fig. 5) indicating more conservative species (long lifespan; species larger in size; one reproductive stage per year) reflecting pristine in nature.

Bubbles Plot

Top ten bio-indicator species *Capitella capitata*, *Sternaspis scutata, Cossura coasta*, *Prionospio sexoculata, Ancistrocillis*

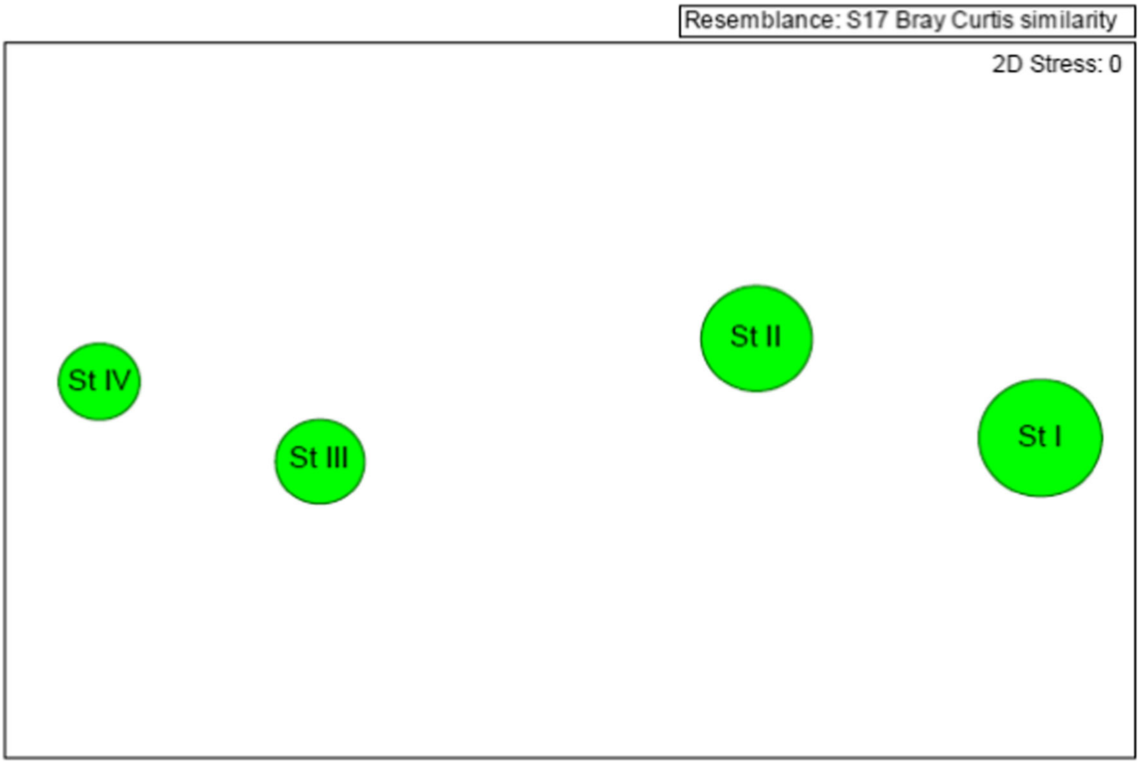

Fig. 6 Bubble plot showing the abundance of top ten species

parva, Cirratulus cirratus, *Nereis* sp., *Glycera longipinnis, Cirriformia* tentaculata, and *Exogone clavator* were selected and abundance of these species superimposed in the bubbles plot. The stations I and II of bubbles were big in size indicating the maximum abundance while stations III and IV showed small in size indicating the lesser abundance of those species (Fig. 6).

Discussion

The physico-chemical parameters like temperature, pH, salinity and DO were fluctuated owing to the seasonal pattern. The maximum total organic content was found in stations I and II (monsoon) and minimum in stations III and IV (summer). Levin et al. (1991) noted that organic carbon frequently viewed as the more significant parameter in the effluent stressed ecosystem. As evidence in the above, maximum TOC content was recorded in stations I & II. These stations are located near the mouth; it means confluence point of fishing harbor and Uppanar back and it can be the reason of maximum TOC recorded in those stations. Besides, the continuous movement of fishing vessels and dredging activities take place in those stations in order to maintain the navigation channel. This leads to affect the benthic faunal distribution in the present study which resulted in lesser diversity. Auster et al. (1996) reported that minimum benthic diversity in the ecosystem receiving anthropogenic runoff and industrial effluents.

Bio-indicator species such as *Prionospio sexoculata* in Spionidae; *Capitella capitata* in Capitellidae; *Ancistrocillis parva* in Pilargidae and *Cossura coasta* in Cossuridae and *Cirriformia tentaculata* in Cirratuladae were found remarkably increase in stations I and II owing to high organic load. These species are adapted themselves in those stations and then proliferate into a number of individuals. These sorts of polychaetes with high abundance were recorded earlier by many researchers elsewhere (Pocklington and Wells 1992; Belan 2003; Rivero et al. 2005; Sivadas et al. 2010).

AMBI indices were applied to Cuddalore coastal waters in order to assess the station having pollution indicator species. Based on that, the stations I & II are being dominated by opportunistic species such as *Capitella capitata, Sternaspis scutata, Cossura coasta, Prionospio sexoculata, Cirratulus cirratus* and *Cirriformia tentaculata* which belongs to ecological groups (EG III-V). Grall and Glemarec (1997) and Sivaraj et al. (2014) reported that these group of species are able to proliferate in reduce sediment and also tolerate in toxic conditions.

Studies conducted elsewhere reported that *C. capitata* was first-order opportunistic species, and preferred a highly organic polluted site (Ajao 1990; Mendez et al. 1998). In our study,

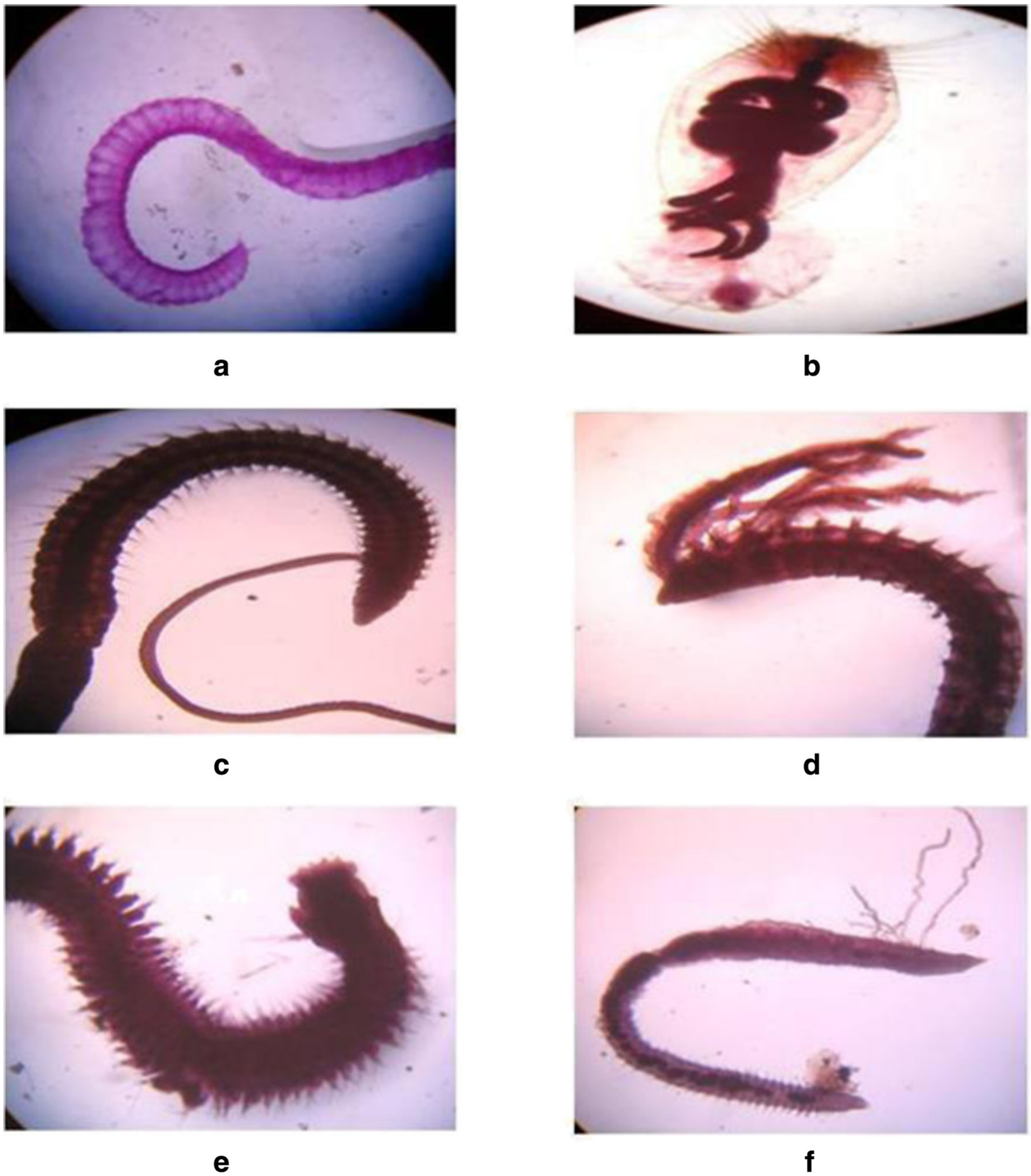

Plate 1 Dominant polychaete species recorded in the study area, **a**; *Capitella capitata* **b**; *Sternaspis scutata,* **c**; *Cossura coasta* **d**; *Prionospio sexoculata* **e**; *Ancistrocillis parva* **f**; *Cirratulus cirratus* **g**; *Nereis* sp. **h**; *Glycera longipinnis,* **i**; *Cirriformia* tentaculata **j**; *Exogone clavator*

the richness of *C. capitata, Prionospio pinnata,* and *Sternaspis scutata* were found in higher abundance in the top ten species belongs to the stations (I & II). Studies conducted in foreign waters (Levin 2000; Rivero et al. 2005), where the organic load was extremely high, in those circumstances, species namely *Prionospio*, *Capitella*, *Streblospio,* and *Mediomastus* were recorded increase in number and identified as bio-indicator species and it is a testimony to the results of the present study.

Generally, in a healthy environment, the shannon diversity ranged between 3.0 and above in the coastal environment (Magurran 1988). In the present study, data were treated in all the station/seasons; the Shannon diversity was in the range of 2.16–3.86 with the maximum in station III and minimum in II. Sivadas (2009) reported in Mormugao harbor, the diversity was more in the stations situated in outer harbour and less in the inner harbor. Likewise, in the present study also, stations III and IV which is situated away from the mouth of Uppanar estuary (outer

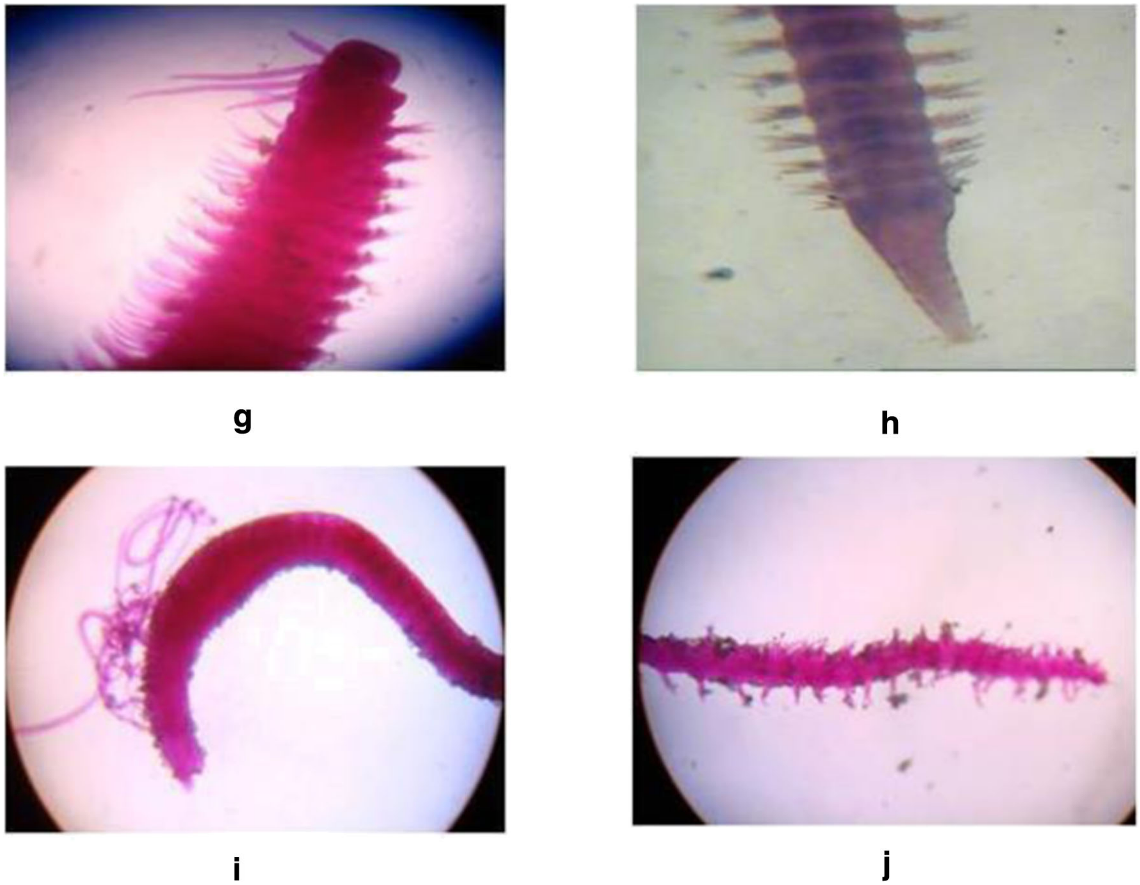

Plate 1 (continued)

harbour) had maximum diversity while stations I and II situated quite close to the mouth of the estuary (inner harbour) showed minimum diversity. This fact was further confirmed through k-dominance curves, the results showed that the curves of stations III and IV were found lying above the other curves indicating more diversity (Harkantra et al. 1980).

In cluster analysis, the stations I, II and III, IV got grouped together and further confirmed through MDS plot which was also revealed the same pattern of grouping as recognized in the cluster analysis was formed (Muthuvelu et al. 2013; Sivaraj et al. 2015). In BIO – ENV procedure, the combination of eight variables was allowed to match the biota. The result showed that salinity, DO, silt, clay, and TOC showed the important variables influencing the faunal distribution (ρω-0.94). Likewise, studies conducted elsewhere; Mackie et al. (1997) in the Irish Sea. Murugesan et al. (2011) in Tuticorin waters and Manokaran (2011) in the southeast coast of India recorded similar combinations of parameters influencing faunal distribution.

The ABC – plot is drawn clearly demonstrated that the stations I and II are polluted due to the abundance curves of this two stations were found to lie above the biomass curve while the abundance curves of stations III and IV were found to lie below the biomass curve showing undisturbed situation. In addition, W – statistic values were also on the negative side for stations I and II indicating the polluted nature while other stations III and IV on the positive side indicates pristine in nature. Sivaraj et al. (2015) conducted a study using AMBI indices and multivariate approach to assess the Vellar-Coleroon estuary, in which they clearly elucidated that the abundance curve of the polluted station was lying above the biomass curves.

Conclusion

Nowadays researchers are focusing on the use of bio-indicator species for assessing the health of the coastal ecosystem. In the present study, we made an attempt by using polychaetes as bio-indicator to assess effluent stressed ecosystem of Cuddalore coastal waters by applying multivariate statistical tools. In cluster and MDS analysis stations, I and II form a separate cluster indicating polluted nature. As well in ABC plot, abundance curves lie above the biomass curves indicating pollution of the station I and II, and even so in a bubble plot, indicator species predominantly occur in those stations. To sum up, polychaetes as a good bio-indicator, hence they had great potential to assess the coastal environment facing industrial activities and man-made pressure.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that there is no conflict of interest.

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