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Benthic Polychaetes: A Veritable Indicator of Ecosystem Health

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Abstract: **Polychaetes are the most abundant taxon in benthic communities and have been most often utilized as indicator species of environmental perturbations. Taking into account the confluence point of fishing harbor and Uppanar back waters, in the present study four stations were fixed in the Cuddalore coastal waters. Biological entities (polychaetes) and environmental variables such as temperature, salinity, DO, pH and total organic carbon in sediment and soil texture were studied from February 2009 to January 2010. Polychaetes abundance and biomass showed minimum in station I during monsoon and maximum in station III during premonsoon. As found in density, diversity and richness values were more in stations III and IV and less in stations I and II. Seasonally, the minimum diversity value was recorded during monsoon and maximum during summer. K-dominance plot and ABC curves also revealed the trend of diversity indices. Similarly the bubble plot showed unequivocally the abundance pattern in stations I and II. Cluster, MDS plots showed that stations I, II and stations III, IV formed groups themselves indicating variation in species composition.**

Keywords: **Polychaete, Indicator species, Diversity, k-dominance, ABC curve, Cluster.**

I. INTRODUCTION

Polychaetes have long been used as obvious choice to study the environmental health, as they constitute usually the most abundant taxon in macrobenthic groups, both in terms of number and numerical abundance. They include both conservative and opportunistic species in a gradient from pristine to disturbed habitats. They have been used successfully as bioassay organisms, monitors for toxic compounds and also as pollution indicators at species, population and community levels [1, 2]. They also play an important role in the stability and functioning of the benthic community ecology [3]. Unlike nektonic or crawling organisms, the polychaetes usually live within the sediments or attached to hard objects while their larvae may move rapidly. This relative immobility facilitates chronic exposure to any toxic materials in the environment rather than the episodic exposures of more free movement organisms. Any long-term changes in the well-being of the benthos will be evident through the polychaete community of any given environment [4].

The utility of polychaetes in bio-monitoring studies is of special value since they are extremely responsive to changes in environmental conditions over spatially and temporally. The presence or absence, especially the mass proliferation of certain polychaete families, provides a good ‘snapshot’ of the health of the benthic habitats. Thus, the species of the 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 [5].

When a benthic community is undergoing stress due to detrimental environmental conditions, there are presumed to be striking changes in community structure such as diversity, abundance, dominance, biomass, and so on [6]. As the polychaetes constitute a major component in the benthic community, the changes in community structure would be

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mirrored by the polychaete community. Pollution monitoring studies conducted elsewhere found that a considerable decrease in species diversity along a gradient from relatively pristine area to areas highly impacted by pollution [7]. One important characteristic of this decrease in diversity is due to increase in dominance of a few species of polychaetes [8].

In view of the facts stated in the foregoing sections, in recent times many initiatives across the world emphasized the utility of polychaetes in environmental impact assessment studies. The reasons are obvious;

(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 trophic guilds and reproductive strategies that might be reason of their success in many environments and (c) they respond to disturbance induced by different kinds of pollution exhibiting quantifiable changes in the community structure of benthic biodiversity [9].

Having this in mind, an attempt has been made to ascertain the healthiness of an environment receiving industrial and domestic sewages from nearby source. To achieve this, four stations were selected in the inshore waters of Cuddalore coast. These stations were fixed in such a way that the changes could be easily discernible while analysing the data.

II. MATERIALS AND METHODS

2.1 Study area:

For the present study, four stations were selected in the inshore waters of Cuddalore. These four stations were fixed considering the proximity of discharge point of Uppanar estuary, which is known to receive considerable quantum of untreated effluents from SIPCOT (State Industries Promotion Corporation of Tamilnadu) industry besides fishing harbor, which is again to receive waste waters and sewage from nearby domestic settlements.

The effluents from the SIPCOT industrial complex Cuddalore is directly released into the Uppanar estuary. Besides, it is one of the highly polluted estuaries along the southeast coast of India. This industrial cluster 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 raw and partially treated effluents accrue from SIPCOT immediately enter in to the estuary, which resulted in water at lower reaches gets polluted.

Stations I and II were fixed near the inner harbour (mouth of the estuary station I: Lat. 11^0 40’ 701” N; Long. 79^0 47’ 154”E and station II is located 500 m away from station I: Lat. 11^0 40’ 789” N; Long. 79^0 48’ 162”E and stations III and IV fixed 1000 m and 1500 m respectively away from stations I and II (station III, Lat. 11^0 39’ 668” N; 79^0 48’402” E and station IV Lat. 11^0 39’ 742” N; 79^0 49’653” E) and depth of each stations varied from 15-20m (Fig. 1). Monthly sampling was made from February 2009 to January 2010. For the sake of interpretation of data, the monthly data were pooled for seasons and analysed with various methods.

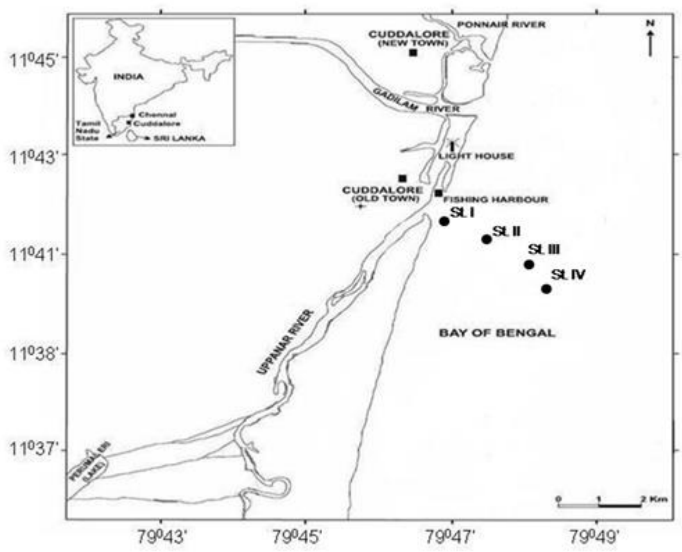

Fig 1: Map showing the study area

2.2 Sample collection:

Three replicate sediment samples were collected in each station using van Veen grab, which covered an area of 0.1m^2. Immediately after collection of samples, the larger organisms were handpicked and the rest were was sieved through 0.5 mm screen [10]. The sieve retains were fixed in 5-7% formalin. Subsequently, the organisms were stained with Rose Bengal solution for enhanced visibility during sorting. After sorting, the organisms were enumerated and identified using standard references [11, 12].

Physical parameters such as temperature was measured using thermometer with ±0.5^0 C accuracy; salinity by Hand Refracto meter (Atago co. Ltd, Japan); pH by pH pen (Eutech Instruments, Singapore), and total organic carbon (TOC) [13] and dissolved oxygen (DO) using Winkler's method [14].

2.3 Data analysis:

Further, the data were treated with various statistical methods namely univariate (Shannon-Wiener index, Margalef index and Pielou's index), graphical (k-dominance, ABC-plot, bubble plot) and multivariate (Cluster, MDS) analyses using the statistical software PRIMER- Ver.6.0 [15] and Origin-Pro (ver. 7.5).

III. RESULTS

3.1 Environmental variables:

When the results were viewed, temperature varied from 27 to 32^{0}C (28.95± 2.99) with higher during summer (May) at station III and lower during monsoon (November) at station I (Fig. 2a); salinity from 28 to 36psu (32.69± 2.82) with lower during monsoon (December) at station I and higher in summer (May) at station III (Fig. 2b); DO varied from 3.4 to 6.5mg/l (5.13 ± 1.12) with higher during monsoon (November) at station III and lower during summer (May) at station I (Fig. 2c); pH values were from 7.8 to 8.3 (8.26± 0.22) with lower during monsoon (December) at station III and higher in summer (May) at station I (Fig. 2d). Total organic carbon varied from 2.11 to 9.72mgc/g (6.48 ±2.47) with higher value during monsoon (October) at station I and lower during summer (May) at station IV (Fig. 2e). Two-way ANOVA showed significant seasonal variations in temperature, DO, TOC and salinity ($P < 0.05$) and the variations between stations were also found to be significant.

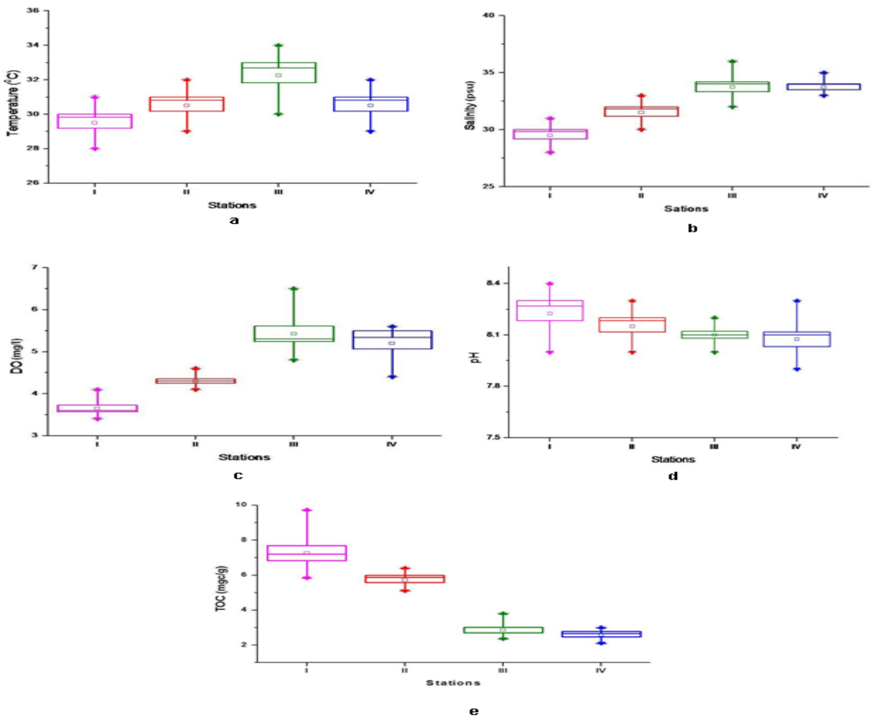

Fig 2: Water quality parameters (mean and SD) recorded in selected stations: a-Temperature (°C); b-Salinity (psu); c-DO (mg/l); d-pH and e-TOC (mgC/g). (Note: Data presented as mean (*squares*), ±1 SE (*boxes*) and ±1 SD (*whiskers*). *Upside- down triangles*: minimum; *right-side-up triangles*: maximum)

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3.2 Soil texture:

Coming to soil texture, the sand content was found to vary from 63.8 to 89.5% (78.1±7.45); silt content from 8.7 to 32.5% (19.5±7.1) and the clay content from 1.3 to 3.7% (2.4±0.5). Among the stations, the maximum sand was recorded in station IV (monsoon) and minimum in station I (summer), silt showed maximum in station I (summer) and minimum in station IV (monsoon) and the maximum clay content was in station I (summer) and minimum in station IV (monsoon) (Table 1).

Table 1 Seasonal variations of soil texture recorded in the study area

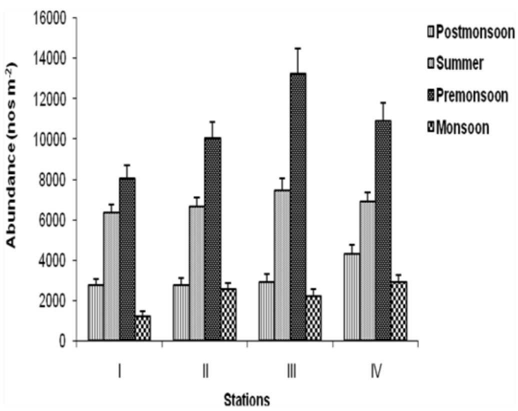
Seasons	Sand (%)				Silt (%)				Clay (%)			
	St-I	St-II	St-III	St-IV	St-I	St-II	St-III	St-IV	St-I	St-II	St-III	St-IV
Summer	63.8	69	72.7	77.1	32.5	28.1	24.7	21.1	3.7	2.9	2.6	1.7
Postmonsoon	67.7	73.9	76.8	75.96	29.2	23	20.5	21.7	3.2	3.2	2.7	2.4
Premonsoon	75.4	79.1	83.5	88.5	21.9	18.6	14.7	9.8	2.7	2.3	1.8	1.7
Monsoon	84.3	84.2	88	89.5	13.2	13.8	10.3	8.7	2.5	2	1.8	1.3
Mean ±SD	72.8±9.1	76.6±6.6	80.3±6.8	82.9±7.4	24.2±8.6	20.9±6.1	17.6±6.3	15.3±7.0	3.0±0.5	2.6±0.5	2.2±0.5	1.8±0.5

3.3 Benthic assemblages:

With respect to bottom fauna, as many as 51 species belonging to 18 families were recorded (Table 2). Species composition and density varied greatly among the sampling stations. About 12% of the species were found to occur in all the stations. The abundance of polychaetes varied from 1,241 to 13,270 no m^{-2} with minimum at station I during monsoon and maximum at station III during premonsoon (Fig.3). Among the total species, top 10 species were taken and the dominance was calculated. The abundance of *C. capitata* varied from 996 to 2072 nos m^{-2}; *Pista cristata* from 247 to1876no m^{-2}; *Glycera longipinnis* from 358 to 1673no m^{-2}; *Nephtys dibranchis* from 80 to 1315nos m^{-2}; *Euclymene* sp. from 518 to 1995 no. m^{-2}; *Prionospio sexoculata* from 319 to 737nos m^{-2}; *Exogone clavator* from 40 to 547nos m^{-2}; *Thelepus* sp. from 40 to 478nos m^{-2}; *Syllis gracilis* from 80 to 478nos m^{-2} and *Ophelia* sp. from 40 to 358nos m^{-2}.

The percentage compositions of dominant species are given in Table 3. *Capitella capitata* contributed 11-18%; *Glycera longipinnis* 8-15%; *Prionospio sexoculata* 3-14%; *Exogone clavator* 7-9%; *Euclymene* sp. 6-13%; *Nephtys dibranchis* 5-14%; *Ophelia* sp. 3-8%; *Syllis gracilis* 5-10%; *Thelepus* sp. 6-7% and *Pista cristata* 11-16% of the total abundance.

With regard to biomass (wet weight), minimum (16.6g^{-2}) was recorded at station I and maximum (80.2g^{-2}) at station III. Seasonally, maximum biomass was recorded during premonsoon and minimum in monsoon (Fig. 4). Two-way ANOVA calculated for the differences in polychaetes biomass were found to be significant between seasons (P>0.05) and not between stations.



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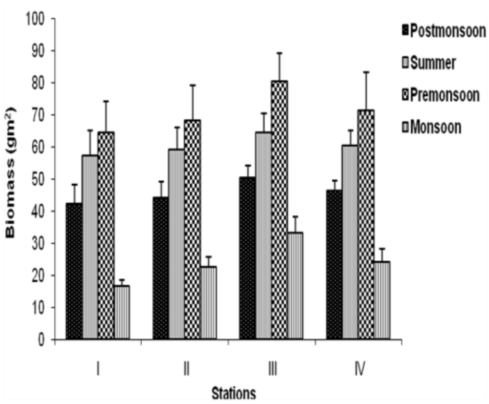

(4)

Fig 3: Seasonal variation of polychaete abundance in selected stations

Fig 4: Seasonal variation of polychaete biomass in selected stations

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Table 2: Check list of polychaetes recorded (nos. m^{-2}) in the study recorded during February 2009 to January 2010

Species	St. I	St. II	St. III	St. IV	Species	St. I	St. II	St. III	St. IV
Family: Amphinomidae					**Orbiniidae**				
Amphinome rostrata	-	40	80	-	*Phylo capensis*	-	-	80	80
Amphinome sp.	40	80	-	40	*Phylo* sp.	-	80	40	40
Pisionidae					**Ophelidae**				
Pisione sp.	-	-	40	80	*Polyphthalmus pictus*	-	-	40	80
Syllidae					*Ophelina acuminata*	-	-	80	80
Sphaerosyllis capensis	40	-	-	-	*Ophelia* sp.	159	159	80	80
Syllis anops	-	-	40	-	**Capitellidae**				
S. gracilis	80	159	120	-	*Capitella capitata*	280	199	199	239
S. longissima	-	80	-	-	*Pulliella armata*	-	-	80	40
Exogone clavator	199	159	120	120	**Maldanidae**				
Nereidae					*Euclymene annandalei*	-	-	80	80
Ceratonereis mirabilis	40	40	-	-	*Euclymene* sp.	120	199	120	120
Nephtyidae					*Maldane sarsi*	40	-	120	120
Nephtys dibranchis	40	-	120	239	**Flabelligeridae**				
N. hombergi	-	80	-	-	*Pherusa monroi*	-	80	80	-
Glyceridae					**Pectinariidae**				
Glycera benguellana	80	80	-	-	*Pectinaria* sp.	80	120	120	-
G. longipennis	40	80	40	-	**Terebellidae**				
G. unicornis	80	80	40	80	*Thelepus comatus*	-	-	199	159
Glycera sp.	239	159	159	159	*Thelepus* sp.	-	199	-	-
Goniada sp.	80	40	40	80	*Pista cristata*	-	120	159	199
Eunicidae					*P. macrolobata*	-	80	80	-
Lumbrineris aberrans	80	40	80	40	*P. quadrilobata*	-	80	120	-
L. albidentata	40	80	80	-	*Amphitrite* sp.	-	-	-	40
Eunice sp.	120	120	40	80	**Sabellidae**				
Spionidae					*Sabella* sp.	120	80	120	159
Prionospio ehlersi	-	-	120	-	*Potamilla reniformis*	-	80	-	-
P. malmgreni	-	40	-	-	*Fabrica filamentosa*	-	-	80	120
P. sexoculata	199	159	80	159	*Branchiomma* sp.	40	-	-	-
Prionospio sp.	40	80	-	-	*Chone collaris*	80	80	-	120
Polydora capensis	-	-	40	40	**Serpulidae**				
P. hoplura	-	80	-	-	*Vermiliopsis* sp.	-	80	-	-
Cirratuladae				-	*Serpula vermicularis*	-	120	-	-
Cirratulus cirratulus	40	-	40	-					
C. filiformis	-	-	80	-					
Cirratulus sp.	120	80	120	-					

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Table 3: Percentage composition of dominant species recorded at the sampling stations

Species	St. I	St. II	St. III	St. IV
Capitella capitata (DF)	18	15	11	13
Glycera longipinnis (SF)	15	10	10	8
Prionospio sexoculata (DF)	14	11	3	6
Exogone clavator (C)	9	7	7	-
Euclymene sp. (DF)	6	12	13	10
Nephtys dibranchis (SF)	5	-	6	14
Ophelia sp. (DF)	7	8	3	6
Syllis gracilis (C)	5	10	6	-
Thelepus sp. (SF)	-	-	6	7
Pista cristata (SF)	-	11	16	12
Others	21	16	19	24

DF-deposit feeder; **SF**-surface feeder; **C**-carnivore

3.4 Univariate methods:

As regards diversity indices, Shannon diversity index showed less (2.16) at station II during monsoon and more (3.86) at station III during summer (Fig. 5); Margalef's species richness showed higher (5.29) at station II in summer and lower (2.95) at station I in monsoon (Fig. 6) and the species evenness varied between 0.85 and 0.92 with higher at station III during summer and lower at station II during postmonsoon (Fig. 7). Dominance index ranged from 0.67 to 0.89 with maximum in station I during summer and minimum in station IV during monsoon.

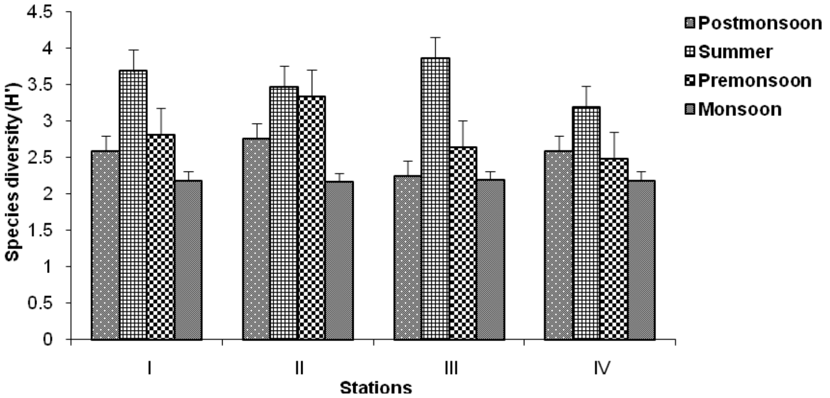

Fig 5: Seasonal variation of species diversity (H') in selected stations

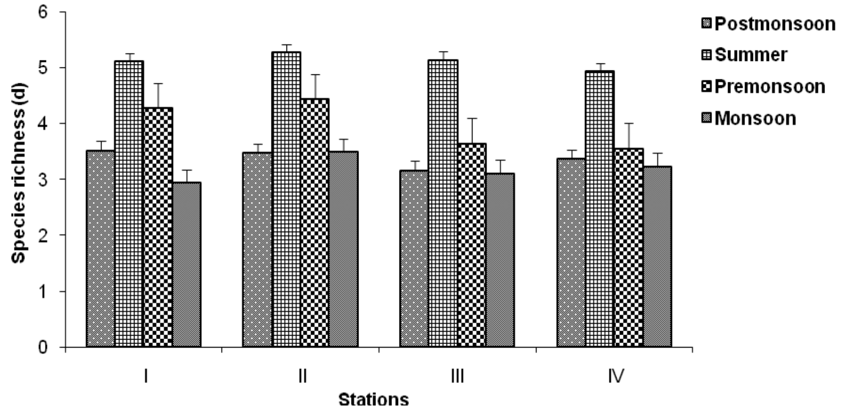

Fig 6: Seasonal variation of species richness (d') in selected stations

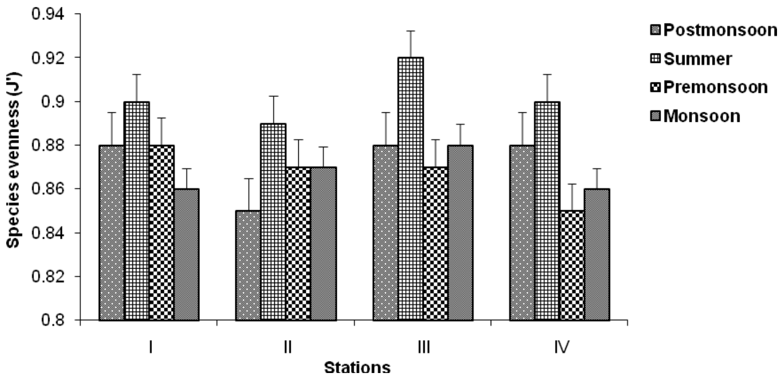

Fig 7: Seasonal variation of species evenness (J') in selected stations

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 so also species richness and evenness ($P>0.05$).

3.5 Graphical techniques:

The k- dominance plot drawn clearly demonstrated the diversity pattern in four stations. Conforming to the trend observed in diversity indices, curves of stations III and IV were found to lie on the lower side and rose slowly due to the presence of more number of species. As the percentage contribution of each species is added, the curve extends horizontally (species number is evident in the X- axis) before reaching the cumulative 100%. The curves of stations I and II rose quickly above the curves of stations III and IV due to the greater abundance of a few species. Thus, this plot also amply proved the rich diversity in the stations III and IV compared to stations I and II (Fig. 8). Further, the data pertaining to species abundance and biomass were allowed as inputs to draw ABC – plot for four stations. The ABC – plot showed clearly that the abundance curves of stations I and II were found to lie above the biomass curve indicating disturbed nature while abundance curves of stations III and IV were found to lie below the biomass curve indicating more conservative species and suggested healthiness of the systems (Fig. 9). Correspondingly the W – values, which are seen at top right corner of the plot, for stations I and II were found to be negative, which is again vouching for polluted situation of stations I and II.

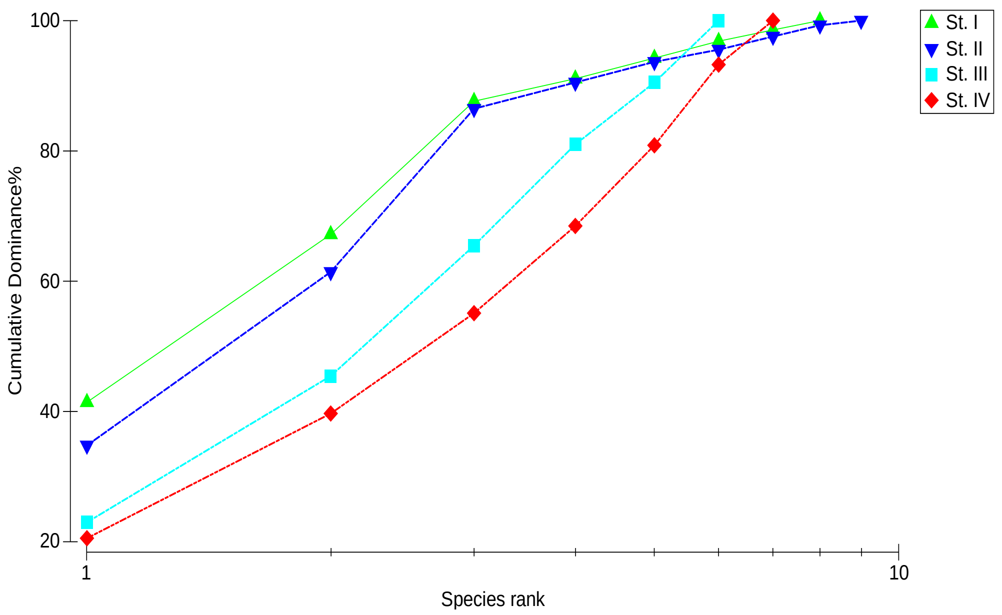

Fig 8: *k*- Dominance curves for species abundance data in selected stations

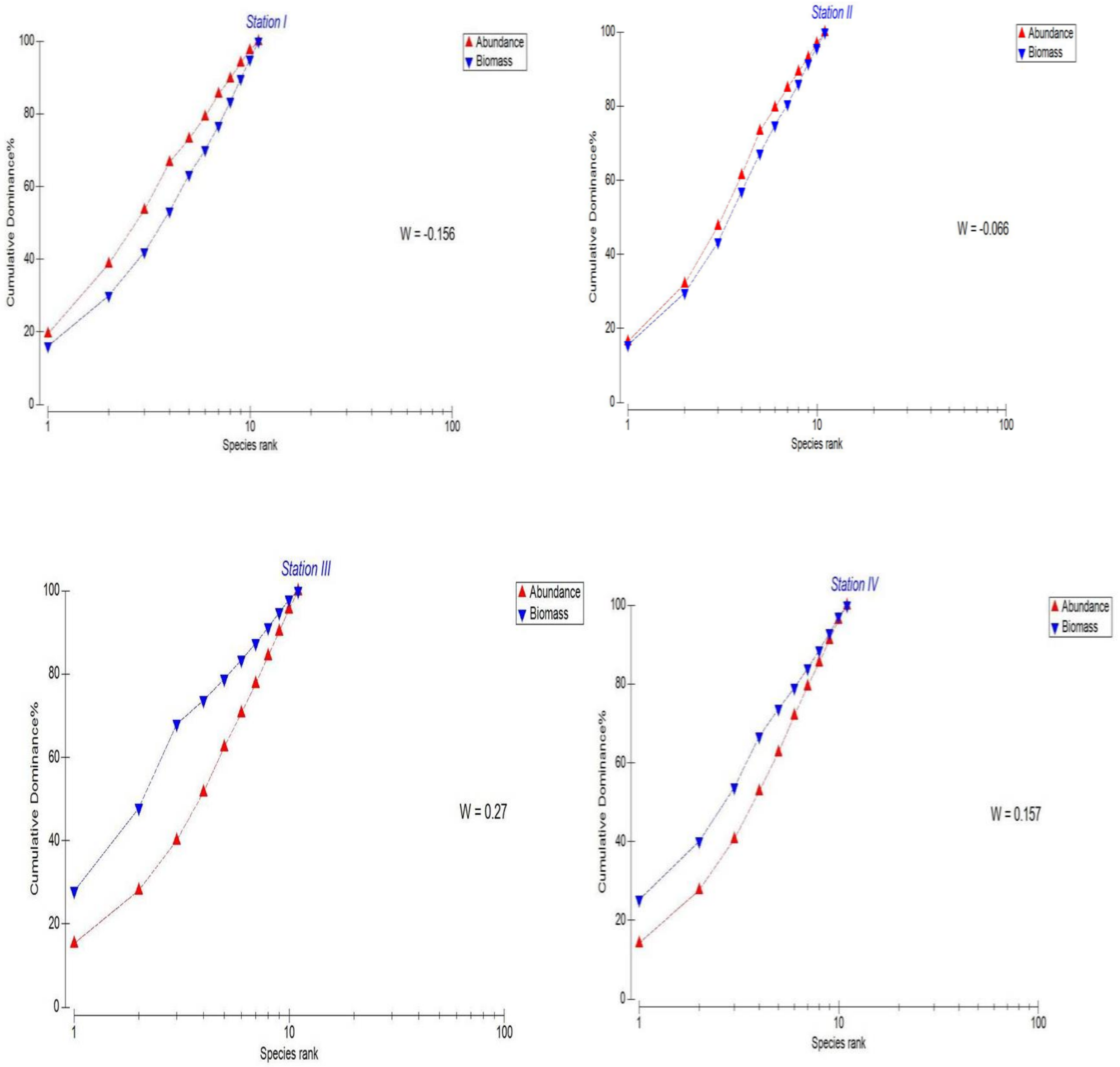

Fig 9: ABC plot drawn for the stations I to IV

3.6 Multivariate methods:

Cluster and MDS analysis was done to find out the similarity between stations. The dendrogram showed unequivocally 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 (97%) compared to stations III and IV (Fig. 10). MDS plot revealed the same groupings as observed in cluster analysis (Fig. 11).

The bubble plot was drawn to show the relative abundance of dominant (indicator species) species recorded in the stations. In this map, the abundance of species, which vouched for the dissimilarity between stations, was superimposed as circles of different size. Larger the bubble size greater is the value of the superimposed variable (abundance). In the present study, most dominant species like *Capitella capitata, Glycera longipinnis, Syllis gracilis, Exogone clavator, Euclymene* sp. *Nephtys dibranchis* and *Prionospio sexoculata* were selected and abundance of these species was superimposed in the MDS plot. Bubbles of stations I and II had larger size indicating the maximum abundance while bubbles of III and IV showed smaller size indicating lesser abundance of those species (Fig. 12).

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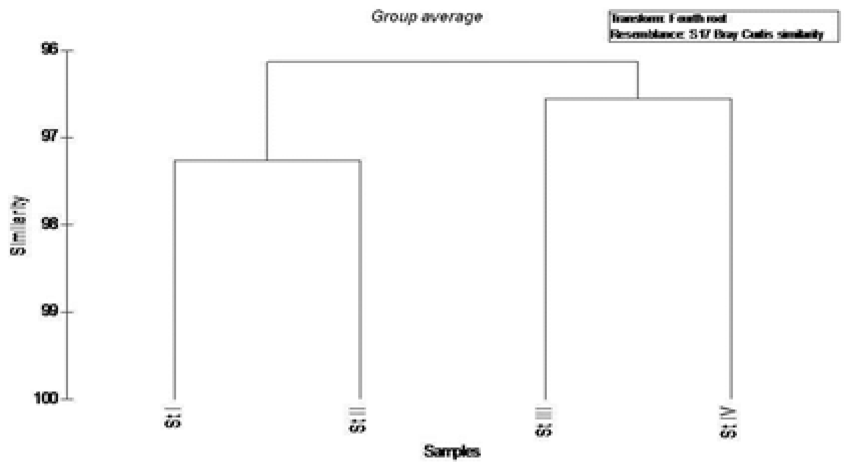

Fig 10: Cluster analysis based on species abundance in selected stations

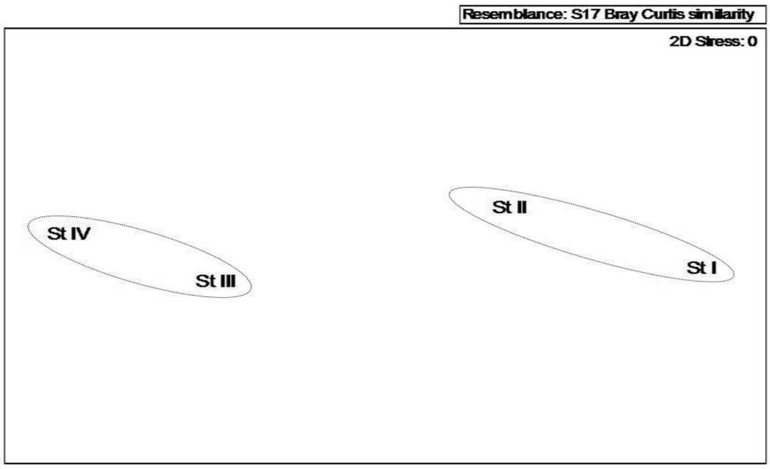

Fig 11: MDS ordination based on species abundance in selected stations

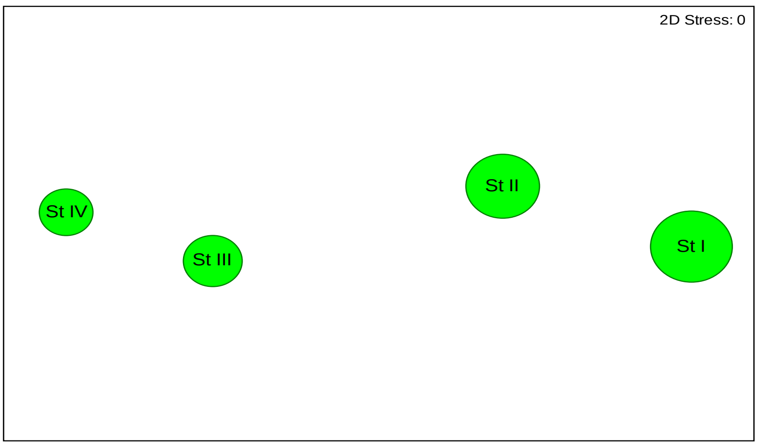

Fig 12: Bubble plot showing the abundance of top ten species in selected stations

3.7. BIO-ENV:

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, eight environmental variables were allowed to match the biota. They were sand, silt, clay, total organic carbon (mgC/g), temperature, salinity, dissolved oxygen and pH were allowed to match the biota. The results of best combinations are given in Table 4.

In this study, the salinity, DO, silt, clay and TOC were featured as the major variables explaining the best match (0.92) with faunal distributions. Sand and temperature were also implicated of particular importance among the best variable combinations.

Table 4: Harmonic rank correlations (ρω) between faunal and environmental similarity matrices in various stations

o. of variables	Best variable combinations	Correlation (ρω)
5	salinity – DO – silt – clay – TOC –	0.92
5	DO - sand – Temperature – pH - TOC	0.90
4	Sand – silt – clay –TOC	0.88
4	silt – clay – DO – salinity	0.76
3	salinity – clay - silt	0.70

IV. DISCUSSION

In the present study, when the results of water quality were viewed, there is no striking variations was noticed except a few. Temperature showed higher at station IV during summer and lower at station I during monsoon. Similar monsoonal lower and summer higher was reported in Cuddalore waters [9, 16]. Salinity is one of the important key factors, which profoundly influences the abundance and distribution of the benthic organisms. It showed typical seasonal pattern in their distribution. Hydrogen ion concentration (pH) in surface waters remained alkaline in all the stations throughout the study period, with maximum value during summer and minimum in monsoon. Generally, fluctuations in pH values during different seasons of the year might be attributed to factors like removal of CO_2 by photosynthesis through bicarbonate degradation, dilution of seawater by freshwater influx, reduction in salinity and temperature, and decomposition of organic matter [17]. In the present study, DO levels were high during monsoon and low during summer at all the stations. This might be due to the cumulative effect of higher wind velocity coupled with heavy rainfall and freshwater mixing. Lower values observed during summer, could be mainly due to reduced agitation and turbulence of the coastal waters [18].

In addition to industrial effluents, the domestic sewage and wastes from fishing harbor find their way immediately into the study area, which resulted in reduced dissolved oxygen in bottom waters. Consequent of this, extinction of benthic communities, reduced growth rates and changes in benthic community structure as has been reported by Nielsen and Jernakoff [19]. True to the above, in the present study, minimum DO level was recorded in the stations I and II which are situated close to sewage outfall. Industrial discharges may also carry a significant thermal load to receiving environments. Impacts of NPS (non-point source) and PS (point source) pollutants include; sedimentation and infilling of waterways, nutrient enrichment, organic loadings are known to alter benthic dissolved oxygen dynamics, increased contaminant cycling in estuarine biota and thermal effects [20].

Maximum TOC content was found in stations I and II (monsoon) and minimum in stations III and IV (summer). Sedimentary organic carbon content is viewed as a weak proxy for food availability in any given environment and they are strongly influenced by the particle size, which is often a function of hydrodynamic regime [21]. Levin et al. [22] noted that organic carbon is frequently viewed as more significant parameter determining the polychaete diversity. True to the above, maximum TOC content was recorded in stations I &II.

Sediment composition (sand, silt, and clay) indicated a diverse nature of the benthic substratum along the study area. Among the stations, the maximum sand was found in station III and IV followed by silt and clay. Similarly, Ansari [23] reported high density and biomass of polychaetes are associated with sandy substrate. Generally, water content of the sediments reflects an increase in the fine particles (mud and clay) which can retain more water than coarse particles (sand and gravel). Such fine deposits or particles were commonly composed of decomposable organic constituents.

With respect to faunal density, minimum was recorded in station I and maximum in station III. As station I is located near the mouth, where continuous movement of fishing vessels and the annual maintenance of dredging activities to deepen the channel after the monsoon, might have affected the benthic faunal distribution which resulted in lesser diversity. This above-said view point is in close agreement with Auster et al. [24] who studied the benthic diversity in a system receiving industrial effluents and reported similar results.

During the study, polychaetes showed significant seasonal variations. Postmonsoon and summer months registered the maximum diversity and monsoon months the minimum diversity. Similar pattern of density was also recorded earlier by Murugesan [25] in Vellar estuary, Kundu et al. [16] in the shelf waters of southeast coast of India

In the present study, the indicator species such as, *Prionospio sexoculata* in Spionidae; *Capitella capitata,* in Capitellidae; *Syllis gracilis* in Syllidae and *Pista cristata* and *Thelepus* sp. in Terebellidae were found exceedingly large in number in stations I and II. Similar species of polychaetes (indicator species) with high abundance was recorded earlier by many researchers elsewhere [5, 26].

Further, many studies conducted elsewhere reported that *C. capitata* as the most dominant species, which is known to inhabit and prefer a highly organically polluted area [27, 28]. Occurrence of *Prionospio pinnata* and *C. capitata*, the deposit feeders and indicators of organic pollution suggested the sampled area is organically rich. Polychaete abundance was found to be higher along the west coast and was attributed to sediment texture due to high sand and sandy silt resulting in higher interstitial space for organisms to harbor [29]. In the present study also, the richness of *C. capitata* was more in terms of abundance in the top ten species.

Studies made in other places where organic load is extremely high with low oxygen level, polychaetes belonging to families Spionidae, Capitellidae, Cirratulidae and Eunicidae and more particularly species belonging to genera namely *Prionospio*, *Capitella*, *Streblospio* and *Mediomastus* were found to record large in number and they were also proposed as indicator species of organic pollution, which is again testimony to the results of the present study [30, 31].

Devi and Venugopal [32] studied benthos in Cochin backwaters and proposed *Dendronereis aestuarina*, *Prionospio polybranchiata* and *Lycastis indica* as indicator species of industrial pollution [33]. Similarly, proposed *P. cirrobranchiata* as indicator of industrial pollution in Uppanar backwaters [34]. Dean [35] reported *Prionospio cirrifera*, *P. sexoculata*, *P. cirrobranchiata*, *Ancistrosyllis parva*, *Nephthys sphaerocirrata*, *Baccharis singularis*, *Malacoceros indicus*, *Tharyx* sp. and *Dendronereis* sp. as pollution tolerant species.

A brief list of positive indicators of a stressed benthic community due to pollution was brought out by various researchers which include the capitellids *C. capitata*, *Heteromastus filiformis* [5, 26] and the spionids *Malacocerus fulginosus*, *Paraprionospio pinnata*, and *Polydora ligni* [36] the nereid *Nereis* (*H.*) *diversicolor*, the dorvilleid *Ophryotrocha adherens* [37] and the cirratulids *Chaetozone setosa* [38], which is in close agreement with the results of the present study since the representative from polychaete families such as capitellids, spionids, nereids and cirratulids were recorded in the top ten species. This might be due to continuous discharge of effluents which got settled down at the bottom has led to decimation of other conservative species and flourishing of opportunists.

With respect to diversity indices, generally, in a healthy environment, the Shannon diversity will be more than 3.0 [39]. In the present study, the Shannon diversity was in the range of 2.16 - 3.86 with maximum in station III and minimum in II. While Margalef richness was in the range of 0.69 - 5.29 and evenness values from 0.85 to 0.92. In an earlier study conducted in Marmagao harbor found that the diversity was more in the stations situated in outer harbour and less in the stations of inner harbour [5]. Similarly, in the present study also, stations III and IV, which are situated away from mouth of Uppanar estuary (outer harbour) had maximum diversity and minimum richness while stations I and II, situated quite close to mouth of the estuary (inner harbour), had minimum diversity and maximum richness.

Seasonally, diversity showed monsoonal minimal and summer maximal which is in agreement with earlier studies made by Murugesan [40] in Vellar estuary; Devi et al. [41] in Coleroon estuary and Kumar (1995) in Cochin backwaters. Maximum diversity during summer in the study area might be due to stable environmental factors prevailed, which play an important role in faunal distribution. This fact was further confirmed through k- dominance curves. Having a smoothening effect, this curve is found to be extremely useful in comparing diversity between stations. The results showed that the curves of stations III and IV were found to rise slowly showing '*J*' shape indicating more diversity while curves of stations I and II rose quickly by the fact that dominance of a few species as demonstrated[42].

The ABC – plot drawn clearly demonstrated the polluted nature of the stations I and II by the fact that the abundance curves of these 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 signaling the undisturbed situation. Very similar to this, earlier study made by Murugesan et al. [9], clearly elucidated the polluted nature of the stations by showing the abundance curves to lie above the biomass curves. The W – statistic values were also on the negative side for stations I and II indicating the polluted nature while it is in positive side for stations III and IV signaling pristine nature. The cluster analysis derived showed unequivocally that the distinct species composition in four stations. The stations I, II and III, IV got grouped separately indicating species dissimilarity. This was further confirmed through MDS plot. The groupings recognized in dendrogram were evident with stations I, II and stations III, IV were falling apart.

The BIO – ENV procedure is a method to measure the agreement between the rank correlations of biological (Bray-Curtis similarity) and environmental (Euclidean) matrices [42]. This is done by rank correlating the matching elements in the two similarity (dissimilarity) matrices with three possible choices for the coefficient as (i) a standard Spearman rank correlation (ii) a weighted Spearman rank correlation and (iii) a standard Kendall rank correlation. The conclusions of this method tend to be robust to the choice of correlation coefficient [43].

In the present study, the combinations of eight variables such as temperature, salinity, pH, dissolved oxygen, total organic carbon, sand, silt and clay were allowed to match the biota. It showed that, salinity, DO, silt, clay and TOC were featured as the key variables explaining the best match (0.92) with faunal distributions. Following this, sand and temperature were also manifested as important variables influencing the faunal distribution. Likewise, in a study made by Mackie et al. [42] in Irish Sea, Murugesan et al. [9] in Tuticorin waters and Manokaran [44] in southeast coast of India recorded similar combinations of parameters influencing faunal distribution.

V. CONCLUSION

In short, the present investigation is an attempt to ascertain the species, which are indicative of polluted situations in a poorly studied environment using state-of-the art statistical methods. This study yielded some good amount of novelty in terms of polychaete species; however, extensive study is warranted along the coast to know the spatial and temporal variations in polychaete diversity for formulating sustainable management strategies for effective conservation of bio resources and also for policymaking.

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