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Response of macrobenthic community to seasonal sediment environmental parameter changes in a tidal estuary of the Seto Inland Sea, Japan

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Abstract : Changes in macrobenthic communities were studied in a tidal estuary of the Seto Inland Sea, Japan from November 1998 to February 2000 at eight stations. Selected chemical components in sediments and the abundance and biomass of five dominant macrobenthos species were determined. High abundance of species indicative in unstable bottom, such as the bivalve *Theora fragilis* and the polychaete *Lumbrineris* were recorded. Moreover, stations nearest the facility have continuous input of organic matter, and gross structure changes in the macrobenthic communities (*e.g.* reduced specific richness, diversity, and dominance of opportunistic species *Capitella* sp.I). And changes in seasonal pattern of macrobenthic communities were observed. The community structural changes were analyzed by means of univariate and multivariate techniques.

Key words : *Macrobenthic community, total organic carbon (TOC), Acid Volatile Sulfide (AVS), Seto Inland Sea, univariate measures, cluster analysis, Abundance Biomass Comparison (ABC) plot*

1. Introduction

Estuaries are the major conduits between land and sea, through which the flow of large amount of soluble and particulate materials derived from the nearby area of each estuary. These loads deposited to the benthos and changes in benthic environments characteristically. Dissolved oxygen is rapidly depleted and aerobic respiration is limited to a narrow zone at the surface of non-bioturbated sediments. The activity of heterotrophic organisms maintains reducing conditions below a thin oxidized surface layer in most coastal sediments. The stratification provides the basis for bacterial sulfate reduction in the deeper anoxic sediment where sulfate is reduced to toxic sulfide. Sulfide results from inhibition of the electron transport chain in aerobic respiration may be important for the distribution and density variations of benthic organisms. In organically the polluted sediments are generally assumed to be characterized by macrofauna with small body sizes and infauna living at or near the sediment-water interface (WESTON 1990; MIRON and KRISTENSEN 1993; DRAKE and ARIAS 1997; Marvin-DiPasquale and Capone 1998; Trimmer *et al.* 2000).

Tidal estuary in front Yashima mount at Takamatsu, Japan is now surrounded by densely populated urban residential neighborhoods, quay, industries and river runoff from Tsumeta, Kasuga and Shin rivers which carry huge amount of particle matters. And several large sewage effluents also plus street runoff and combined sewer overflows continuing major impacts. It has been a progressive increase of opportunistic green macroalage *Ulva* sp. on the intertidal flat where is near by the present study sampling site. In this areas MAGNI and MONTANI (1998) found that *Ulva* sp. shown recurrent seasonal patterns, growing heavily in spring and summer and decomposing in late summer to early autumn. Consequently, strong increase in biomass of bivalves *Ruditapes philippinarum* and *Musculista senhousia* indicated a highly production during spring–summer. After the decomposition of high amounts of the macroalgae, a massive

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mortality of the bivalve *R. philippinarum* on the intertidal flat and a drastic reduction of the macrobenthic biomass on an adjacent subtidal station were observed . In this context, the aim of this research was to detect and follow the changes in the macrobenthic communities. We report on patterns of macrobenthic communities' structure and diversity related to sediment characteristic.

2. Materials and methods

We divided the sampling site into three transect lines for 8 sampling stations. First three sampling stations were set on the tidal flat area (Stns. 1, 2 and 3), next other three sampling stations (Stns. 4, 5, 6 and 7), on quay area and one sampling station (Stn. 8) which was placed in the seagrass area and beside domestic communities. For transaction classify, the study area was considered to two areas from the shore as intertidal area (Stn. 4), and subtidal area which component with the inner stations (Stns. 2, 3, 5 and 6) and outer stations (Stns. 1, 7 and 8) (Fig. 1). Sampling of the benthic environment at a tidal estuary was conducted every three months at 8 stations from November 19, 1998 to February 7, 2000. At each station, vertical profiles of temperature and dissolved oxygen (DO) were measured at intervals of 1 m in depth with a STDDO (Alec, Model ADO 1050-D) and sediment samples were obtained by two 4-cm diameter gravity core samplers for chemical analysis. The surface layer of the sediment sample up to 2 cm in depth from each gravity core was determined the Acid Volatile Sulfide (AVS) level of the sediment with an AVS test column (Gastec, Hedorotec 201H and 201L) and the total organic carbon (TOC) level of the sediment with a CHN analyzer (Yanaco, MT-500). One sediment grab for particle size distribution study by re-suspending sediment in pure ionexchanged water and wet sieving through a range of stainless steel meshes (2000, 1000, 500, 250, 125 and 63 μm pore sizes). Each fraction was collected, re-dried and re-weighed. Particle size was expressed as a percentage of the total dry weight.

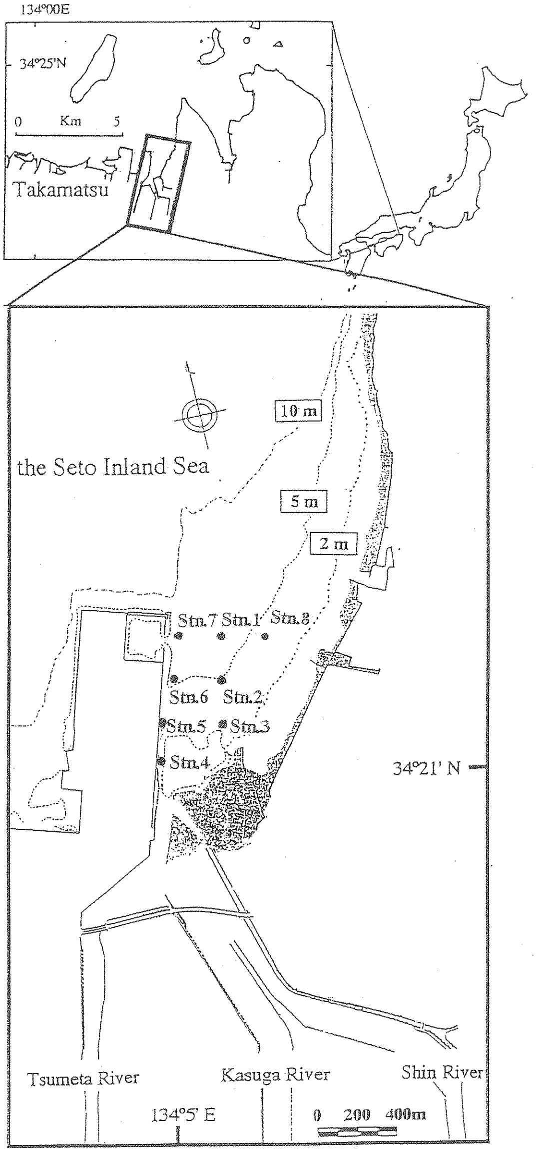


Fig. 1. Map of the study site in tidal estuary of the Seto Inland Sea.

Benthic samples were collected two grab samples with $0.04m^{-2}$ Eckman-Birge grab sampler. Samples were screened through a 1.0-mm mesh sieve to separate macrofauna animals from sediments. After screening, organisms were sorted under a dissecting microscope, identified to the lowest possible taxonomic levels, counted and weighed.

Several traditional univariate measures (abundance, biomass, specific richness, evenness (J′) and diversity (H′) indices) were employed in the analysis of the community structure. And using a multivariate ordination technique, the Bray Curtis similarity index coefficient for double square root transformed species abundance data. Multivariate patterns of assemblages were visualized using metric multidimensional scaling plots (MDS). The identified assemblages were tested by the ABC (abundance, biomass comparison) method to judge the degree of environmental disturbance (CLARKE and WARWICK, 1994).

3. Results

Spatial patterns of macrobenthos and environmental factors

Table 1 showed the summary of the particle size distribution at each sampling station. The bottom have moderately sorted fine median particles with high percentage of silt clay at Stns. 1, 2, 3, 5 and 6 (73, 61, 76, 81 and 76 %, respectively) but there was high percentage of sand at Stn. 4 (77%) and about 50 to 60 percent sand at Stns. 7 and 8. Because of sampling stations were situated in shallow waters. Therefore water column showed vertical well mixed throughout the water depth at all sampling stations. Thus mean temperature, salinity and dissolved oxygen values for each seasonal sampling at the sampling site are shown in Fig. 2. During the study period, the pattern of temperature was increased from 18±0.14℃ in May 1999 to 27± 0.06℃ in August 1999 and de-

Table 1. Average of particle size distribution in eight sampling stations at tidal estuary of the Seto Inland Sea (expression in percentage)

Size class [a]	Station							
	1	2	3	4	5	6	7	8
Silt/clays	73.03	60.72	75.97	23.23	81.22	75.54	44.79	39.54
Very fine sands	15.13	10.27	8.25	26.62	13.12	11.52	13.89	42.71
Fine sands	7.74	6.37	5.62	20.59	4.82	7.51	7.03	5.09
Medium sands	3.49	1.56	3.76	22.95	0.84	3.84	13.4	3.51
Course sands	0.61	2.54	6.4	6.61	–	1.59	20.89	9.15

[a] Wentworth classification(Mudroch and Bourbonniere, 1991) : median sands, 500 to 250 μm; 250 to 125 μm; very fine sands, 125 to 63 μm; silt/clay, < 63 μm.

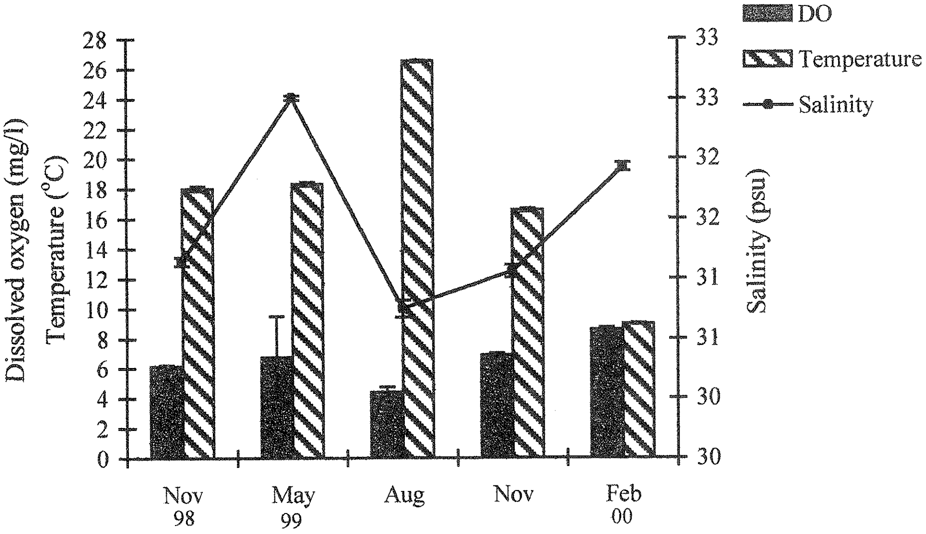


Fig. 2. Mean values of temperature(℃), salinity (psu) and dissolved oxygen (mg/l) of bottam waters at the sampling sites.

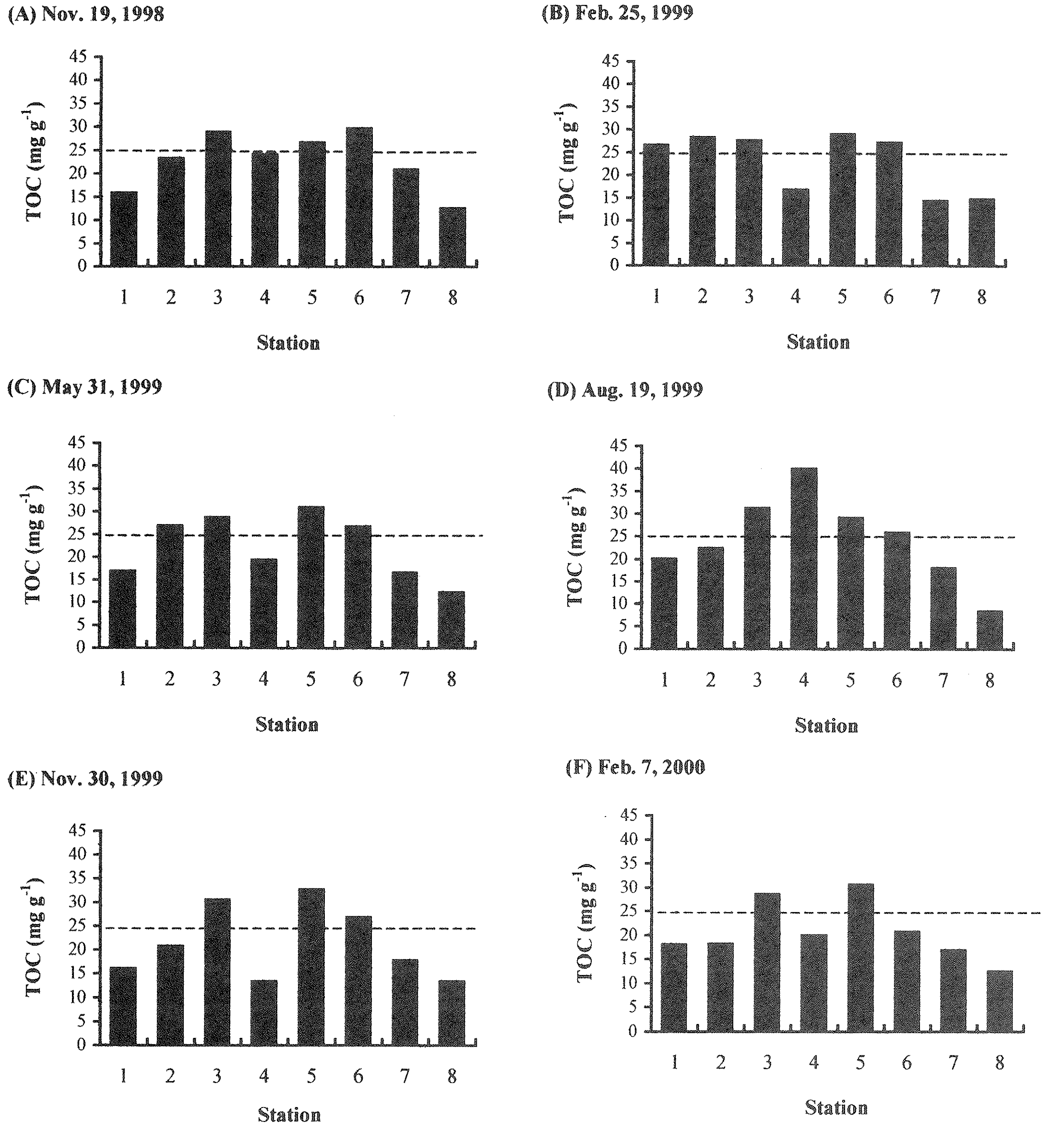


Fig. 3. Seasonal fluctuation in sediment TOC level at eight sampling stations in the tidal estuary.

creased to the lowest (9±0.04℃) in February 2000. Salinity ranged between 30±0.07 and 33 ±0.02 psu while dissolved oxygen was saturated or oversaturated within a range 4±0.34 to 8.5±0.15 mg l^{-1}.

The surface layer sediment TOC levels at all sampling stations were shown in Fig. 3. Station 3 and 5 showed stability of sediment TOC levels throughout sampling period. While sediment TOC levels at Stn. 4 was evidently increase from 20 mg g^{-1} in May 1999 to 40 mg g^{-1} in April 1999 and decrease drastically in November 1999 (14 mg g^{-1}). The remaining stations slightly fluctuated in sediment TOC levels.

There was a fluctuation of surface layer sediment AVS levels at sampling site also. At Stns. 2, 3, 4, 5, and 6 sediment AVS levels ranged between 2 to 2.5 mg g^{-1} in February 1999 and slightly decreased within range 0.7 to 1.7 mg g^{-1} in May 1999 (Fig. 4). As sediment TOC levels, sediment AVS levels at Stn. 4 was rapidly

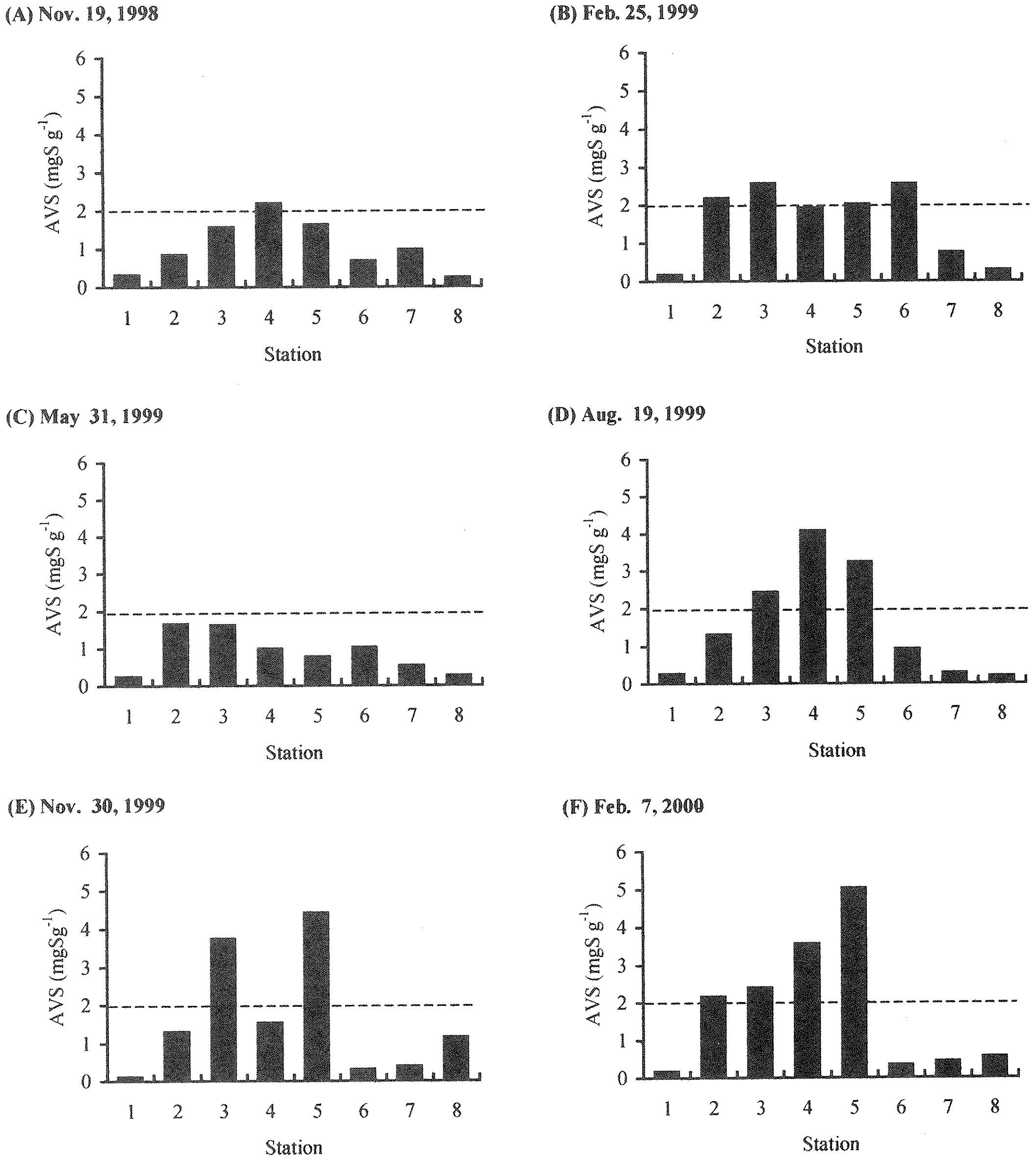


Fig. 4. Seasonal fluctuation in sediment AVS level at eight sampling stations in the tidal estuary.

increase from May to August 1999 (1 mg g^{-1} to 4 mg g^{-1}) and decrease to 1.7 mg g^{-1} in November 1999. While continued develop of sediment AVS level to high value was occurred at Stn. 3 (1.7 to 3.6 mg g^{-1}), from May to November 1999 before it decreased in February 2000. However, sediment AVS level was continued developing and reach to the highest value in February 2000 at Stn. 5 (0.8 to 5 mg g^{-1}). The low sediment AVS levels were occurred at Stns. 1 and 8 (Fig. 4). There was positive relationship between sediment TOC and AVS level only Stn. 4 (r= 0.73, data not shown). But significant increased in sediment AVS levels with sediment TOC levels were found in seasonal sampling (Fig. 5).

The high number of individuals was recorded in February 1999 and 2000 (47,303 and

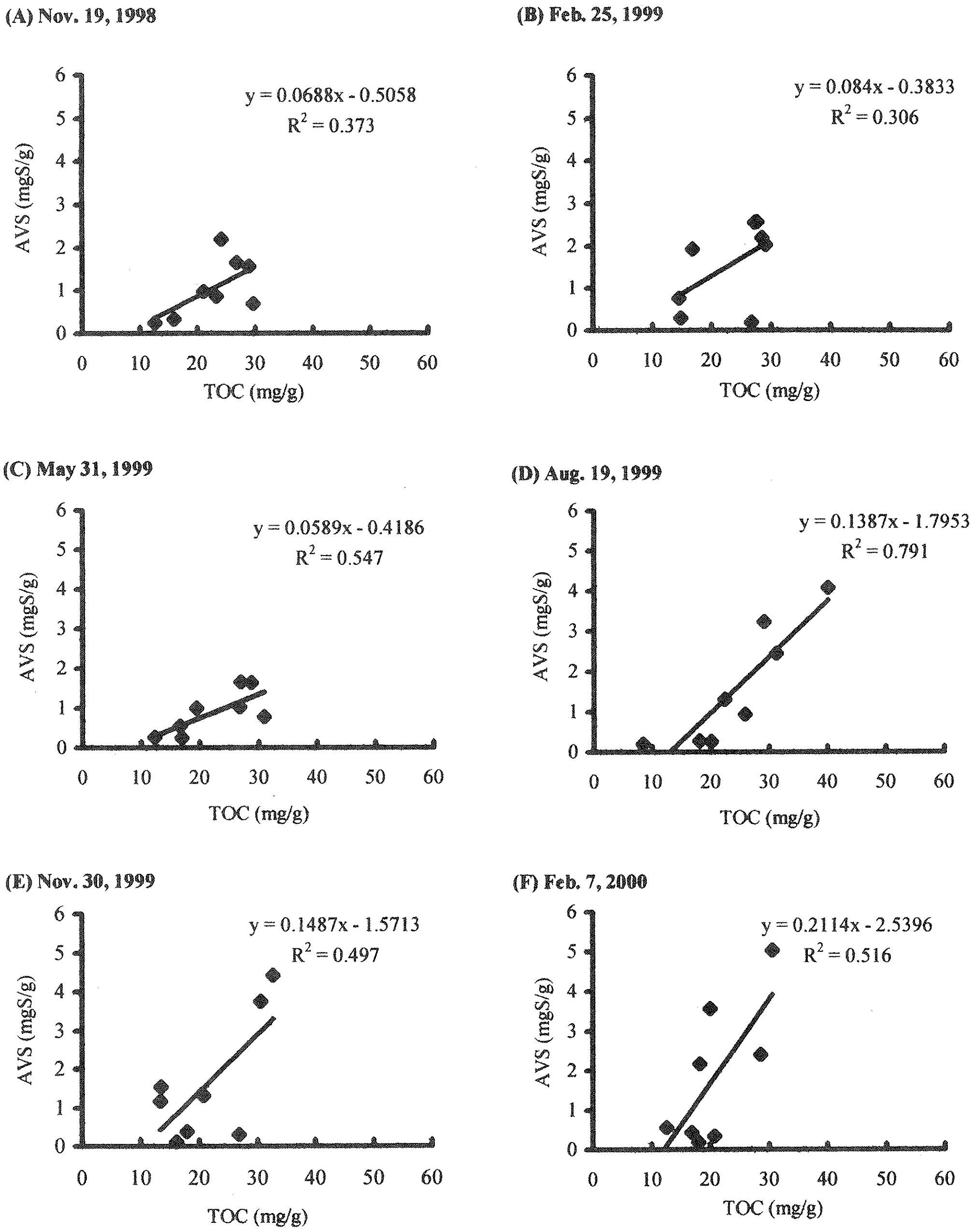


Fig. 5. Relationship between seasonal sediment TOC and AVS levels.

55,889 ind m^{-2}) while biomass was obtained in August and November 1999 (865 and 701 gWW m^{-2}, approximately 80% of which was *M. senhausia*). The polychaetes, *Capitella* sp. I, *Pseudopolydora kempi* and *Rhynchospio* sp., occurred dominantly with numbers in February 1999 and 2000. Changes in community structure throughout the whole period of study are shown in Figs. 7and 8. The total number of species ranged over the stations from 3 to 25 ($3 \leq S \leq 25$). Evenness (J′) and diversity (H′) showed a similar pattern throughout the study period.

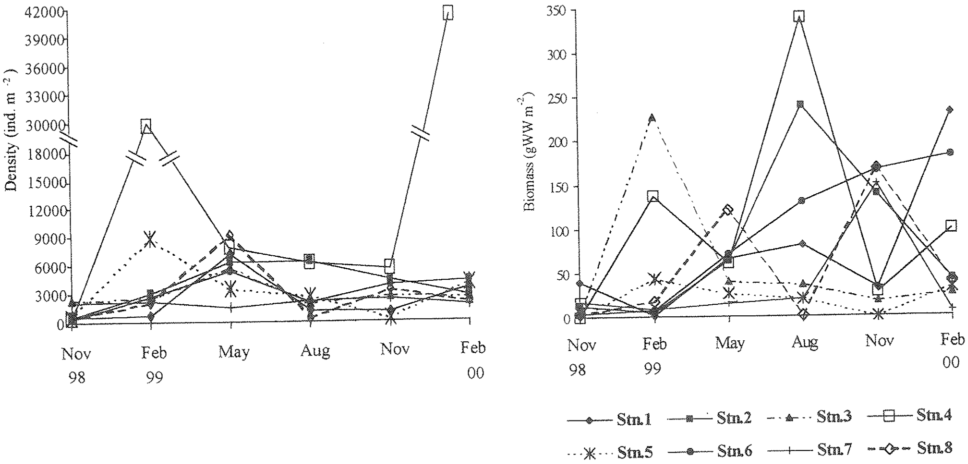
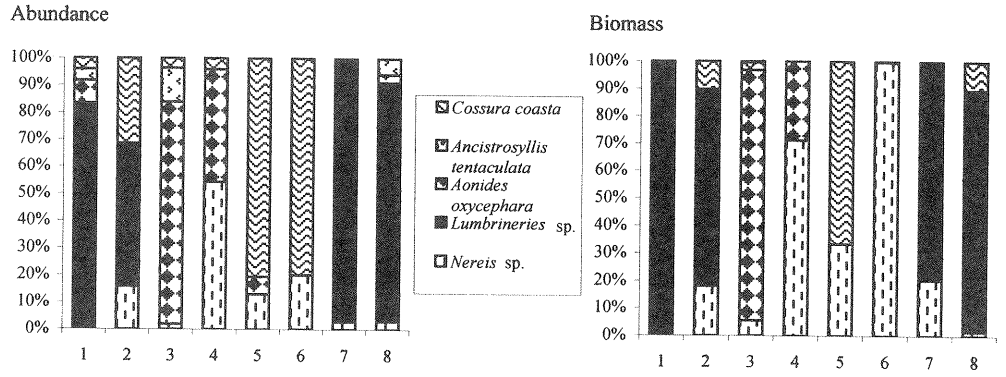


Fig. 6. Seasonal fluctuations in density (ind./m^2)and biomass(gWW/m^2)at eight sampling stations in the tidal estuary.

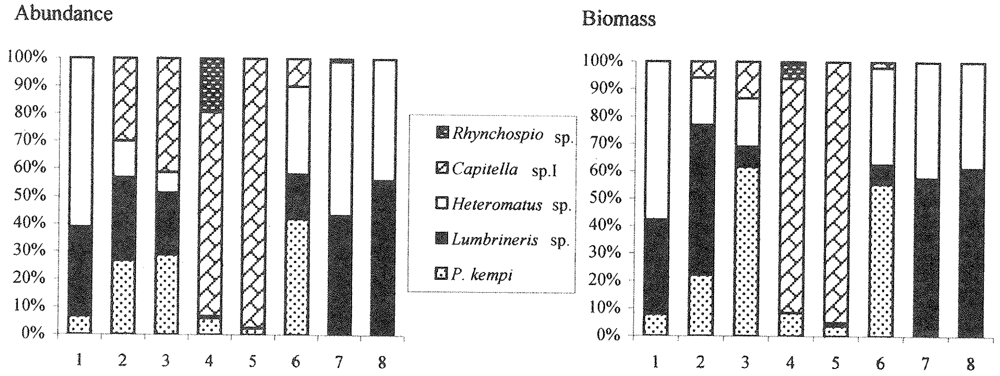
The range of evenness over all sampling stations was from 0.23 to 0.9(0.23 $\leq J' \leq 0.9$) and diversity was from 0.68 to 3.93 (0.68$\leq H' \leq$ 3.93). Seasonal fluctuation in the species diversity indices reflected the recovering and subsequent degenerating processes of the macrofauna. During the earliest stage in the faunal recovery, diversity (H′) was low at Stns. 3, 4 and 5 (Fig. 8) due to the occurrence of only a few pioneer species and the dominant of *Capitella* sp. I in November 1999 (Stns. 3 and 5), February 1999 (Stn. 5) and February 1999 and 2000 (Stn. 4). Which accounted for 90 and 95% in February 1999 (Stn. 4 and 5, respectively), 95 and 99% in November 1999 (Stns. 3 and 5, respectively) and 40% and 65% in February 2000 (Stns. 4 and 5, respectively) of the abundance. As subsequent species recruited, the specific richness increased with the dominance by single species reduced, increases of the evenness (J′) occurred in May and August 1999 (Fig. 9).

Consequently, a change of dominant species was occurred in May 1999 (Fig. 8). During this changes the bivalves *Theora fragilis* (Stns. 3, 5 and 6) and *M. senhausia* (Stns. 1, 2 and 8) and the polychaete *Lumbrineris* sp. (Stns. 2, 3, 6, 7 and 8) became to main composition of abundance species and play up to increase of biomass values. *Capitella* sp. I was decreased at Stns. 4 and 5 in both number and biomass. In August 1999, *M. senhausia* was dominated at Stns. 1, 2, 4 and 6 (90, 80, 35 and 75 %, respectively) and showed the highest biomass values (99, 95, 90 and 95%, respectively). In this sampling month, the beginning of sediment AVS accumulation was appeared at Stns. 3 and 5. *Lumbrineris* sp. (43% at Stn. 3), *Cossura coasta* (75% at Stn. 5) and *T. fragilis* (33 and 20 % at Stns. 3 and 5, respectively) were dominated in abundance, only *T. fragilis* (63 and 80% at Stns. 3 and 5, respectively) was played on biomass dominator. When sediment AVS level was decreased in November 1999 at Stn. 4, *Heteromatus* sp. and *Rhynchospio* sp. became dominator (70 and 10%, respectively) and small number of *Capitella* sp. I was observed. Presented with *Heteromatus* sp. were *Lumbrineris* sp. and *M. senhausia* at Stns. 1, 2, 6, 7 and 8 where *M. senhausia* was biomass dominator. While *Capitella* sp. I dominated at Stns. 3 and 5 more than 90% of abundance and biomass and associated with reduced of diversity (H′), evenness (J′) and specific richness. Due to sediment AVS levels kept relatively high values at these stations. As February 1999, *Capitella* sp. I increased in number to the highest values at Stn. 4 (from 10% to 40%) and dominated at Stn. 5 (65%). When the rapidly increased of sediment AVS level occurred at Stn. 4 and increased to the highest value at Stn. 5. Two polychaetes, *P. kempi* and *Rhynchospio* sp., presented in large number with *Capitella*

(A) November 19, 1998



(B) February 25, 1999



(C) May 31, 1999

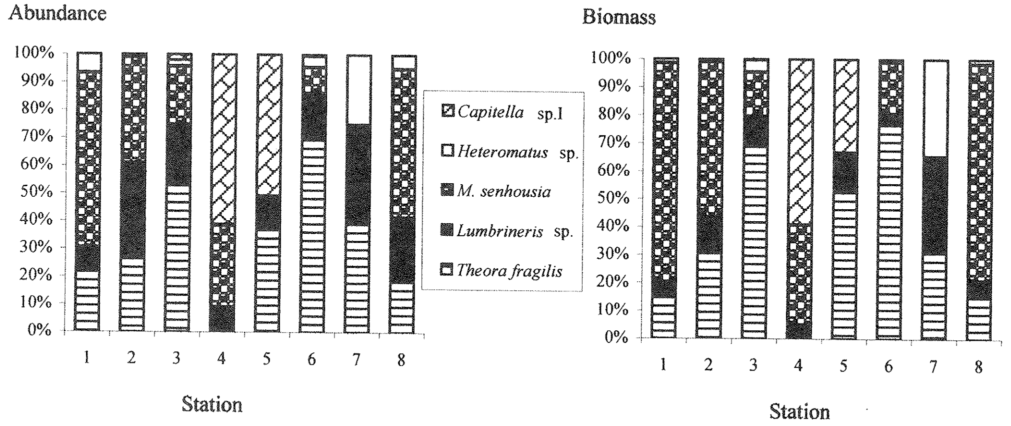
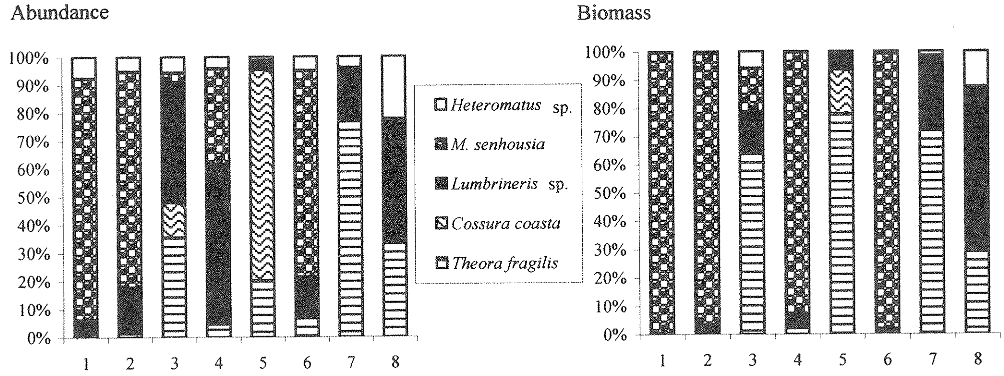
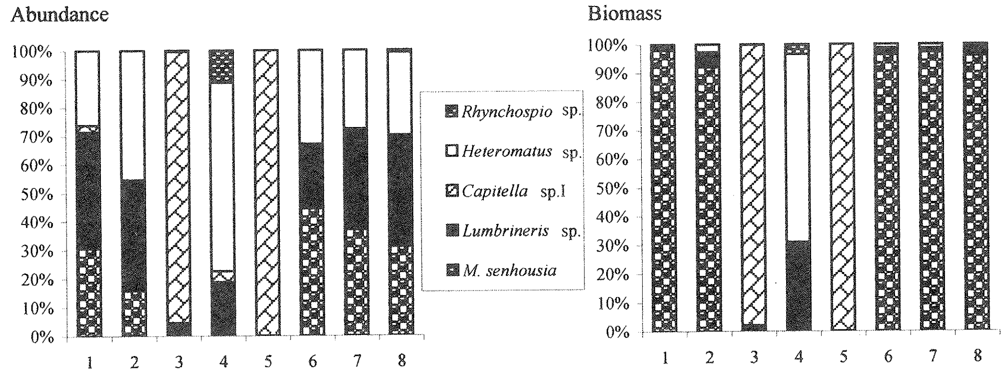


Fig. 7. Percent composition of abundance and biomass of five dominant macrobenthic animal species at the eight stations. (A) on November 19, 1998, (B) on February 25, 1999, (C) on May 31, 1999.

(D) August 19, 1999



(E) November 30, 1999



(F) February 7, 2000

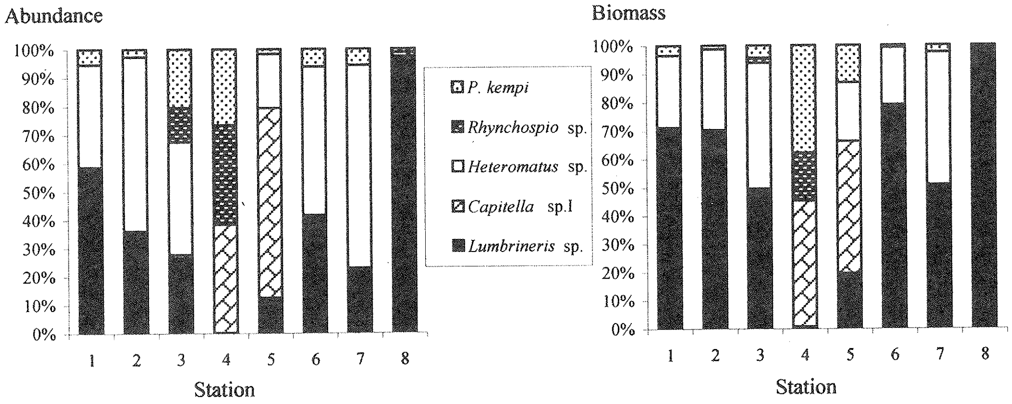


Fig. 7 (continued). Percent composition of abundance and biomass of 5 dominant macrobenthic animal species at the eight stations. (D) on August 19, 1999, (E) on November 30, 1999, (F) on February 7, 2000.

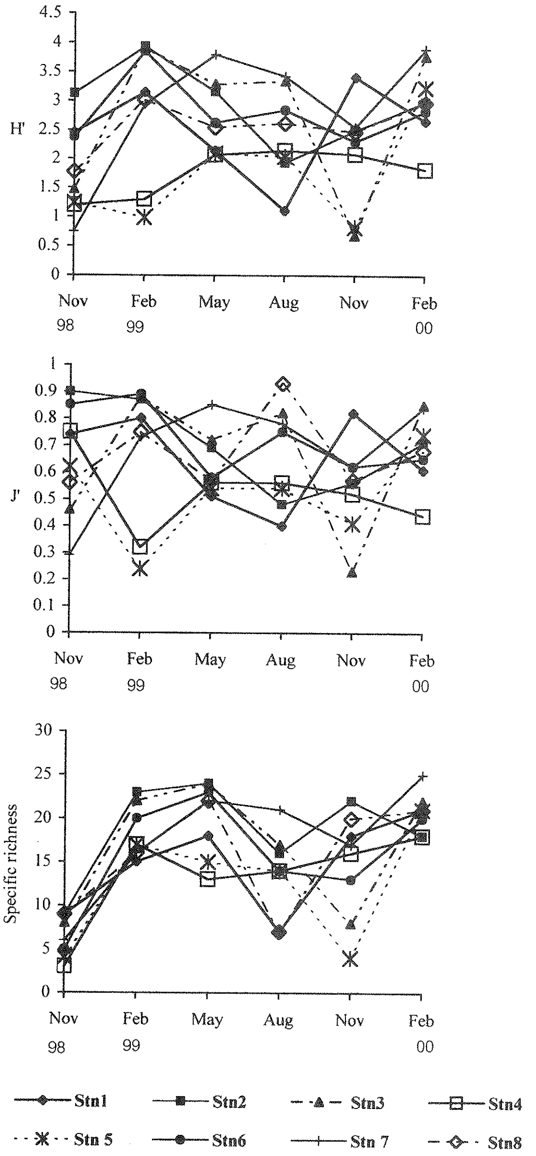


Fig. 8. Seasonal fluctuations in specific richness, evenness(J′), and diversity (H′) at eigth sampling stations in the tidal estuary.

sp. I at Stn. 4 and small number at Stn. 3. Specific richness, diversity (H′) and evenness (J′) increased at Stns. 3 and 5 (Fig. 8). While other two polychaetes, *Heteromatus* sp. and *Lumbrineris* sp. were dominated in number and biomass at other stations in February 2000 (Fig. 7).

Abundance–Biomass Comparison

Figure 9 shows the classification analysis for species abundance, the dendrogram for the samples were divided into four distinct clusters, lettered A through D, which were considered to represent different communities on the basis of their geometric means. The first cluster includes 4 stations (2, 3, 6 and 7) in the subtidal zone (quay and tidal flat transect). The most abundance species found at these stations were two polychaetes (*Lumbrinereis* sp. and *Heteromatus* sp.) and two bivalves (*M. senhousia* and *T. fragilis*). The second cluster had 2 stations at the outer stations in subtidal zone (Stns. 1 and 8) and characterized by the most abundant four species as same as those in the first two clusters but recognized the difference in density. The third and forth clusters were Stns. 5 and 4 where opportunistic polychaetes like *Capitella* sp. I, *P. kempi* and *Rhynchospio* sp. were dominated in autumn and reached to the peak in winter (Figs. 6 and 7). MDS model exhibited the similar patterns described previously, with the stations–points of the four clusters. According to criteria proposed by WARWICK (1986) for detecting the severity of disturbance in the macrobenthic community. Then the response of four major macrobenthic assemblages to environmental disturbance was tested by the ABC method (Fig. 10). Species are ranked in order of dominance on the abscissa (logarithmic scale), and cumulative percentage composition is plotted on the ordinate. The assemblage "A" showed the undisturbed condition with the biomass curve above the abundance curve of its length. While contrary position of the two curves in assemblages "C" indicates grossly state of disturbance, respectively. Under moderate disturbance, the 2 curves will tend to be superimposed, often crossing one another in assemblages "B" and "D".

4. Discussion

The discharged loads in the watershed and the run-off loads are the loads that actually reach the Seto Inland Sea through rivers and gutters (OKAICHI and YANAGI, 1997). The determinants of community composition and abundance were related to natural features in the

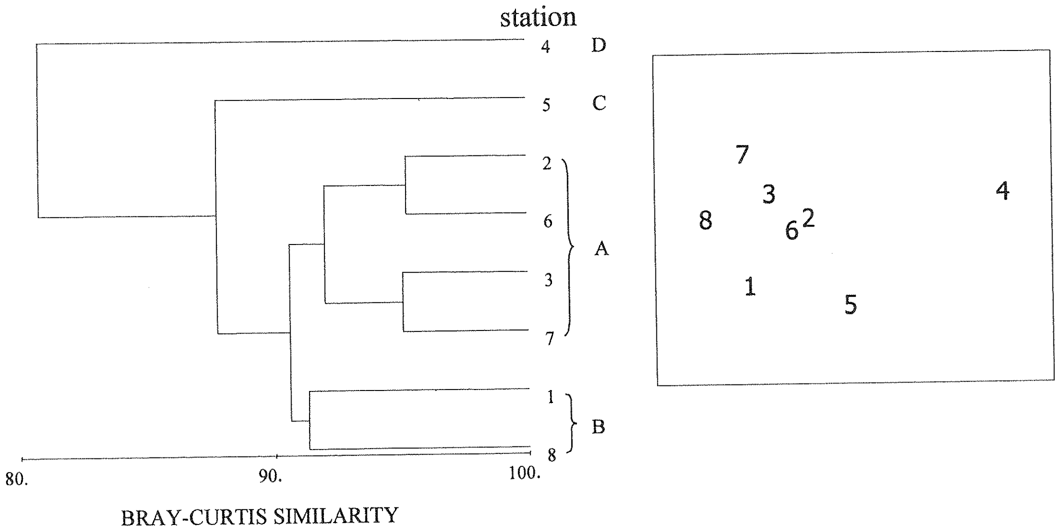


Fig. 9. Cluster analysis of the macrobenthos assemblage similarity in tidal estuary. And two-dimensional non-metrci multi-dimension scaling plot of stations based on similarity matrix abundance; Stress=0.05. Dendrogram showing similarity between the stations, dicision of estuary into zones A-D.

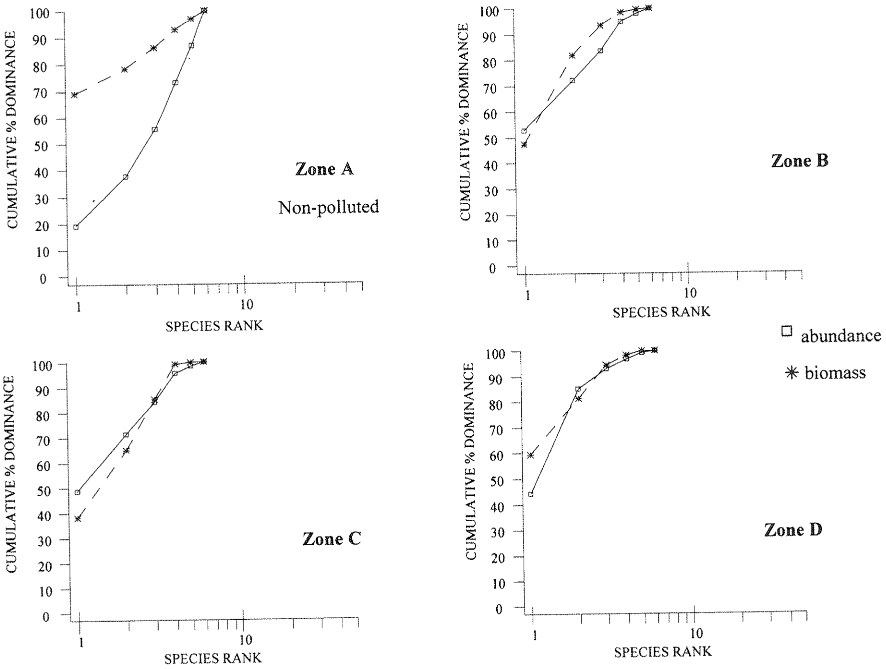


Fig. 10. Combined k-dominance cureve for species biomass(crosses and dashed lines) and abundance (squares and continuos lines) in four zone in tidal estuary.

study area and sediment characteristics. Alteration of sediment chemistry as a result of organic enrichment was evidently only a Stn. 4. Because this station was placed in intertidal area where *Ulva* sp., from adjacent tidal flat, grows heavily in spring and summer and decompose from late summer to early autumn. Therefore sediment AVS level was highly related to sediment TOC level. In *Palude della Rosa*, Italy, the accrual phase of *Ulva rigida* was followed, in summer, by a massive decline of the algae biomass (TAGLIAPIETRA *et al*, 1998). When macroalgal vegetation broke down completely, the decomposition of huge amounts of organic matter resulting in prolongs hypoxia and anoxia, and release of hydrogen sulfide. As a consequence of the massive degradation of *Ulva* which occurred during summer, macroalgae did not accumulate in *Palude della Rosa* in autumn.

Although sediment TOC levels were not the highest at Stns. 3 and 5, they still kept high through sampling periods. When the low temperature occurred in winter, the rapid development of sediment AVS was present at these stations. Apart from the supply of nutrients and factors that control the bioavailability of organic compounds, the chief abiotic factors influencing microbial transformations are temperature, pH, and salinity. An organic pollutant is quickly destroyed in one environment will persist at another one if these factors preclude or retard microbial activity. The prevailing temperature is of paramount importance. When organic compound exists near the surface of soil or water and at the same time immediately preceding and following the winter are typically associates with little or no biodegradation of many organic substrates. Changes in rate of degradation associated with the season are a consequence of the concomitant changes in temperature (ALEXANDER, 1994). KALEJTA and HOCKEY (1991) found the correlation between temperature and production suggested that a lack of extreme temperatures, especially cold temperatures might prolong reproduction of invertebrates and a continuous supply of food for their maintenance at Berg River Estuary, South Africa.

When the beginning of hydrogen sulfide releasing was observed from August to February 1999, the macrobenthic communities are dominated by *Capitella* sp.I at Stns. 4 and 5 and occurred at Stn 3. Associated with the appearance of species recruited (as is *Capitella* sp.I in my study), the specific richness and diversity (H′) decreased and evenness (J′) increased. Decrease in diversity is a primary indicator of community response to organic gradients or stresses (PEARSON and ROSENBERG, 1978). Reduce in density of a single dominant species occurred as the changes in macrobenthic composition.

The density of *Capitella* sp.I decreased drastically before the beginning of the environmental deterioration. The observed decline in the *Capitella* sp.I population may be caused by a food shortage, if organic rich sediment containing available food is indispensable for maintaining a large population of *Capitella* sp. I, and if this food supply has already been consumed during high density phase of this species. Present in large number with *Capitella* sp.I were two polychaetes *P. kembi* and *Rhynchospio* sp.. *P. paucibranchiata* is the second species to re-populate at nutrient-rich particles in the form of unconsumed food particles (YOKOYAMA *et al.*, 1997). Usually peak of abundance in *Capitella* sp. I, *P. kembi* and *Rhynchospio* sp. occurred in February 1999 and 2000 at Stn. 4 and November 1999 at Stns. 3 and 5. The maximum density values of *Capitella* sp. I (31,000 individuals/m^2) was observed at Stn. 4.

At other stations, there were no clear trends in any of the density, biomass, diversity (H′) and specific richness. *Heteromatus* sp., *T. fragilis* and *Lumbrimeris* sp. were dominant in these stations, and presented throughout the year. *Lumbrineris* and *Heteromatus* are considered as indicator of environmental instability and immaturity such as in early succession stage communities (CREMA *et al.*, 1991; SIMBOURA *et al.*, 1995).

The ABC technique developed the results inconsistent with many of the other biological indices. It was used successfully to identify the areas disturbed by organic enrichment (WARWICK, 1986; AUSTEN *et al.*, 1989; DELVALLS *et al.*, 1998). The ABC method indicated that only Stn. 5 was grossly disturbed while Stn. 4 and Stns. 1 and 8 were moderately disturbed and Stns. 2, 3, 6 and 7 were undisturbed areas. Stn. 5 was the most organically polluted station, as the most affected one from tidal export from the inner part of the estuary. From the bathymetry of location, Stn. 5 was the deepest. Where the high accumulation of organic matter seasonally enhanced the process of anaerobic decomposition dissolved oxygen concentration depletion and supports the sediment AVS development. Indeed Stn. 4 should be grossly disturbed area as Stn. 5 because the numerical dominance of a single species (*Capitella* sp. I) clearly indicated the area to be typical of gross enrichment. However, Stn. 4 as located in creek where receive running freshwater and particles from rivers. Most of big size particles precipitated at this station. That made bottom sediment particle character was highly percent in sand fraction, which was appropriated for filter feeder as *M. senhousia* (the major biomass contributor). Stns. 1 and 8 showed abundance curve lies above biomass curve at the beginning and change to the opposite pattern. Indicated that inequality in size between the numerical and biomass dominants is reduced and adjusts to stable condition. In consideration of Stns. 1 and 8 location, they was outermost station and surround with seagrass boundary (Stn. 8) which act as sediment trap. Therefore the contents of total organic and AVS in the sediments are much lower. The results of limited food resource at these stations were low macrobenthic density and biomass. ABC curves of Stns. 2, 3, 6 and 7 clearly correspond to stable unpolluted condition. These stations were located in an intermediate zone and better position to sustain a large biomass of the bivalve *M. senhousia*, as food supply was still abundant but not extreme. DRAKE and ARIAS (1997) suggested that the ABC method would lead to an over- or underestimation of disturbance state of the community in short term studies. And the ABC plots are a very good approach for evaluating the organic enrichment (WESTON, 1990; DELVALLS *et al.*, 1998).

In this study, the results show seasonal changes of macrobenthic community fluctuation. They corresponded with the summary of benthic effects for hypoxic systems around the world by DIAZ and ROSENBERG (1995). Which the system levels responding to hypoxia of the Seto Inland Sea were indicated as seasonal hypoxia type, moderate hypoxia level, mortality of response of benthic communities and annual benthic recovery.

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