Density, Biomass and Community Structure of Megabenthos in Ise Bay, Central Japan

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In order to know the general features of megabenthos in Ise Bay in relation to the development and prevalence of oxygen-poor water in summer, an investigation was undertaken throughout the year from April 1993 to April 1994. Crustaceans and fishes were absolutely dominant from April to September 1993, while echinoderms being dominant since November. Five species of megabenthos were absolutely dominant: *Oratosquilla oratoria* (Stomatopoda), *Carcinoplax vestita*, *Charybdis bimaculata* (Brachyura), *Luidia quinaria* (Asteroidea), and *Repomucenus valenciennesi* (Pisces). Community structure (e.g. species diversity, ABC-comparison, rank-abundance relationships and community type) of megabenthos in Ise Bay drastically changed with season, intimately related with development and perishment of oxygen-poor water at the bottom of the bay.

Key words: megabenthos, community ecology, oxygen-poor water

A relatively large number of studies have been carried out on the slope and deep-sea megabenthos communities^{1,2)} and commercially important demersal fish communities,^{3–6)} but it is ironical that there is little information available on megabenthos communities in the inlet and coastal waters.

In the inlet and coastal waters, oxygen-poor water develops and prevails in the bottom layer every summer mainly due to eutrophication. Consequently defaunation takes place. In particular, mass mortality of macrobenthos and commercially important megabenthos (e.g. bivalves, fishes etc.) caused by the development of oxygen-poor water has frequently been reported.^{7–11)} Unfortunately, except for comprehensive works on commercially important megabenthos done in Tokyo Bay,^{10,12)} features of megabenthos communities in the inlet and coastal waters and further influences upon the communities of oxygen-poor water have not yet been examined in detail.

The present study was undertaken in order to know seasonal variations in the general features of megabenthos communities in Ise Bay, particularly focussing on the influences upon megabenthos communities of oxygen-poor water which develops every summer in the bay.

Materials and Methods

Study Area

Ise Bay is a semi-closed bay located along the Pacific coast of central Japan and covers a surface area of 1,738 km² with a mean depth of 19.5 m¹³⁾ (Fig. 1). The depth is slightly more than 30 m in the main basin and separated from the Pacific Ocean through the Irago passage, 13 km wide and 73 m deep. The Kiso Rivers (Kiso, Nagara and Ibi), one of the biggest rivers in Japan, flow into the innermost part of the bay. The northern and central parts of the bay have silt-clay bottom sediments, while the south and southwestern parts have bottom sediments of sand, muddy sand and sandy gravel (Fig. 2).

The water in the bay is rich in nutrients and highly turbid due to the freshwater discharge and sewage effluent from the cities situated on the western and northern coasts of the bay. With the recent progress of eutrophication in the bay, red tides have often been observed, so that the dis-

Fig. 1. Ise Bay and the location of sampling stations.

The solid circles and lines indicate sampling stations and depth isopleth in meter, respectively.

Fig. 2. Bottom sediment types in Ise Bay (from Kitamori *et al.*³⁰⁾. C-f sand indicates coarse to fine sand.

solved oxygen content in the bottom layer of the bay shows remarkable changes with the season, particularly oxygen-poor water prevailing mainly in the central part of the bay every summer.⁹⁾

Seasonal and spatial distributions of the dissolved oxygen content in the bay are shown in Fig. 3. In the present study oxygen-poor water (i.e. 2 ppm or less) occurred and prevailed widely in the bottom layer (1 m above the bay bottom) of the central part of the bay mainly during July to October, particularly in August. Of course, a similar situation has often been observed in the bay in the

previous years.^{9,13)} However, strong mixing of water due to typhoons passing by the bay more times in the summer of 1993 prevented extreme oxygen-poor water from developing and prevailing in the bottom layer of the central part of the bay.

Sampling and Data Processing

Samples were obtained six times (27–28 April 1993, 1–2 July 1993, 13, 17 September 1993, 24–25 November 1993, 19–20 January 1994 and 13–14 April 1994) in Ise Bay on board the T/V *Seisui Maru* of Mie University, and at 15–19 sampling stations during each sampling time (Fig. 1). For sampling megabenthos, a gear (a small fishing trawl net) was towed on the bottom with a 900 m distance, usually done for 15 minutes with a ship speed of 2 knots (1 m/sec) at each station. But a sampling in September 1993 was done on board a small fishing boat. The gear was towed with a ship speed of 3 knots. Accordingly, the bottom area covered at each station is equivalent to ca. 1500 m². This gear has an iron frame fixed to the net that is 4.4 m length with a stretch mesh size of 27 mm (Fig. 4). This iron frame has a length and height of 165 cm and 30 cm, respectively, and is provided with a number of thorns (13 cm height) along the bottom side of the frame. We define here the term ‘megabenthos’ as benthic animals collected using this gear, though we neglected fish with total lengths exceeding 15 cm (except *R. valenciennei*) because of avoiding extreme bias due to the occurrence of a few species.

Catches, being frozen immediately after sampling, were identified, to the specific level, and numbers and weights of specimens of each species were measured in the laboratory.

As measures of species diversity, the number of species

Fig. 3. Seasonal change of the dissolved oxygen content (ppm) in water 1 m just above the bottom in Ise Bay (from Prompt Report of Mie Prefectural Institute of Fisheries Technology).

The shady area indicates the area with the dissolved oxygen content less than 2 ppm.

Fig. 4. Schematic illustration of a megabenthos sampling gear.

(SR), Shannon-Wiener function (H') and equitability index (E) (Pielou's evenness component of diversity, see J' in Pielou¹⁴) were used. The later two indices, based on information theory, were calculated from the following:

$$H' = - \sum_{i=1}^s P_i \ln P_i, \quad P_i = N_i / N$$

$$E = H' / \ln SR.$$

Where SR = number of species in a sample, N_i = number of individuals (or weights) of the i -th species in the sample and N = total number of individuals (or total weights) of the sample.

For classification of community types based on the species composition, the similarity index C_π ¹⁵) was used. The index between the i -th sample and j -th sample is:

$$C_\pi = 2 \sum_k n_{ik} n_{jk} / (\pi_i^2 + \pi_j^2) N_i N_j$$

$$\pi_i^2 = \sum_k n_{ik}^2 / N_i^2, \quad \pi_j^2 = \sum_k n_{jk}^2 / N_j^2,$$

$$N_i = \sum_k n_{ik}, \quad N_j = \sum_k n_{jk}$$

where n_{ik} and n_{jk} are the density of species k in samples i and j , respectively. A BASIC program of clustering by group average method¹⁶) was employed for the between-sample similarity matrices constructed by the C_π index.

Known as one way to characterize a community is a rank-abundance diagram.¹⁷) The diagram shows the relationship between relative abundance P_i and rank i , where i is the sequence of species from the most to least abundance based on the number of individuals or on weights. The observed patterns were compared to the fol-

Table 1. Seasonal variations in number of megabenthos taxa and species diversity in Ise Bay

PHYLUM	SUPERCLASS	CLASS	SUBCLASS	ORDER	SUBORDER	Number of species					
						Apr. 93	July 93	Sept. 93	Nov. 93	Jan. 94	Apr. 94
Porifera						0	0	0	1	0	2
Coelenterata											
		Anthozoa				0	2	3	4	4	5
Nemertinea						0	0	0	0	1	1
Mollusca											
		Gastropoda				5	9	5	9	6	8
		Bivalvia				4	4	4	6	6	12
		Cephalopoda				0	1	0	1	0	1
Annelida											
		Polychaeta				0	0	0	0	0	1
Arthropoda											
	Crustacea										
			Cirripedia			1	0	0	1	1	2
		Malacostraca									
			Stomatopoda			1	1	1	1	1	1
			Decapoda								
					Dendrobranchiate	4	3	5	2	2	1
					Pleocyemata	18	13	11	12	14	12
Echinodermata											
		Crinoidea				0	1	0	1	1	1
		Ophiuroidea				0	1	0	0	1	1
		Asteroidea				3	3	4	5	5	5
		Echinoidea				2	2	0	3	4	3
Protochordata											
		Ascidacea				2	2	2	2	4	4
Vertebrata											
		Osteichthyes				14	21	10	13	18	13
		Total number of species				54	63	45	61	68	73
		H' (in ind)				1.73	1.62	1.93	1.81	1.76	2.60
		H' (in wt)				2.17	2.21	2.27	1.85	1.26	1.18

H' (in ind.), number-based species diversity of Shannon-Wiener function; H' (in wt.), weight-based species diversity of Shannon-Wiener function.

lowing three models: geometric series,¹⁸⁾ broken stick model¹⁹⁾ and lognormal distribution.²⁰⁾

Results

Seasonal and Spatial Distributions of the Number of Species and Species Diversity of Megabenthos in the Bay

The total number of 132 megabenthos species were identified in the bay, so the number of species ranged from 45 (in September 1993) to 73 (in April 1994) (Table 1). Four taxa (crustaceans, molluscs, echinoderms and fishes) were predominant throughout the investigations; the numbers of species of crustaceans, molluscs, echinoderms and fishes were 32, 33, 13 and 39, respectively. On the other hand, the overall species diversity H' that was based on the number of individuals ('number diversity') ranged from 1.62 (0.48–2.38 at each station in July) to 2.60 (1.24–2.59 at each station in April 1994), while that based on weights ('biomass diversity') ranged from 1.18 (0.5–2.40 at each station in November 1993) to 2.17 (1.08–2.77 at each station in April 1993) (Table 1). Seasonal variations were not similar between these two indices. Interestingly, the 'biomass diversity' was clearly higher than the 'number diversity' from April to September 1993, while the reverse occurred from November 1993 to April 1994.

Spatial distributions of the number of species per station are shown in Fig. 5. In April 1993, higher numbers of species were found mainly in the central part of the bay with the highest being 31 at stn. 9. Then, a decrease of the numbers was detected in the same part in July and September with the highest being 23. Although the number of species of megabenthos continued to decrease at most of the stations, particularly at stations within the central part of the bay from April to September 1993, the total number of species were a little higher in July than in April 1993 (Table 1). Interestingly, in April 1994, a higher number of species were found mainly in the southern part of the bay, much different from the case in April 1993 (Fig. 5). On the

Fig. 5. Spatial distributions of species richness (number of species per station) of megabenthos in Ise Bay.

Solid circles indicate sampling stations.

Table 2. Relationships between species diversity and density of megabenthos in Ise Bay

		Correlation	p
Apr. 93	H' (in ind) vs. density (in ind)	—	<0.05
	H' (in wt) vs. density (in wt)	—	ns
	SR vs. density (in ind)	+	<0.05
	SR vs. density (in wt)	+	<0.001
	E (in ind) vs. density (in ind)	—	<0.001
	E (in wt) vs. density (wt)	—	<0.001
July 93	SR vs. H' (in ind)	—	ns
	SR vs. H' (in wt)	+	ns
	H' (in ind) vs. density (in ind)	—	<0.001
	H' (in wt) vs. density (in wt)	—	<0.001
	SR vs. density (in ind)	—	ns
	SR vs. density (in wt)	—	ns
Sept. 93	E (in ind) vs. density (in ind)	—	<0.001
	E (in wt) vs. density (wt)	—	<0.001
	SR vs. H' (in ind)	+	ns
	SR vs. H' (in wt)	+	ns
	H' (in ind) vs. density (in ind)	+	ns
	H' (in wt) vs. density (in wt)	+	ns
Nov. 93	SR vs. density (in ind)	+	<0.05
	SR vs. density (in wt)	+	<0.001
	E (in ind) vs. density (in ind)	—	<0.05
	E (in wt) vs. density (wt)	—	ns
	SR vs. H' (in ind)	+	<0.05
	SR vs. H' (in wt)	+	<0.05
Jan. 94	H' (in ind) vs. density (in ind)	—	ns
	H' (in wt) vs. density (in wt)	—	ns
	SR vs. density (in ind)	+	<0.05
	SR vs. density (in wt)	+	<0.05
	E (in ind) vs. density (in ind)	—	ns
	E (in wt) vs. density (wt)	—	<0.05
Apr. 94	SR vs. H' (in ind)	+	ns
	SR vs. H' (in wt)	+	ns
	H' (in ind) vs. density (in ind)	—	ns
	H' (in wt) vs. density (in wt)	—	<0.05
	SR vs. density (in ind)	+	<0.0001
	SR vs. density (in wt)	+	<0.05
	E (in ind) vs. density (in ind)	—	<0.001
	E (in wt) vs. density (wt)	—	<0.001
	SR vs. H' (in ind)	+	ns
	SR vs. H' (in wt)	+	ns
	H' (in ind) vs. density (in ind)	—	ns
	H' (in wt) vs. density (in wt)	—	<0.05

+, positive type of correlation; —, negative type of correlation; P, level of significance (F-test); H' , Shannon-Wiener function; SR, number of species; E , equitability index; ind, individual; wt, weight; ns, not significant.

other hand, spatial distributions of species diversities were not similar to those of the number of species per station, rather higher diversities were found mainly in the areas where the number of species was lower. This indicates that species diversities are influenced strongly by distribution of individuals among species rather than the number of species.

Relationships between species diversity (H') and density, between number of species (SR) and density, between equitability index (E) and density, and between species diversity and number of species are shown in Table 2. Simi-

lar tendencies were found between the number-based and weight-based relationships. According to our investigations, both of the species diversity and equitability index fluctuated in inverse proportion to density (except Sept. 93), while the number of species was proportional to density (except July 93). Furthermore, relationships between species diversity and species richness were not significant statistically at any sampling time except for September 1993. Whether establishment of the relationships occur or not clearly depended on sampling times and/or on seasons (Table 2).

Seasonal and Spatial Distributions of the Biomass and Density of Megabenthos

The biomass of megabenthos and percentages in weights of different taxa are shown in Table 3. The biomass of megabenthos and crustaceans (one of the dominant taxa among megabenthos) showed a similar tendency to decrease from April towards September 1993. Three taxa (crustaceans, molluscs and fishes) were predominant from April to September 1993: biomass of crustaceans was first in rank, occupying 70% or more of the megabenthos biomass while that of fish was second in rank, occupying 10% or more of the same. On the other hand, since November 1993 the biomass of megabenthos increased again with the highest being in April 1994. The biomass of echinoderms was in first rank during this period.

Of the megabenthos species collected in the present study, the following five species were absolutely dominant in biomass: *O. oratoria* (Stomatopoda), *C. vestita*, *Ch. bimaculata* (Brachyura), *L. quinaria* (Asteroidea) and *R. valenciennesi* (Pisces). Seasonal changes of biomasses of these species are shown in Table 4. The five species occupied 32% of megabenthos biomass in November 1993 and 82% in April 1994. These five species can broadly be clas-

sified into two groups according to seasonal variations in their biomass (Table 4). Biomass of the first group (*R. valenciennesi*, *C. vestita*, *Ch. bimaculata* and *O. oratoria*) occurred abundantly during April to September 1993 and decreased drastically in November. Among the species of the first group, biomasses of *R. valenciennesi*, *C. vestita* and *Ch. bimaculata* were highest in April and decreased toward July 1993, while the biomass of *O. oratoria* was highest in September 1993 and decreased toward January 1994. On the other hand, biomass of the second group (*L. quinaria*) was abundantly found in November and con-

Fig. 6. Spatial distributions of density (wet weight, gram per station) of megabenthos in Ise Bay. Solid circles indicate sampling stations.

Table 3. Seasonal variations in megabenthos biomass in Ise Bay

	Apr. 93		July 93		Sept. 93	
	Wet Weight (g)	%	Wet Weight (g)	%	Wet Weight (g)	%
Total megabenthos	49,985	100.00	38,000	100.00	34,769	100.00
Porifera	0	0.00	0	0.00	0	0.00
Coelenterata	0	0.00	96	0.25	765	2.20
Nemertinea	0	0.00	0	0.00	0	0.00
Mollusca	1,014	2.03	1,950	5.13	3,894	11.20
Annelida	0	0.00	0	0.00	0	0.00
Crustacea	35,183	70.39	28,182	74.16	24,637	70.86
Echinodermata	1,697	3.40	2,730	7.18	374	1.08
Protochordata	236	0.47	1,112	2.93	425	1.22
Pisces	11,855	23.72	3,930	10.34	4,674	13.44
	Nov. 93		Jan. 94		Apr. 94	
	Wet Weight (g)	%	Wet Weight (g)	%	Wet Weight (g)	%
Total megabenthos	41,939	100.00	63,713	100.00	114,479	100.00
Porifera	6	0.01	0	0.00	45	0.04
Coelenterata	170	0.41	171	0.27	196	0.17
Nemertinea	2	0.00	18	0.03	82	0.07
Mollusca	1,463	3.49	1,972	3.10	6,389	5.58
Annelida	0	0.00	0	0.00	37	0.03
Crustacea	4,862	11.59	4,203	6.60	4,766	4.17
Echinodermata	32,877	78.39	55,205	86.65	98,773	86.28
Protochordata	240	0.57	290	0.46	701	0.61
Pisces	2,319	5.53	1,854	2.91	3,490	3.05

Table 4. Seasonal variations in biomass of five dominant megabenthos species in Ise Bay

	Total	<i>R. valenciennei</i>		<i>C. vestita</i>	
	Wet Weight (g)	Wet Weight (g)	%	Wet weight (g)	%
Apr. 93	49,985	10,313	20.63	19,264	38.54
July 93	38,000	2,528	6.65	17,837	46.94
Sept. 93	34,769	1,400	4.03	6,156	17.71
Nov. 93	4,939	434	1.03	990	2.36
Jan. 94	63,713	925	1.45	1,697	2.66
Apr. 94	114,479	1,993	1.74	982	0.86

	<i>C. bimaculata</i>		<i>O. oratoria</i>		<i>L. quinaria</i>	
	Wet Weight (g)	%	Wet Weight (g)	%	Wet weight (g)	%
Apr. 93	3,860	7.72	5,402	10.81	536	1.07
July 93	2,664	7.01	4,117	10.83	1,642	4.32
Sept. 93	3,636	10.46	11,937	34.33	109	0.31
Nov. 93	239	0.57	2,488	5.93	9,468	22.58
Jan. 94	200	0.31	915	1.44	47,955	75.27
Apr. 94	632	0.55	1,260	1.10	89,491	78.17

tinued to be predominant among the megabenthos since then.

Spatial distributions of megabenthos density (weight per station) are shown in Fig. 6. Higher densities were found mainly in the whole central part of the bay in April to July 1993 with the highest being 5 kg/stn and 7 kg/stn, respectively. Then, in September several higher densities of more than 3 kg/stn were located separately at the marginal stations within the central part of the bay. In November 1993 to April 1994, higher densities were found at western or eastern sides of the central to the southern parts of the bay. From April to September 1993, spatial distributions of the *C. vestita* density were similar to those of the megabenthos density, while since November the distributions of *L. quinaria* were similar to those of the megabenthos density.

Marked contrasts were detected in dominant species, biomasses and spatial distributions of megabenthos density between April of both years (1993 and 1994) (Tables 3, 4; Fig. 6).

Community Types Based on Species Composition

Clustering analysis, that used the similarity index (C_r) measured by the number of individuals or by weights of each megabenthos species at each station, revealed several community types as shown in Fig. 7. Clustering patterns were similar between the clustering analyses based on number of individuals and on weights, so in the following we refer only to the analysis based on the number of individuals. We defined A-1, A-2, A-3, E and F-3 as the major communities, while the others were done as minor communities. However, some communities that occupied one or two stations with meager number of megabenthos were neglected.

Spatial distributions of different community types are shown in Fig. 8. The major community type A-1 was detected in April and July 1993. This community occupied the central to innermost part of the bay, and was dominated by four species (*C. vestita*, *Ch. bimaculata*, *O. oratoria* and *R. valenciennei*). The community B in April 1993 was composed of species other than the four dominant species mentioned above, while the community C in July was

dominated by *Styela clava* (Ascidiacea). In September 1993 the community A-1 was divided into two communities A-2 and A-3. The community A-2, that was dominated by *O. oratoria*, occupied the western area of the central to innermost parts of the bay, while the community A-3 was dominated by *C. vestita* and *Ch. bimaculata* and occupied the eastern area of the same parts.

However, a drastic change of megabenthos communities was observed in November as indicated in the previous section (Table 3; Fig. 6). Since November 1993 one major community E, that was dominated by *L. quinaria*, occupied wider part of the bay (Fig. 8) while the other minor communities (A-4, A-5, F-1, F-2, F-4, G) were composed mainly of *C. vestita*, *O. oratoria*, *Echinocardium cordatum* (Echinoidea) and *Fulvia mutica* (Bivalvia).

The rank-abundance diagram of megabenthos at each station, based on the number of individuals, is shown in Fig. 9. Since the patterns of number-based and weight-based rank-abundance diagrams were found to be almost similar, so in the following we refer only to the diagram based on the number of individuals. Most of the stations indicated linear arrangement of rank-abundance diagrams that suggested geometric series with high abundance of a few species. However, patterns of the diagrams differed much depending on station and season.

Rank-abundance diagrams of each community type and of the whole megabenthos in the bay are shown in Fig. 10. Regardless of seasons and types of major communities, patterns of the diagrams were similar to each other, though the dominant species were replaced according to seasons and types of community as mentioned above and also as shown in Tables 3 and 4. The major communities (A-1, A-2, A-3, E and F-3) including many stations (i.e. larger sample sizes) showed that the observed patterns are more likely fitted to lognormal distribution, while those in the minor communities are fitted to geometric series (Figs. 9, 10).

The combined 'number and biomass curves' are shown in Fig. 11. The 'number curves' were above the 'biomass curves' from April to September 1993 for the major communities and also the whole megabenthos in the bay, indicating higher 'biomass diversity' than 'number diversity'

Fig. 7. Dendrograms showing the classification of community types in Ise Bay.

Numericals and alphabet letters indicate sampling stations and community types, respectively. Community types are based on the similarity index measured by species composition in terms of number of individuals. See text for further explanation.

(Table 1), while the reverse occurred from November when oxygen-poor water, which developed and prevailed in summer, disappeared (Fig. 3).

Discussion

As is well known, with the progress of eutrophication, Ise Bay and other bays (estuaries) show marked seasonal variations in environmental conditions, particularly development and prevalence of oxygen-poor water at the bottom in summer.⁹⁾ The development and prevalence of oxygen-poor water at the bottom indicate the occurrence of other more deteriorated conditions for benthic organisms, i.e. hydrogen sulfide and etc. Thus, oxygen-poor water, which is related intimately with production of hydrogen sulfide, has a great influence on benthic animals.^{8,11)} Apparently in response to the development and prevalence of oxygen-poor water in every summer, features of megabenthos communities in the bays may show marked seasonal and also interannual variations,⁹⁾ e.g. in species composition, species diversity, biomass, community types, their spatial distributions and so on, as made clear in the previous section of the present study.

As shown in the present study, marked contrasts were observed between features of megabenthos communities before and after October: Dominant species were replaced (Table 4) with season, i.e. *L. quinaria* was predominant among megabenthos in November and onward while crustaceans (*O. oratoria*, *C. vestita* and *Ch. bimaculata*) were predominant before November. However, based on size distribution of the species (*L. quinaria*) in November

Fig. 8. Spatial distributions of community types identified in Ise Bay. Alphabet letters and solid circles indicate community types and sampling stations, respectively.

(unpublished data), specimens of the species were composed of two large-sized cohorts (probably year classes). The reason why the catch of this species abruptly increased in November is unknown. The lowest number of species and also the lowest biomass of the total megabenthos were found in September (Tables 1 and 3). The lowest number

Fig. 9. Rank-abundance diagrams of megabenthos at each station in Ise Bay.

Rank indicates the sequence of the most to the least in terms of number of individuals. See text for further explanation.

of species in September may be attributed to influences of the prevalence of oxygen-poor water in the bay.

Seasonal variations in number- and weight-based species diversity were not similar to each other. The weight-based diversity was always higher than the number-based diversity before November while the reverse was true since November (Table 1), so that according to the so-called ABC method of Warwick²¹⁾ 'number curves' were above 'biomass curves' before November while the reverse was true since November (Fig. 11). Based on Warwick²¹⁾ Warwick *et al.*,²²⁾ and Beukema,²⁵⁾ 'biomass curves' above 'number curves' indicate benthic communities under stable and/or undisturbed conditions, while the reverse occurs for the communities under unstable and/or disturbed conditions. In megabenthos communities of Ise Bay, 'biomass curves' above 'number curves' may indicate re-establishment or recovery of the communities in November and onward when the oxygen-poor water disappeared in the whole bay. These marked seasonal variations could be

caused by the development and prevalence of oxygen-poor water in summer with the deteriorated conditions at the bottom of the bay, that is supported by spatial distributions in July to September of species number and megabenthos density in the bay. Unfortunately, it is not apparent whether drastic changes in megabenthos communities, as found in the present study, occur every year or not, and further about mechanisms by which these variations are caused and the megabenthos communities are re-established in the bay. Deducing from differences between features of megabenthos in the bay in April 1993 and in April 1994, marked interannual variations in megabenthos communities may be detected in addition to the above-mentioned seasonal variations.

It has been well-known that features of bottom sediment affect the distribution, and the structure and function of benthic communities.²⁶⁻²⁸⁾ Clustering analysis using a similarity index revealed several major megabenthos communities in the bay throughout the study period. Some

Fig. 10. Rank-abundance diagrams of total megabenthos catches and major community types in Ise Bay.

Alphabet letters and rank indicate community types and the sequence of the most to the least in terms of number of individuals. See text for further explanation.

communities appeared to be related intimately with a certain sediment type, e.g. the three major communities (A-1, A-2, A-3) in which crustaceans and fishes were predominant mainly occupied the central to the innermost parts of the bay where we find silt-clay bottom sediment (Fig. 8), indicating highly enriched and/or organic contents. However, the other major communities (E, F-3) in which echinoderms were predominant, extended over several types of bottom sediment (Fig. 8). In particular, distributional patterns of *L. quinaria*, the absolutely dominant species among the communities, contributed to form much weaker relationships between types of several major megabenthos communities (E, F-3) and sediment in the bay.

Regardless of bottom sediment types, seasons and positions of sampling, rank-abundance diagrams of the major communities in the bay showed lognormal distribution that indicates high relative abundance of a few species (Fig. 10). This is the case for total megabenthos in the bay. Differences of the patterns of rank-abundance diagrams between the major and minor communities may lack ecological meaning, because those probably depend on sample

size as already pointed out by Morishita.²⁴⁾ Thus, the rank-abundance diagram at each station (smaller sample size) is fitted to geometric series (Fig. 9), while those of the major communities or of the whole megabenthos assemblages in the bay (larger sample size) are fitted to lognormal distribution (Fig. 10). To our knowledge, there is no information on rank-abundance models for megabenthos communities, but a lognormal distribution model is fitted to demersal fish communities on the shelf and slope waters.⁶⁾ May²⁹⁾ suggests that rank-abundance diagrams of the communities that include a large number of species, fulfilling diverse niches, are often consistent with a lognormal distribution model.

Unfortunately, except for commercially important demersal fish communities, very little work has yet been done for megabenthos communities in the inlet and coastal waters. Of that work, information on megabenthos is available for Tokyo Bay as compared to our present work done in Ise Bay.

Tokyo Bay is a semi-closed bay located along the Pacific coast of central Japan, being ca. 300 km north of Ise Bay, and covers a surface area of ca. 1,000 km² with a mean

Fig. 11. Abundance/biomass comparisons of total megabenthos catches and major community types in Ise Bay.

H' (in ind) and H' (in wt) indicate number- and weight-based species diversity of Shannon-Wiener function, respectively. N and W indicate number of individuals and weight, respectively. Rank indicates the sequence of the most to the least in terms of number of individuals or weight. See text for further explanation.

depth of 17 m. The bay water is rich in nutrients and is highly turbid mainly due to sewage effluent from the cities situated on the western and northern coasts of the bay.⁹⁾

This indicates Tokyo and Ise Bays are comparable in geographical and oceanographical conditions, therefore a comparison can be made between megabenthos communi-

ties of Tokyo and Ise Bays.

Dr. Shimizu and his colleagues^{10,12)} have done much work on the megabenthos community in Tokyo Bay, though concentrating on commercially important groups and using a sampling method different from ours (see, Shimizu¹⁰⁾). According to Shimizu¹⁰⁾ and Tokimura,¹²⁾ fishes and crustaceans were the predominant groups in the bay (excluding Asteroidea), of which two species were predominant in numbers throughout the year: *R. valenciennei* (Pisces) and *O. oratoria* (Stomatopoda). Oxygen-poor water develops every summer in the northern to central part of the bay where defaunation took place, so that megabenthos were mainly found in the southern part of the bay during summer, while in other seasons they were distributed in the central to innermost parts probably in response to recovery of the environmental conditions in the bay.

Being similar to the megabenthos communities in Tokyo Bay as referred above, fishes, crustaceans and echinoderms were predominant groups in Ise Bay, of which the following five species were predominant and drastically replaced with season: *R. valenciennei* (Pisces), *C. vestita* and *Ch. bimaculata* (Brachyura), *O. oratoria* (Stomatopoda) and *L. quinaria* (Asteroidea). It remains difficult to say whether seasonal replacement of the dominant species is a regular event in the bay every year or not. The total number of megabenthos species collected in Tokyo Bay is 198 while the total collected in Ise Bay is 132. In summary, although the two bays are comparable in geographical and oceanographical conditions, features of megabenthos communities are much different between the two bays.

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