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The Distribution Pattern of the Macrobenthos in the Nagura Tidal Flat Enclosed by Mangrove Forest, Ishigaki Island, Southwest Japan

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Abstract : The distribution of macrobenthos was studied on a tidal flat of Ishigaki Island, Okinawa Prefecture. The tidal flat is enclosed by a mixed forest of *Bruguiera gymnorrhiza* and *Rhizophora stylosa*, and receives a large supply of decomposed leaf litter, from the inflow of turbid water. Such suspended organic matter arriving at the open space of the tidal flat, changes the conditions of the bottom sediment and the distribution pattern of the benthic animals. The macobenthic communities investigated include 46 taxa and a larval form, in which 34% was allied to detritivorous species or groups of feeding types. The distribution pattern of the detritivores showed a reasonable trend to accommodate the habitat and corroborated the results of water quality and sediment analyses. Divisions of the benthic communities came from mathematical analysis of their similarity. These communities are expected to be relevant to the composition of the detritus-based ecosystem of the next step of the study.

Key words : macrobenthos, detritivore, Nagura tidal flat, Ishigaki Island

Introduction

The trend that particulate organic matter decomposed from mangrove litter, contributes to estuarine ecosystem as a part of the energy flow has been explicated by Odum and Heald (1975) in a study of the Everglades. As stressed by Mclusky(1981), it is the main source of the detritus-based food web in estuarine waters regardless of primary production by phytoplankton. The litter decomposition process has been demonstrated in only a few phanerogamous plants i.e.*Spartina* (Odum and de la Cruz, 1967), *Zostera* (Imai et al., 1951; Harrison and Mann, 1975) and mangroves (Odum and Heald, 1975), noting the consumption by estuarine animals such as macrobenthos at the secondary trophic level of the ecosystem. How much does the particulate organic matter contribute to the feeding of macrobenthos? Thus, the secondary production of mangrove waters should be evaluated. The objective of the present study is the distribution pattern of macrobenthos, with classification of the taxa by feeding types which include detritivore, the feeder of particulate organic matter precipitated as detrirtus.

The study area is the Nagura estuary located at

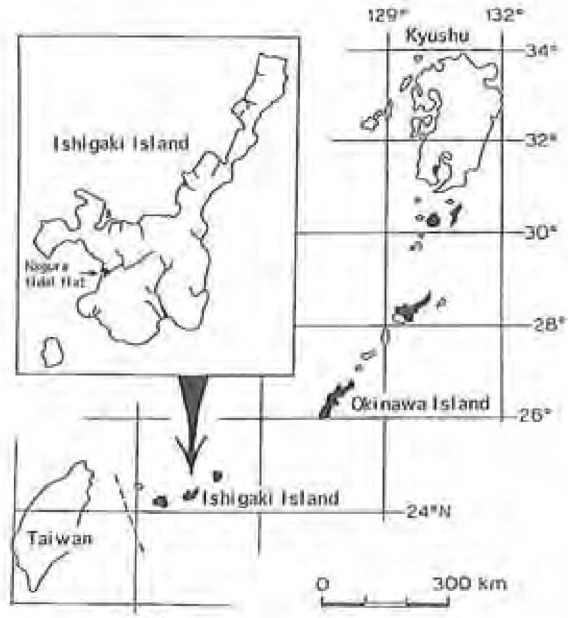

Fig. 1 Map showing the sampling site of Ishigaki Island and the islands of Nansei-Shoto, southwest Japan.The dark parts indicate mangal vegetation

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south coast of Ishigaki Island, Okinawa Prefecture. The estuary looks like a tidal flat at ebb tide and like an estuary when it floods, at which time streams flowing from the mangrove forest into the estuary have a high turbidity rich in particulate organic matter. Therefore, the macrobenthos distribution would be characterized by the source of food supply and would reflect the specialty feeding of macrobenthos such as detritivore.

Macrobenthos distribution in the mangrove swamps or in the watered areas have not often been reported in benthos studies, except in results by Walsh (1967), Paphavasit and Setti (1985) and Nishihira et al. (1996) which are worthy of discussion in the results of the present study.

Materials and Methods

The study site is an elongated lagoon-like tidal flat with 43.3 *ha* surface area and a mixed forest of *Bruguiera gymnorrhiza* and *Rhizophora stylosa* consisting of 41.1 *ha* behind the inner coast. Its main inflow is the Nagura River and a few of smaller streams passing through the mangrove forest which connect to the waterways at the tidal flat and join as one opening into the outer sea. The shape and location (24° 4′ N, 128° 8′ 30″ E) was shown in Fig.1 as the same as that of the previous report (Kuwabara and Shiroma, 1996).

Sampling of the macrobenthos was carried out on April 29-May 1, 1998 of 16 stations on the tidal flat (Fig.2), using frame-quadrates of 10cm× 10cm, 20cm× 20cm, or 50cm× 50cm, twice at each station at ebb tide. Samples were sieved immediately with a metal sieve with 0.5mm aperture. The animals collected were fixed with a 10% formalin solution for later sorting and counting of each species.

At the time of ebb and flood tides on July 27, 1999, water qualities for each station were determined with HORIBA Water Quality Checker U-10 (HORIBA Ltd., Japan). The stations were submerged at this time.

Sampling of the sediment was carried out on April 30, 1998, at the same time of sampling of the macrobenthos. Sediment analyses for grain size composition and for ignition loss as an indicator of organic matter were done. In grain size analysis, fractions of coarse to fine sand were measured by the sieve method. Silt-clay fraction was estimated from weight loss through 0.063mm sieve. Ignition loss was determined at 500℃ for 2 hours.

The same species and the same genus or taxonomical similar group from the literature on the feeding habits of the macrobenthos were identified, using Bienbaum (1979), Day (1967a, 1967b), Dorsey (1982), Enequist (1950), Fauchald and Jumars (1979), Gaston (1987), Graham (1955), Hawkins and Hartonall (1983), Kuwabara and Akimoto (1986), Kuwabara and Imai (1997), Kuwabara et al. (1997), Maurer and Leathem (1981), Whitlatch (1980).

Results and Discussion

1. Distribution of the macrobenthos

The result of the macrobenthos analysis is shown in Table 1. A list of species with a feeding type assigned to each taxon and a numerical density are outlined for each station. A total of 46 taxa and a larval form (zoea larva) were identified. Of the major groups, Polychaeta had 10 taxa, Bivalvia had 4 taxa, Gastropoda had 18 taxa, and Crustacea had 10 taxa. Most gastropod species were epifaunal inhabitants. The designation of the feeding type was followed in the original descriptions. SD, DET and D / S included the same detritivore, at least in part of the feeding behavior. Sixteen taxa of the total 47 species and groups (34%) were detritivores.

Each station yielded 4-18 species, and 8.8 species in average, considerably fewer in comparison to estuary, or inner bay area. Numerical density showed a range of 625-77,400 ind /m², and the average showed 22,266 ind /m². Species showing higher than 10,000 ind /m² were two common gastropods, *Batillaria multiformis* and *B. zonalis*. They were concentrated at St. 4-7 at the northern site of the tidal flat close to an opening to the outer sea where two streams, namely, the Nagura River and the secondary big river flowed into the surrounding waterways. Another concentration of the species was seen at St. 14 close to the fringe of the central mangrove forest (Fig.2). Showing the highest numerical density at each station were the taxa *Langerhansia rosea, Areunimitra exasperata, Batillaria multiformis, B. zonalis, Corophium* sp.and a chironomid of Orthocladiinae, in which the latter four species were detritivores. A species found at almost all the stations was the *Areunimitra exasperata*, a small epifaunal gastropod of which the feeding type is unknown but may be a detritivore because its habitat is similar to the *Batillaria*.

The distributions of a number of species and the numerical density at every station were illustrated in Fig.3. Although any tendency towards large numerical densities was hard to recognize, lower numerical densities were seen just at the inner site of the opening to the outer sea, and higher numerical densities at just behind the site. Thus the generalized pattern of nu-

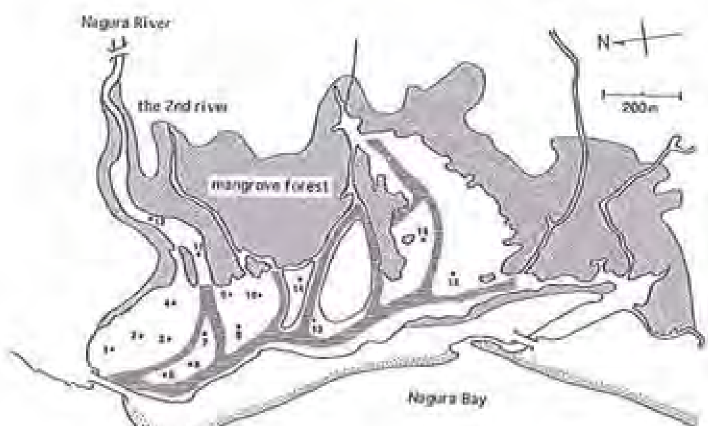

Fig. 2 The sampling stations of macrobenthos in the Nagura tidal flat, Ishigaki Island (stripes: waterway at ebb tide)

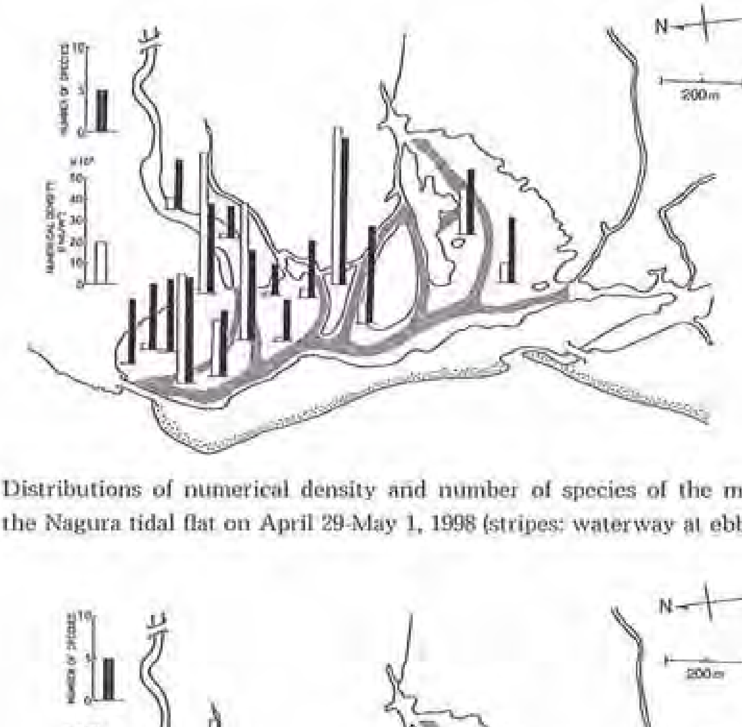

Fig. 3 Distributions of numerical density and number of species of the macrobenthos in the Nagura tidal flat on April 29-May 1, 1998 (stripes: waterway at ebb tide)

Fig. 4 Distributions of numerical density and number of species of detritivore macrobenthos in the Nagura tidal flat on April 29-May 1, 1998 (stripes: waterway at ebb tide)

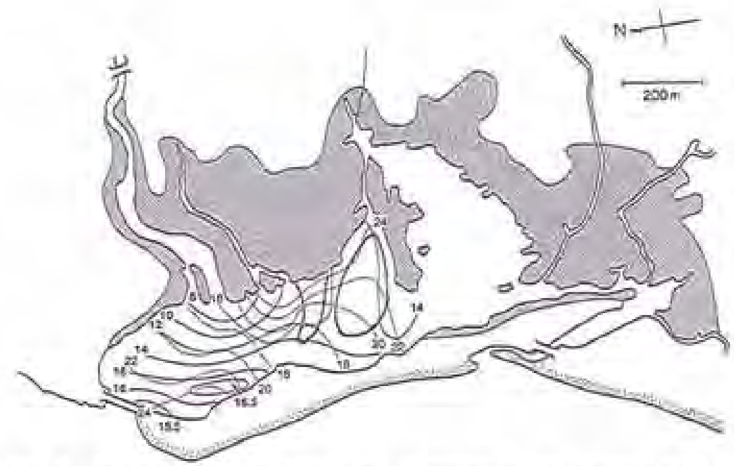

Fig. 5 Distribution of salinity (‰) in water of the Nagura tidal flat on July 27, 1999 (solid lines: ebb tide, dotted lines: flood tide, solid lines with convexes: tidal flat at higher level)

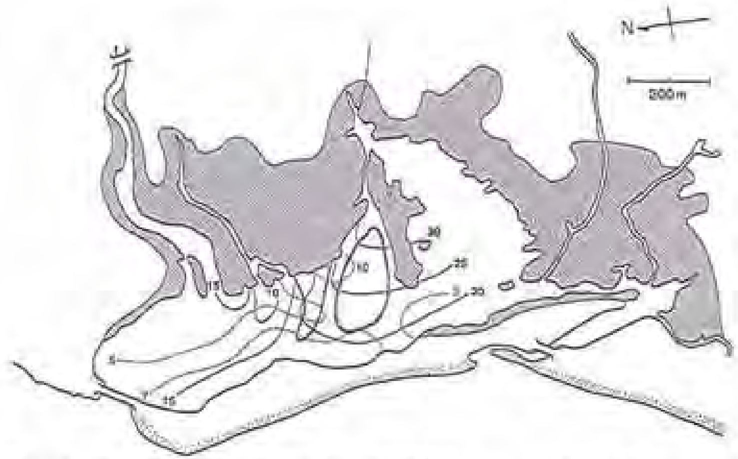

Fig. 6 Distribution of turbidity (NTU) in water of the Nagura tidal flat on July 27, 1999 (solid lines: ebb tide, dotted lines: flood tide, solid lines with convexes: tidal flat at higher level)

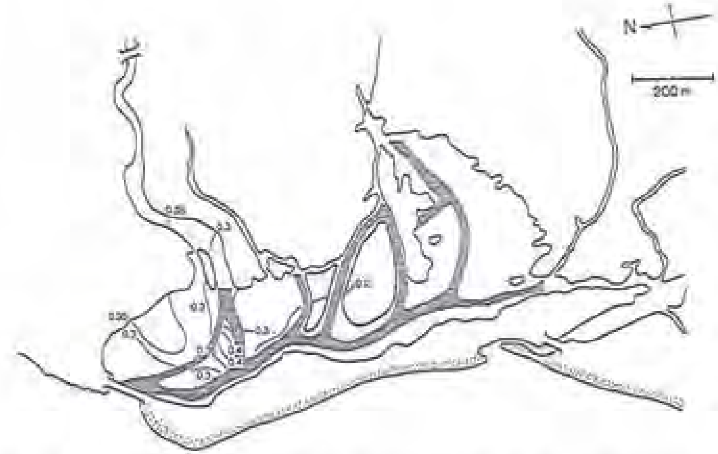

Fig. 7 Distribution of median diameter (㎜) of the sediment in the Nagura tidal flat on April 30, 1998 (solid line with convexes: tidal flat at higher level, stripes: waterway at ebb tide)

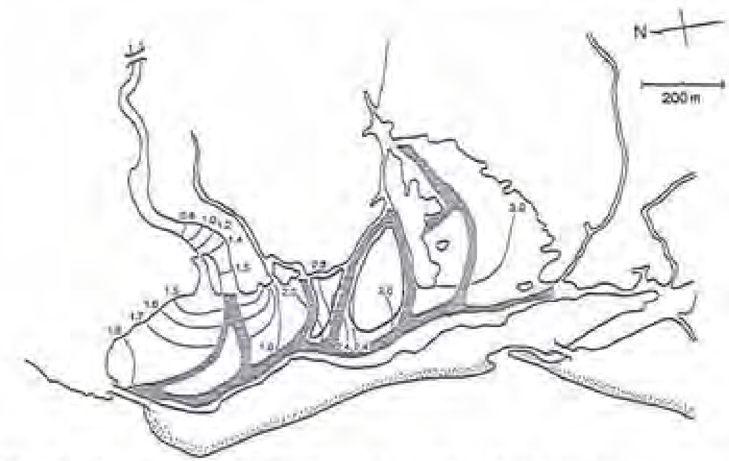

Fig. 8 Distribution of ignition loss (%) of the sediment in the Nagura tidal flat on April 30, 1998 (solid line with convexes: tidal flat at higher level, stripes: waterway at ebb tide)

St.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1																
2	59.6															
3	20.8	58.2														
4	7.4	78.2	78.8													
5	31.8	60.7	95.6	78.8												
6	7.7	64.1	97.8	95.6	78.4											
7	8.4	42.1	2.2	97.8	80.1	99.2										
8	20.6	69.4	55.2	2.2	42.4	2.0	2.4									
9	5.9	32.7	3.9	55.2	77.3	58.6	58.7	70.6								
10	26.0	22.2	0.7	3.9	35.6	2.3	3.3	75.5	68.6							
11	61.7	12.6	0.7	0.7	39.1	0.5	1.4	49.1	20.3	29.2						
12	8.3	34.3	4.3	0.7	13.5	0.5	0.8	26.5	20.3	23.1	19.5					
13	4.0	47.1	22.0	4.3	36.4	3.5	4.2	81.0	78.1	88.4	25.5	25.7				
14	2.5	35.6	7.0	22.0	52.8	18.7	20.1	83.1	83.6	83.2	24.3	26.4	91.8			
15	1.7	31.2	2.6	7.0	37.2	5.6	6.5	85.5	73.1	77.8	31.2	26.7	88.7	86.7		
16	1.3	7.0	3.6	2.6	33.1	1.8	2.6	79.1	75.0	82.1	28.4	25.1	98.0	86.6	87.2	

0–30 30–50 50–70 70–100

Fig. 9 Diagram showing similarity of macrobenthos community among total stations (Each number indicates Kimoto's similarity index $C\pi \times 100$)

Fig. 10 Division of macrobenthic community pattern in the Nagura tidal flat, examined from diagram of similarity in Fig. 9 (dotted lines: approximate boundary of the divisions, stripes: waterway at ebb tide)

Table 1 Macrobenthic taxa with their feeding types and numerical densities obtained from the Nagura tidal flat, Ishigaki Island, April 29-May 1, 1998

SPECIES & FEEDING TYPE	STATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
OLIGOCHAETA																	
Limnodrilus sp.		100															
POLYCHAETA																	
Aulolytus sp.					100												
Langerhansia rosea	DEP	50	1,200	50	100	200											
Ophiodromus sp.	C	25															
Neanthes japonica	C,O											25					
Ceratonereis erythraeensis	O												125	500	1,000	1,300	300
Hemipodus sp.	C			100	400												
Glycera lancadivae	C					100											
G. prashadi	C										100						
Heteromastus filiformis	DEP	75	150					200						300	400	300	300
MALDANIDAE	DEP		50														
NEMERTINEA	DEP										100						
NEMATODA	DEP														100		
BIVALVIA																	
Musculista senhousia	SF					200								200			
Gafrarium tumidum	D/S	125	50								1,300			600	500		
Psammolaea minor	D/S								200			375	250			2,100	1,700
Psammolaea elongata	D/S				100												
GASTROPODA																	
Angaria distorta							100										
Nerita squamulata	G				300	1,600	400	600									
Ritena costata	G					400											
Clithon retropictus	G						200										
Melanoides tuberculatus	SD													100			
Batillaria multiformis	SD				21,200	4,900	3,800	12,200			100			100	6,600	200	
Batillaria zonalis	SD	25		450	44,100	22,300	21,300	47,400		600				100	6,600	200	
Cerithidea rhizophorarum morchii	SD			300	1,100		600	4,500									
Cerithideopsilla cingulata	SD															100	
Cerithium kobelti	SD																
Proclava kochi	SD				100			100									
Clypeomorus petrosus	SD				100	3,800	1,000	300	100		100			300	5,600	100	
Niso hizenensis	PA													100			100
Japeuthria ferrea	O							100									
Plicarcularia bellula															200		
Arenimitra exasperata			100	250	1,300	10,200	400	1,300	700	600	2,300	425	850	7,800	41,800	5,100	18,900
Didontoglossa koyasensis															100		
Melampus nuxcastanea	G													100			
CRUSTACEA																	
Photis sp.	SF-SD (DET)			50									625	200	4,800		100
Corophium acherusicum	SF-SD (DET)					300									7,200		
C. sp.	SF-SD (DET)												3,100				
Idotea sp.								100									
Cirolana sp.	C,O														100		
Tanais cavolinii	D/S														1,200		
Mictyris brevidactylus			100							100							
Scopimera globosa		25	200	100		200			300	100					500		100
ANOMURA						100									200		
Zoea larva	P														100		
INSECTA																	
Enochrus sp.				100													
ORTHOCLADIINAE	DET	200	850	100		9,000		400	200		200	1,550	400		200		300
Nos. of species		6	8	9	11	13	8	11	5	4	7	4	6	12	18	8	8
Numerical density (Ind/m²)		625	2,700	1,500	68,900	53,500	27,800	67,200	1,500	1,600	4,200	2,375	5,350	10,400	77,400	9,400	21,600

C: carnivore, O: omnivore, SF: suspension feeder, SD: surface detritivore, DEP: deposit feeder, DET: detritus feeder,
D/S: deposit-suspension feeder, G: grazer, P: plankton feeder, PA: parasitic

merical distribution was variegated in comparison to that of species number shown at the same time in Fig.3. However, the illustration for detritivores showed a fine locational difference as seen in Fig.4. Very high numerical density was recognized at the site showing high numerical density for the total number of species including St. 4-7 and St. 14, allied to the abundance of *Batillaria multiformis* and *B. zonaris* mentioned above. Looking at the geography, these sites are influenced significantly by the flow of the two rivers, the Nagura River and the second river.

Meanwhile, three reports have been published on the faunal and the distributional studies of the macrobenthos in mangrove waters under a different scale and a different condition for each other: 1) a riverine zone of 250m length in a Hawaiian mangrove swamp, Walsh (1967), 2) a big scale coastal and varied stony area in Pan-naga Bay, Thailand, Paphavasit and Setti(1985), 3) Klong Kone mangrove swamp in Samut Songkhram, Thailand, Nishihira et al.(1996).

In the study by Walsh (1967) under the conditions of black mud with gravel bottoms, and salinity 0.1-36‰ or over, a total of 23 benthic taxa including 6 molluscan and 14 crustacean taxa was recorded from the riverine of two mangrove species, *Bruguiera sexangula* and *Rhizophora mangle*. After reviewing the data, 7 taxa (30%) can be attributed to detritivore type.

Paphavasit and Setti (1985) identified 80 taxa or more of macrobenthos including 30 polychaete, 6 bivalve, 15 gastropod and 27 crustacean taxa from three coastal stations where 12 species of mangrove trees were observed. Numerical density ranged from 115-546 ind/m² of the epifauna, and from 1,305-6,691 ind/m² of the infauna. The Shannon-index of species diversity for the infauna ranged from $H' = 0.7562$-1.1892 are considerably low against the richness of species. Comparing the result of the present study, polychaete and crustacean taxa were abundant. Otherwise, the numerical density and species diversity showed smaller values. The difference might be due to a sampling method such as line-transect sampling in their research of Thailand compared to the quadrate method of the present study.

Nishihira et al. (1996) also studied macrobenthic communities of an outer mud flat and an ex-mangrove fringe of mangrove forest composed of the species, *Avicennia alba* and *Sonneratia caseolaris* in Thailand. Although the report had no list of macrobenthos species, a total of 63 species have been identified with 9 polychaete, 6 bivalve, 9 gastropod and 18 crustacean species. Only 11-21 species occurred at each station. The average density was 578 ind/m², which is very small compared to the abundance of species. The Shannon-index ranged from $H' = 1.85$-2.39 except for a value of mangrove-less stations. A cockle, *Anadara* sp., and an ocypoid crab, *Macrophthalmus*, were common to the area studied.

Compared to the data of these publications, the result of the present study shows a moderate number of total taxa and of species in the main taxonomic groups. The high numerical density and low species diversity which is shown in the Section 3, are characteristic of the area studied. The community was occupied predominantly by epifaunal gastropods such as *Batillaria* spp. and *Arenimitra exasperata*.

2. Water and sediment environments

As hydrodynamics are the major agents forming the distribution pattern of the inhabitants of mangrove waters, physico-chemical data of water quality were requested at the study site. When the benthos sampling was carried out there in 1998, no water quality determination had been applied. Additional research was done on the analyses of the water environment. Some of the data were discussed as follows.

Salinity ranged from 7.2-16.7‰ in ebb tide and 17.1-24.7‰ in flood tide on July 27, 1999. In the illustration of the results (Fig.5), the distribution of isometric lines in ebb tide showed that the freshwater flow from the Nagura River influenced from the inside of the barrier to the opening of the estuary to the outer sea. A similar reflex lines-pattern is seen in the flood time with a few modifications caused by the invasion of seawater. It is recognized that the repeated movement of water mass is greater in the outer part of the tidal flat where the macrobentic inhabitants should be more or less tolerant of salinity changes. As suggested by Wolanski (1992), high salinities seen in 20, 22 and 24‰ of the isometric lines of the inner part of the tidal flat might be the effect of evapo-transpiration of the shallow and warmed water under the remained state.

Turbidity ranged from 8-33 NTU in ebb tide and from 4-10 NTU in flood tide in the same survey, which suggests that the high turbidities were derived from land-source origins. The distribution shown in Fig.6 recognizes that the high turbidity water advances from the fringe of the mangrove forest toward the central part of the tidal flat. The fact suggests that since there is almost no other source of producing turbidity except litter decomposition and accumulation around the mangrove forest, particulate organic matter would be dispersed from muddy sediment under the mangroves, which supply the litter leaves and the decomposed substance. Distribution of the isometric lines in the flood tide show a similarity to the distribution of salinity during the movement of the same water mass.

The sediment condition directly affects the inhabitants such as macrobenthos. The major particle sized physico-chemical elements and the nutritional substance are also analyzed and discussed in this study, using data taken at the same time as the macrobenthos sampling in 1998.

The median diameter of the sediment exhibited a range of 0.135-0.48㎜ of fine sand and medium sand at every station. As seen in Fig.7, while grain smaller than 0.2㎜ (within the range of fine sand) disperses in the inner part of the total area, grain larger than 0.35㎜ (within the range of medium sand) is isolated in the northern side toward the opening, the riverine of the Nagura River, and a central spot surrounded by two waterways flowing toward the opening to the outer sea.

Ignition loss as an index of organic matter content exhibited a range of 0.73-3.16%. The distribution of the isometric lines is shown in Fig.8. The highest value and the next highest values were obtained from the inner wide part of the area where finner sands were distributed. In general, ignition loss shows a negative correlation to grain size, because a volume of smaller particles has a greater total surface area for adsorption of organic matter and colonization of bacteria. On the contrary, larger particle has a smaller surface area in the same unit of volume which accompanies lower organic content (Barnes, 1974). Accordingly, the inner area, rich in organic matter, has to yield a high density of macrobenthos, and its virtual abundance was observed mostly in the outer part of the area where ignition loss is lower. This area of well-arranged isometric lines shows a concentration of ignition loss which increases gradually the values. This means that particulate organic matter supplied from the Nagura River increases the successive precipitation of the opened space by decreasing the flow velocity. Thus, the suspending organic matter changes the condition to aggregative detrirus-form in the bottom surface. Therefore, abundant macrobenthos of a particularly detritivore-type as comprehensible in Fig.4 would be raised. Actually, this is the domain of detritivorous *Batillaria* species.

3. The division of community pattern

From the data on macrobenthos species and the density, all possible pairs of stations can be compared by use of Kimoto's similarity Index C_{π} (Kimoto, 1967; 1976) in Fig.9. If two samples are the same composition and numerical density, $C_{\pi} = 1$ is derived. As the values were often very small, $C_{\pi} \times 100$ was used to show the results. Consequently, St. 3-7, St. 8-10, and St. 13-16 are seen as a group with high similarity values from 70-100. The remaining St. 1, 2, 11, and 12 are connected by location and values ranging from 50-70. The division of the community pattern and the location were summarized in Fig.10 showing partitions from Ⅰ - Ⅳ. Waterways seen at the borders have a rapid current mostly in ebb tide, and the sediment conditions are different from the surface of the tidal flat. As simplified explanation of the partitions is described below.

As for the next step of study, the composition of a detritus-based ecosystem for Ⅰ - Ⅳ needs to be researched. In that case, Partition Ⅱ would be chosen because of the higher numerical density of a detritivorous gastropod and the moderate ranges of grain size and the organic matter content in the sediment.

Partition Ⅰ. No. of species : 4-8, dominant species : *Langerhansia rosea, Arenimitra exasperata, Corophium* sp. and Orthocladiinae, numerical density : 625-5,350 ind/m², median diameter of sediment : 0.255-0.40mm, ignition loss : 0.73-1.79%

Partition Ⅱ. No. of species : 8-13, dominant species : *Batillaria zonalis*, numerical density : 1,500-68,900ind/m², median diameter of sediment : 0.275-0.48mm, ignition loss : 1.49-1.73%

Partition Ⅲ. No. of species : 4-7, dominant species : *Batillaria zonalis*, numerical density : 1,500-4,200ind/m², median diameter of sediment : 0.21-0.23mm, ignition loss : 1.37-1.91%

Partition Ⅳ. No. of species : 8-18, dominant species : *Arenimitra exasperata*, numerical density : 9,400-77,400ind/m², median diameter of sediment : 0.17-0.21mm, ignition loss : 2.35-3.16%

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桑原　連*：マングローブ林に囲まれた石垣島名蔵干潟のマクロベントス（底生動物）分布

マングローブ林の落葉由来有機物は河川水中の懸濁態粒子として干潟水域に運ばれデトリタスの形で沈積し、そこに分布するマクロベントスの餌料として生態系の二次生産段階に供されるものと予測される。名蔵干潟における1998年４月29日－５月１日のマクロベントス定量採集で得られた46種群，１幼生型について，ベントス食性に関する文献でその食性を照合すると，34%の種類がデトリタス食であった。デトリタス食種のみで再構成した種類数と個体数密度の分布は，干潟に流入する名蔵川河川水の直接影響域と重なり，落葉由来有機物の供給プロセスを示唆する結果となっている。水質・底質各項目の分布パターンもこれに沿った傾向を示した。

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