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Macrobenthic Communities on the Tidal Flats around Yongjong and Yongyu Islands, Inchon, Korea

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Four tidal flats, covering two dissipative type beaches and two other tidal mud flats, around Yongjong-Yongyu Islands, Inchon, Korea were studied in May 1991 to analyze the spatial distribution patterns of benthic communities on macrotidal flats. From the statistical test on spatial patterns of species number, density, and biomass, significant trends were found in species number and biomass. Although quantitative analysis was not performed, the interpretation showed that the variations were ruled out by environmental gradients such as sediment grain size and tidal elevation. The eight communities revealed in this study are as follows: *Moerella-Mactra*(Group 1), *Ilyoplax-Glycera-Magelona japonica-Magelona* sp.*-Periserrula* (Group 2), *Amphiura-Nephtys californiensis-Bullacta-Eohaustorius* (Group 3), *Leonnates-Heteromastus-Protankyra-Nephtys polybranchia* (Group 4), *Nephtys chemulpoensis-Macrophthalmus* (Group 5), *Ceratonereis-Scopimera* (Group 6), *Haustorioides-Urothoe* (Group 7) and *Cycladicama-Armandia-Minuspio* community (Group 8). Some of these communities were classified into substratum-specific (Group 1 to 3) and tidal elevation-specific communities (Group 4). It was difficult to identify the predominant governing agent in Groups 5, 6, 7 and 8 because of their presence at extreme types of sediment and at uppermost elevations. Mixed effects seemed to act upon the latter four communities (Group 5 to 8). Based on the number of samples, 60% of the target samples were influenced by substratum properties, 20% by tidal elevation effect and 20% by mixed effect of the two factors. From this, it was concluded that substratum properties serve as the most important factors on soft bottom inhabitants in the area studied.

INTRODUCTION

The issue on whether a tidal flat has to be reclaimed for the purpose of territorial expansion and utilization as an industrial estate or not has recently been the focus of undertakings in the field. In this context, a primary investigation prior to reclamation should be carried out in order to avoid fatal environmental destruction and to properly assess the importance of biological resources and their ultimate benefits.

Regarding foreign studies, examinations based on the recognition of the significance of the tidal flat ecosystem have been performed by numerous authors (Beukema, 1974, 1976, 1989; Beukema *et al.*, 1983; McLachlan *et al.*, 1984; Peterson, 1991; Reise, 1985; Tamaki and Kikuchi, 1983). They have uncovered hidden ecological relationships and offered predictions on spatial and future variations of tidal flat communities.

Few benthic ecological studies have been undertaken in the intertidal zones in and around Kyonggi Bay, Korea (Frey *et al.*, 1987a, 1987b; Park, 1991; Shin *et al.*, 1989; Koh and Shin, 1988). The neighboring locations of the area being studied, Yongjong-Yongyu Islands, will be the site of the Inchon International Airport that would be constructed between the two islands after they are reclaimed. In fact, this study was conducted within the framework of the environmental impact assessment prior to the airport construction.

The present paper sought to describe the characteristics of macrobenthic communities on tidal flats around Yongjong and Yongyu Islands. First, an experimental approach was employed to find significant spatial patterns of biological parameters, *i.e.*, number of species, density and biomass. The distribution of faunal assemblages was examined by using classical classificatory analysis.

MATERIALS AND METHODS

Field sampling

To determine the distribution patterns and com-

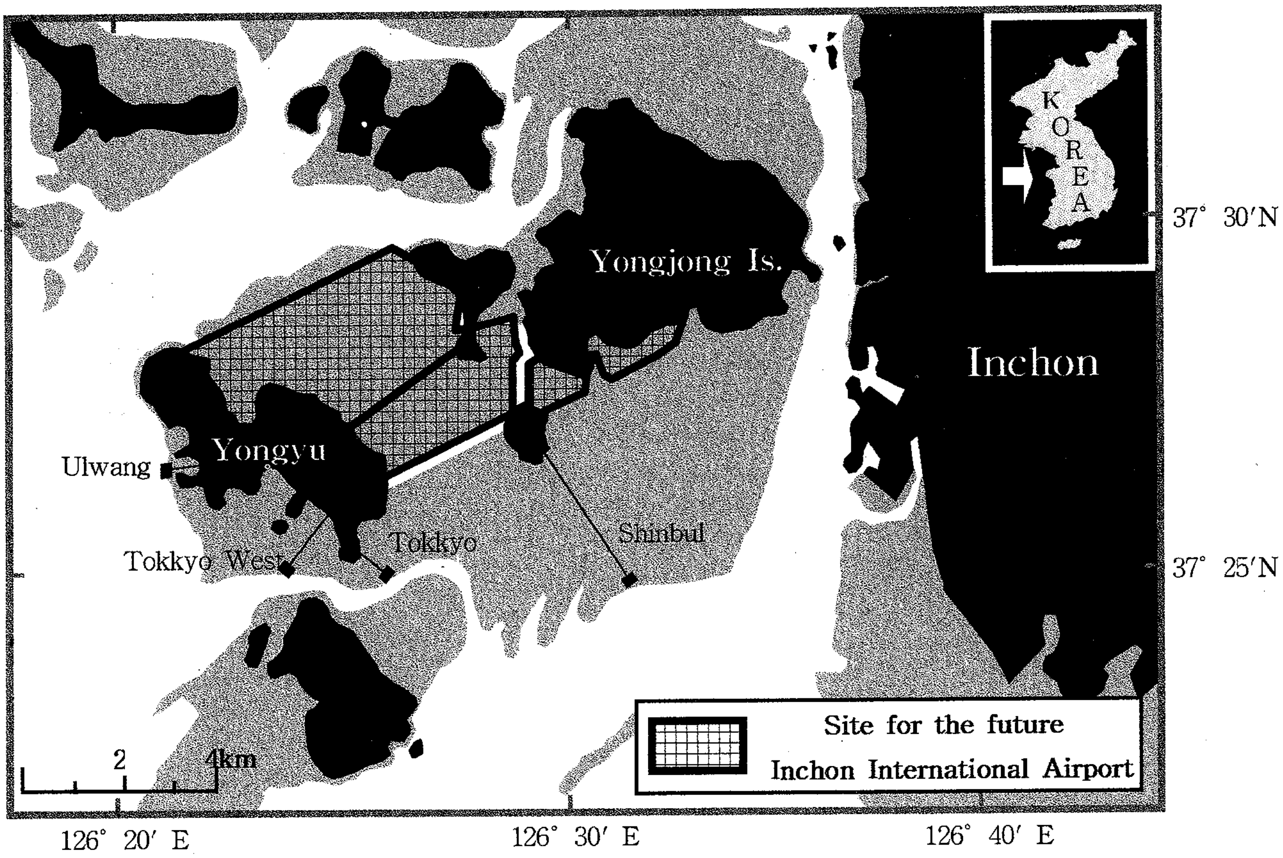

Fig. 1. Study site showing four tidal flats around Yongjong-YongyuIslands, Inchon, Korea.

munity characteristics of benthic macrofaunal assemblages on tidal flats around Yongjong and Yongyu Islands, four tidal flats were visited from May 15—17, 1991 (Fig. 1). One transect was established on a tidal flat and each transect was subdivided into five level stations from upper (Station 1) to lower tidal elevation (Station 5). Six can cores (with surface area of *ca.* 0.2 m^2) were obtained from each station while surface sediment samples were collected simultaneously. Each biological sample was sieved on a screen 1.0 mm in pore size and in the process, macrobenthos were extracted.

Laboratory analysis

Particle size analysis was carried out with the use of a pipette (Folk, 1968). After the salts, organic matter and carbonates were removed, sand and mud fractions were separated by wet sieving with the use of a 4 ϕ mesh. Sand fractions were dried and sieved at 1 ϕ intervals, and mud fractions were dispersed into a 0.1% sodium hexametaphosphate solution. Data for sand, silt and clay were obtained by weighing each separated fraction obtained from sieving and pipetting. Grain-size parameters were calculated according to the equations of Folk and Ward (1957). Faunal samples were sorted, identified to species levels if possible and counted under a dissecting stereomicroscope. Biomass (wet weight in gram) was measured in wet weight (g) using an electronic balance.

Analyzing the Data

To test the null hypothesis that species number, density, biomass, and median grain size are equal among the four transects and among the five tidal elevations, a randomized block design of a model II ANOVA (Analysis of variance) and non-parametric statistics (Satterthwaite and Cochran methods and Kruskal-Wallis test) were employed. In the ANOVA, all pairwise *a posteriori* testing was done by using Duncan's multiple range test. The test of equal variance among data was done by Bartlett's (1937) and Cochran's (1941) methods. ANOVA was carried out step-by-step in the order of 4 transects ×5 elevations, 3 transects ×5 elevations, and 2 transects ×5 elevations. In 3×5 ANOVA for species number, density and biomass, data from the Tokkyo South transect were removed because of the different attribute of variation that the transect exhibited (*e.g.*, no spatial trend in number of species). The Tokkyo West transect was not included in the 3×5 ANOVA on median grain size data due to the large variance that resulted. A variance-stabilizing transformation was performed in vain due to the independence of variance among the means. The 2×5 ANOVA of median grain size was carried out only for the 2 transects, Shinbul and Tokkyo South. This was because of the large variance yielded by data from Tokkyo West, as described above, and because of the different characteristics of the directional changes in the sediments from Tokkyo West and Ulwang (the beaches are finer seawards). Median grain size data of Tokkyo West and Ulwang transect were tested by using non-parametric statistical methods. Differences in variances and means between transects were tested using Satterthwaite and Cochrans methods. Variation along the tidal elevation was also tested with the use of the Kruskal-Wallis method.

Dominance ranking was calculated using the Le Bris index, D_{ij}' (Le Bris, 1988):

$$D_{ij}' = F_{ij} \times D_{ij} \times 100$$

$$= [(p_{ij}/p_j) \times 100] \times \left[\sum_{k=1}^{p_j} (N_{ik}/N_k) \times 100/p_j\right] \times 100$$

where p_{ij}=number of samples including the species, *i*, in the assemblage, *j*; P_j=total number of samples in the assemblage; N_{ik}=density or biomass of the species *i* in the *k*th sample of the assemblage, *j*; N_k= total density or total biomass of the *k*th sample.

The relative Euclidean distance (Ludwig and Reynolds, 1988) was used in order to obtain the resemblance between stations (Q-mode analysis) and between species (R-mode analysis):

$$RED_{jk} = \sqrt{\sum\left[\left(\frac{X_{ij}}{\sum X_{ij}}\right) - \left(\frac{X_{ik}}{\sum X_{ik}}\right)\right]^2}$$

where X_{ij} and X_{ik} are the shared value of variables between each pair of objects.

The linkage method used for agglomerative hierarchical cluster analysis was the flexible strategy with β=−0.25 (Lance and Williams, 1967; Sneath and Sokal, 1973):

$$D(j,k)(h) = \alpha_1 \cdot D(j,h) + \alpha_2 \cdot D(k,h) + \beta \cdot D(j,k)$$

where α_1 and α_2 are 0.625, and −0.25, respectively.

RESULTS

Sediment characteristics

Surface sediment textures were classified using a triangular diagram of Folk (1968) (Fig. 2). Scattering patterns of Tokkyo South and Ulwang transects showed some tendency of concentration on the dia-

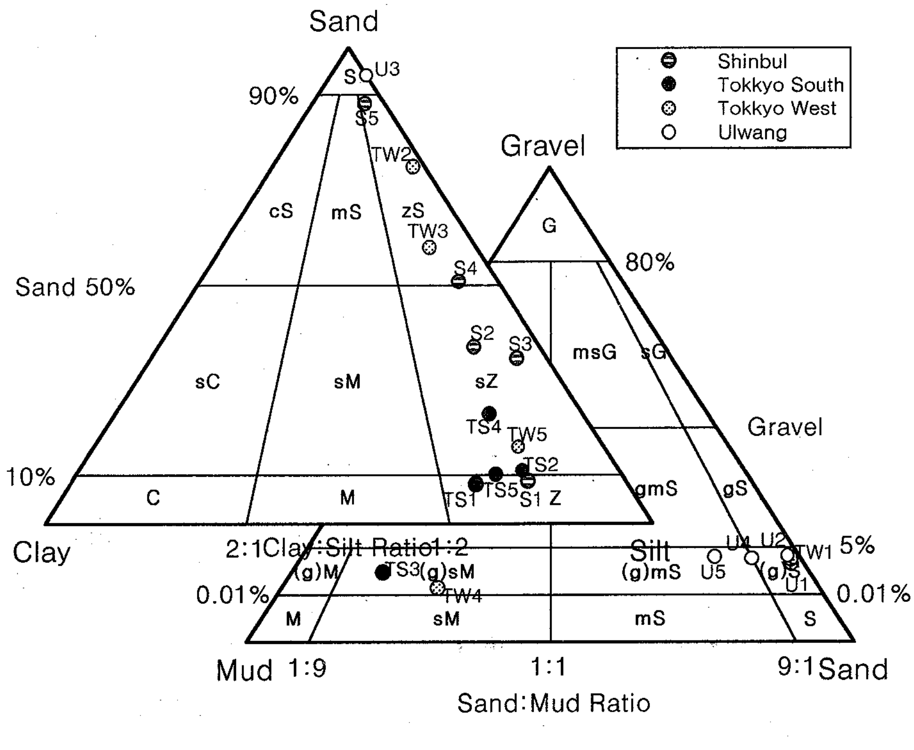

Fig. 2. Classification of surface sediment samples from the four tidal flats according to Folk (1968).

gram, but the others did not. Tokkyo South represented silt bottoms in general. Sediments of Shinbul varied from silt to silty sands. The Tokkyo West transect contained sand and mud bottoms with some gravel. Spatial trends of median grain size that were observed are given below.

Spatial patterns of number of species, abundance, biomass and median grain size

In Table 1 and Fig. 3, the ANOVA results were summarized. The mean species number (3 transects ×5 elevations) was slightly different among the Shinbul, Tokkyo West, and Ulwang tidal flats (p=0.0840), and among the tidal elevations (p=0.0369). In Fig. 3 (b), the mean species number of St. 4 proved to be low and similar to that of St. 1 due to a relatively large variance. When we observed the mean and gradient, however, we found that higher elevations always coincided with a low species number, and lower elevations coincided with a high species number. In terms of density and biomass, no common spatial patterns were detected except for a mean biomass along tidal elevations (Fig. 3 (c)-(f)). Under p-value of 0.0615, biomass manifested a significant seaward increase.

Sediment grain size was significantly different among the tidal flats (Fig. 3(g)). For Shinbul and Tokkyo South, the variation along the tidal elevations showed significant differences at p-value of 0.0784 (Table 1). Variances between Ulwang and Tokkyo West were significantly different (p=0.0003). Although the variation along the tidal elevations in Tokkyo West and Ulwang was found to resemble the expected scores (Kruskal-Wallis test in Table 1), the rank scores of median grain size showed a gradual increase (Fig. 3(h)).

Dominant species

Dominance ranking was calculated on tidal flat macrofaunal assemblages in Yongjong and Yongyu Islands using the Le Bris index (Le Bris, 1988). This index considers both frequency of occurrence and rel-

Table 1. Summary of ANOVA and non-parametric analysis for species number, log-transformed density and biomass, and median grain size of surface sediment

ANOVA (Completely randomized block design)													
Dependent Variable	Species number				Density			Biomass			Median grain size		
Source	4 transects ×5 tidal elevations												
	DF	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value
Transect	3	37.65	1.68	0.2244	0.01	0.13	0.9385	0.16	0.72	0.5579			
Elevations	4	29.08	1.30	0.3260	0.00	0.06	0.9916	0.69	3.02	0.0615			
Source	3 transect ×5 tidal elevations												
	DF	MS	F	p-value*	MS	F	p-value*	MS	F	p-value*	MS	F	p-value*
Transect	2	42.47	3.43	0.0840	0.01	0.11	0.898	0.24	0.77	0.4943	6.82	66.30	0.0001
Elevations	4	53.83	4.35	0.0369	0.02	0.27	0.8887	0.68	2.20	0.1590	0.11	1.09	0.4238
Source	2 transects ×5 tidal elevations												
	DF	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value***
Transect	1										1.06	20.62	0.0105
Elevations	4										0.25	4.82	0.0784

	Non-parametric test for median grain size (Tokkyo West and Ulwang)				
	Variances	p-value	Method	DF	p-value
Transect	Unequal	0.0003	Satterthwaite	4.1	0.4038
			Cochran	4	0.4043
Elevations			Kruskal-Wallis	4	0.2357

Remarks:

*denotes blocks including Shinbul, Tokkyo West and Ulwang

**denotes blocks including Shinbul, Tokkyo South and Ulwang

***denotes blocks including Shinbul and Tokkyo South

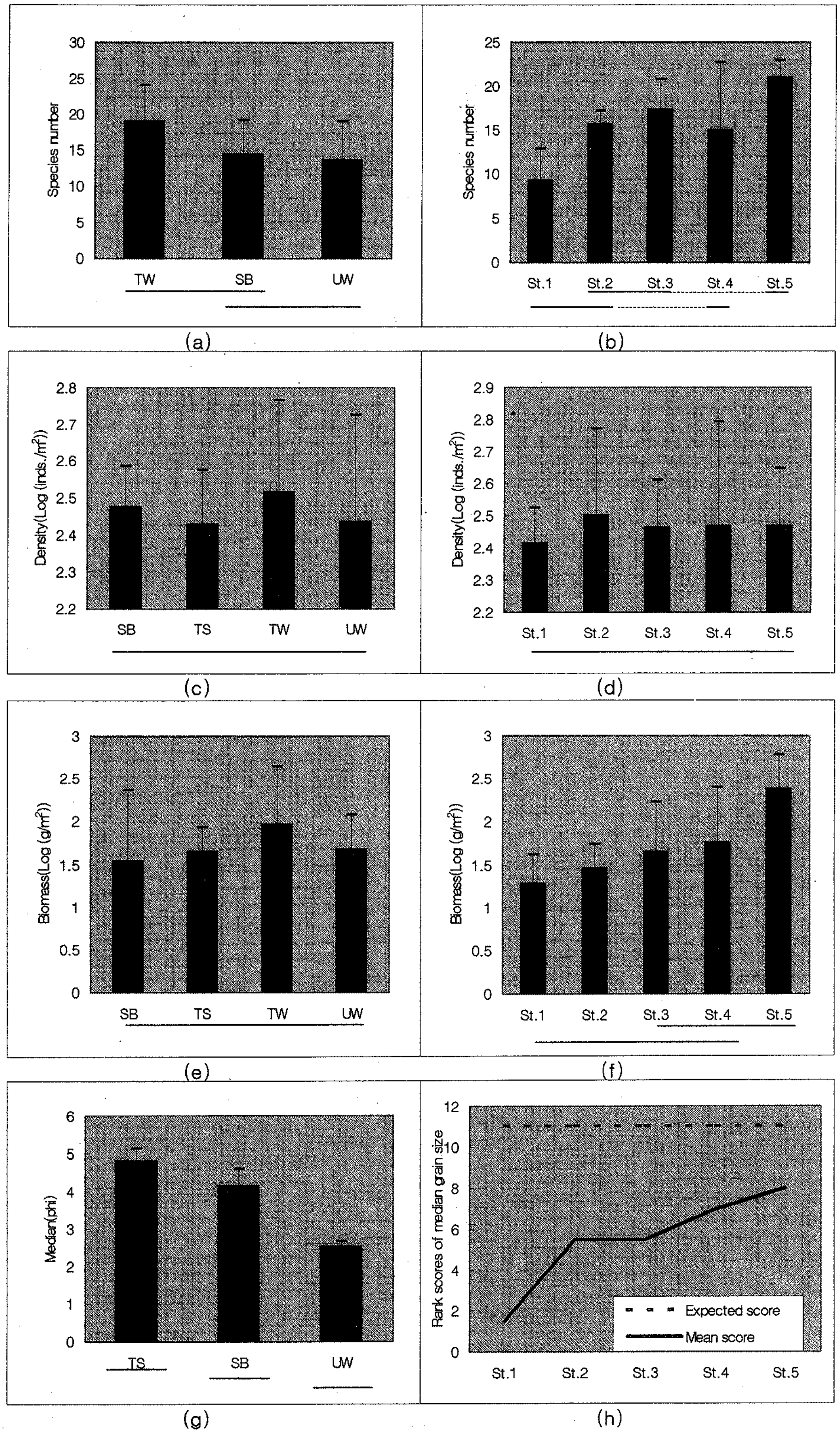

Fig. 3. Multiple comparisons of species number, density, biomass and median grain size among four transects and five elevations (a)–(g) (SB, Shinbul; TS, Tokkyo South; TW, Tokkyo West; UW, Ulwang) and result of non-parametric analysis for median grain size among tidal elevations (h).

ative density or biomass of the species in a given faunal assemblage at the same time.

The top 40 species based on abundance are shown in Table 2. From the results, the most dominant species was the opportunistic capitellid polychaete, *Heteromastus filiformis,* followed by *Glycera chirori, Mactra veneriformis* and *Protankyra bidentata.* Dominance ranking was also applied to the biomass-based

Table 2. The dominant species in terms of density selected by dominance Index (Le Bris, 1988). Note that P=Polychaeta, C=Crustacea, M=Mollusca and Ot=Others

Rank	Taxa	Species	Total	F_{ij}	D_{ij}	D_{ij}'
1	P	*Heteromastus filiformis*	161	90	10.54	94821
2	P	*Glycera chirori*	66	70	4.85	33927
3	M	*Mactra veneriformis*	125	30	8.99	26976
4	E	*Protankyra bidentata*	65	45	5.45	24520
5	P	*Magelona* sp.	32	65	2.87	18675
6	E	*Amphiura sinicola*	26	60	2.43	14564
7	C	*Ilyoplax pingi*	41	40	3.63	14521
8	P	*Cirrophorus furcatus*	30	55	2.31	12682
9	P	*Nephtys californiensis*	34	30	3.72	11151
10	P	*Nephtys polybranchia*	31	55	1.98	10912
11	P	*Magelona japonica*	34	30	2.64	7916
12	P	*Nephtys chemulpoensis*	25	30	2.34	7025
13	C	*Acanthomysis* sp.	26	25	2.05	5120
14	M	*Cycladicama cumingii*	85	15	3.10	4650
15	P	*Leonnates nipponicus*	24	35	1.23	4309
16	M	*Bullacta exarata*	13	25	1.59	3966
17	C	*Eohaustorius longidactylus*	20	15	2.46	3683
18	P	*Periserrula leucophryna*	21	20	1.75	3506
19	C	*Haustorioides* spp.	25	10	3.25	3246
20	P	*Glycera onomichiensis*	14	25	1.22	3047
21	P	*Lumbrineris cruzensis*	19	30	0.95	2849
22	Ot	*Nemertinea* sp.1	7	30	0.82	2457
23	C	*Asthenognathus inequipes*	12	25	0.84	2105
24	P	*Hesperonoe* sp.	15	15	1.05	1581
25	P	*Sternaspis scutata*	9	20	0.76	1516
26	P	*Aricidea pacifica*	8	15	0.94	1405
27	P	*Aricidea assimilis*	6	25	0.56	1387
28	P	*Lumbrineris heteropoda*	5	25	0.54	1357
29	C	*Urothoe* spp.	14	10	1.36	1357
30	P	*Gattyana pohaiensis*	6	25	0.53	1317
31	C	*Macrophthalmus japonicus*	26	5	2.60	1300
32	M	*Laternula boschasina*	13	15	0.82	1237
33	P	*Ceratonereis erythraeensis*	27	5	2.37	1184
34	P	*Haploscoloplus elongatus*	5	20	0.56	1124
35	P	*Eteone longa*	7	15	0.66	989
36	Ot	*Lingula anatina*	9	20	0.43	867
37	C	*Monoculodes koreanus*	4	20	0.43	854
38	P	*Mediomastus californiensis*	6	20	0.41	825
39	M	*Moerella rutila*	7	15	0.54	815
40	M	*Acteocina exilis*	5	10	0.74	742

Table 3. The dominant species in terms of biomass selected by dominance Index (Le Bris, 1988).

Rank	Taxa	Species	Total	F_{ij}	D_{ij}	D_{ij}'
1	E	*Protankyra bidentata*	141.27	45	25.88	116476
2	E	*Amphiura sinicola*	30.25	60	14.55	87309
3	P	*Glycera chirori*	4.44	70	3.04	21305
4	M	*Bullacta exarata*	18.44	25	7.42	18546
5	M	*Mactra veneriformis*	2.54	30	5.79	17376
6	C	*Ilyoplax pingi*	4.14	40	3.87	15467
7	P	*Heteromastus filiformis*	2.34	90	0.63	5690
8	P	*Lumbrineris heteropoda*	2.91	25	2.15	5386
9	P	*Periserrula leucophryna*	1.76	20	1.36	2718
10	M	*Cycladicama cumingii*	1.28	15	1.66	2490
11	M	*Phacosoma japonicum*	168.19	5	4.73	2365
12	C	*Scopimera globosa*	1.10	5	3.96	1978
13	C	*Alpheus brevicristatus*	5.87	15	1.22	1826
14	C	*Macrophthalmus japonicus*	5.28	5	3.63	1815
15	C	*Acanthomysis* sp.	0.46	25	0.61	1533
16	Ot	*Anthopleura japonica*	23.37	5	2.80	1398
17	C	*Alpheus bisincisus*	3.71	5	2.79	1397
18	M	*Moerella rutila*	0.90	15	0.89	1330
19	P	*Leonnates nipponicus*	0.45	35	0.25	860
20	Ot	*Nemertinea* sp.1	0.41	30	0.28	839
21	C	*Haustorioides* spp.	0.56	10	0.81	811
22	P	*Marphysa sanguinea*	7.83	10	0.75	752
23	P	*Nephtys chemulpoensis*	0.17	30	0.24	728
24	M	*Cyclina sinensis*	1.59	5	1.40	698
25	C	*Hemigrapsus penicillatus*	1.04	10	0.69	694
26	P	*Nephtys californiensis*	0.33	30	0.22	673
27	Ot	*Cavernularia obesa*	14.77	5	1.22	608
28	C	*Philyra pisum*	6.32	10	0.55	551
29	C	*Leptochela gracilis*	0.29	10	0.53	529
30	P	*Nephtys polybranchia*	0.11	55	0.09	521
31	Ot	*Paracondylactis hertwigi*	2.71	5	0.98	492
32	C	*Asthenognathus inequipes*	1.12	25	0.19	467
33	C	*Macrophthalmus dilatatus*	0.41	10	0.36	360
34	P	*Magelona* sp.	0.06	65	0.05	341
35	P	*Cirrophorus furcatus*	0.05	55	0.06	316
36	P	*Diopatra bilobata*	1.96	10	0.29	289
37	C	*Camptandrium sexdentatum*	0.63	15	0.19	285
38	M	*Potamorcorbula amurensis*	0.23	5	0.56	280
39	C	*Balanus* sp.	1.70	10	0.26	265
40	P	*Ceratonereis erythraeensis*	0.14	5	0.50	252

data (Table 3). The most dominant species in terms of biomass was *P. bidentata,* followed by *Amphiura sinicola*, *G. chirori*, *B. exarata*, *M. veneriformis*, *I. pingi* and *H. filiformis*. Though *Phacosoma japonicum* exhibited the highest absolute biomass (168.19 g/0.2 m^2), the importance was underestimated because the species only occurred at station 5 in Shinbul transect. In general, the top 40 dominant species were not as different in terms of biomass, despite some rises and falls in the rankings of mollusks and echinoderms (*e.g.*, *B. exarata*, *M. veneriformis*, *P. japonicum*, *Moerella rutila* and *P. bidentata*).

Normal and inverse classification

To enhance the interpretation of the numerical classification results, normal-inverse coincidence examinations were followed (Fig. 4). Benthic macrofaunal assemblages were divided into eight station groups (1–8) and nine species groups (A–I).

Station group 1 was composed mainly of middle- and low-tidal level stations (St. 2, 3 and 4) in the Shinbul transect. The B and D species groups influenced the truncation of group 1. Station group 2 contained four out of five stations in the Tokkyo South transect (St. 1, 2, 3 and 4). The weight of species group B and C played an important role in this group formation. Station group 3 was comprised of five stations in three intertidal transects. The B and D species group largely influenced this group formation. Station group 4 was also composed of three intertidal flats (Tokkyo South, Tokkyo West, and Ulwang transects) and of the lowest stations in each transect. The species groups B, E and F densely occurred in these four stations. Finally, each of the other four stations was allocated into four unique and distinguished station groups. They include one in Shinbul, one in Tokkyo West and two in Ulwang tidal flats, and are characterized by the stations lying on the uppermost tidal elevations. Station 1 in Shinbul transect was recognized by species group H, while station

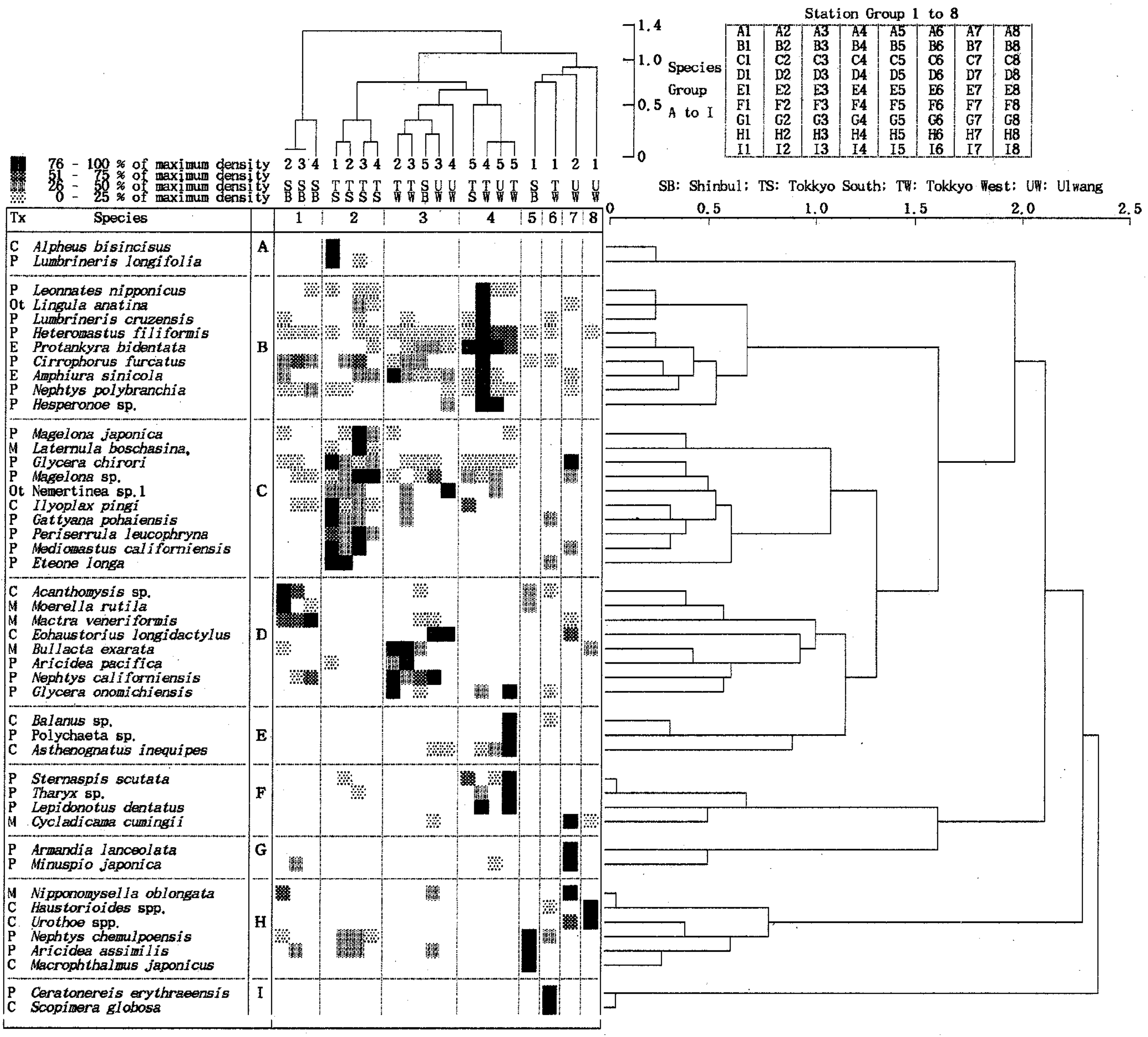

Fig. 4. The result of normal and inverse coincidence analysis.

1 in Tokkyo West was recognized by species group I. Station 1 and 2 in Ulwang tidal flat had their characteristic species group of partial H and G, respectively.

From the r-mode analysis, nine characteristic species groups were established. First, species group A was composed of two species, *Alpheus bisincisus* and *Lumbrineris longifolia*. They only occurred in two stations in group 2 and showed extremely restricted habitat ranges in this study. Group B was represented by nine species (*H. filiformis*, *P. bidentata*, *A. sinicola* and *Nephtys polybranchia*, *etc*.). They were the dominant and widely distributing species. Their peaks in abundance were found in station group 4 (note B4). Group C was also comprised of 10 dominant species (*G. chirori*, *Magelona* sp. and *I. pingi*, *etc*.). However, their distribution attributes were different from those of group B in that they usually occurred and showed peak abundances in station group 2 (note C2). Species group D is composed of eight species and their peaks in abundance occurred in station group 1 and 3 (note D1 and D3). These species are *M. rutila*, *M. veneriformis* and *B. exarata* and showed moderate distributional ranges. The other five species groups, E to I, were characterized by a species of narrow distributional ranges.

By considering the results of Q- and R-mode analyses and numerical or biomass dominance, benthic faunal assemblages were identified. The characterizing species of station group 1 were *Moerella rutila* and *M. veneriformis* (*Moerella-Mactra* community), and those of group 2 were *I. pingi*, *Glycera chirori*, *Magelona japonica*, *Magelona* sp. and *Periserrula leucophryna* (*Ilyoplax-Glycera-Magelona japonica-Magelona* sp.-*Periserrula* community). In the case of groups 3 and 4, they were characterized by the *Amphiura-Nephtys californiensis-Bullacta-Eohaustorius* and *Leonnates-Heteromastus-Protankyra-Nephtys polybranchia* community. Finally, groups 5 and 6 were *Nephtys chemulpoensis-Macrophthalmus* and *Ceratonereis-Scopimera*. Station 1 and 2 in Ulwang tidal flat appeared to have apparent and obvious characterizing species groups. They were easily recognized by the *Haustorioides-Urothoe* and *Cycladicama-Armandia-Minuspio* communities.

Faunal assemblages and the two abiotic factors

The biologically established groups were examined

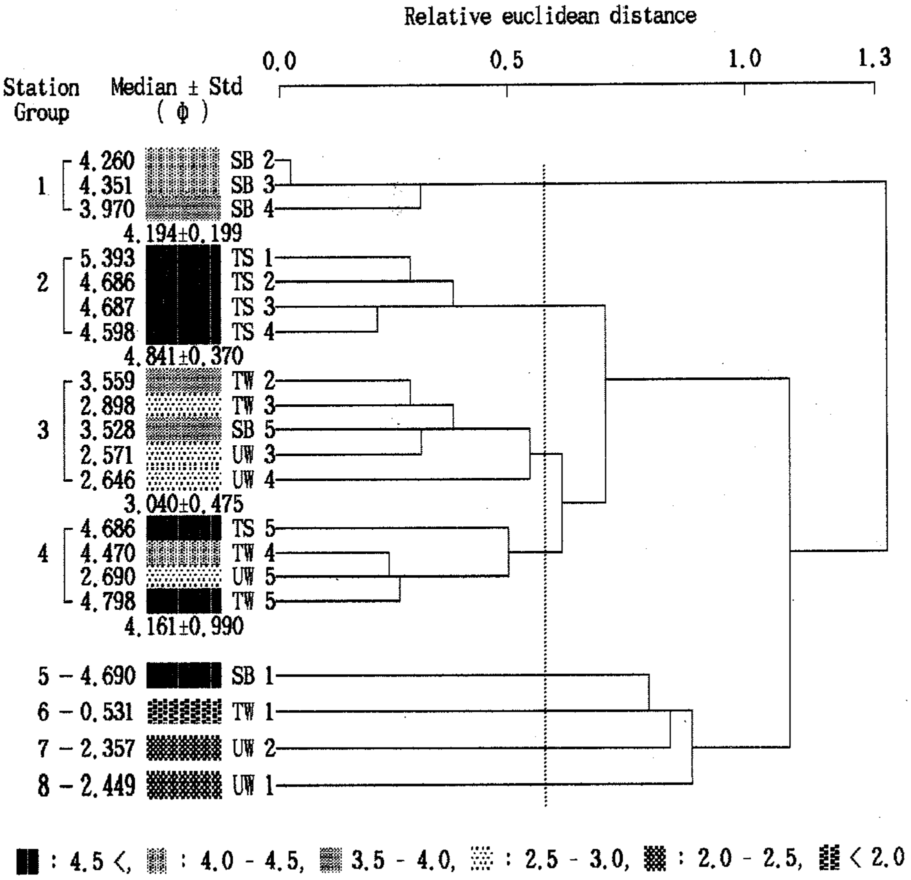

Fig. 5. Comparison of q-mode classification result and abiotic factors, median grain size and tidal elevation (sample number).

in combination with the results of sediment grain size analysis and tidal elevations (Fig. 5). Station groups 1, 2, and 3 were found to be well-distinguished by sediment types. These faunal groups had quite different mean values and narrow ranges of standard deviation in median grain size ($4.194 \pm 0.199\ \phi$, $4.841 \pm 0.370\ \phi$, and $3.040 \pm 0.475\ \phi$). Group 4 was composed of unlike sediments, but of low-level stations. Groups 5, 6, 7 and 8 were uppermost stations and conspicuously differed in sediment types.

DISCUSSION

Variation ranges of macrofaunal species number in tidal flats around the study area

The area studied in Yongjong and Yongyu Islands covers representative types of tidal flats in the central West Coast of Korea. The average numbers of the taxa per 0.2 m^2 in four different tidal flats were 14 (±4) in Shinbul, 18 (±4) in Tokkyo South, 19 (±5) in Tokkyo West and 14 (±5) in the Ulwang area. In the nearby Chokchon macrotidal flat, Seo (1994) found, as a result of a 2-year study from 1990 to 1992, that species figures per 1 m^2 varied with tidal elevations. The numbers ranged from 19 to 32 in the upper elevation (mean species number, $25 \pm 5/m^2$), and from 32 to 42 in the lower elevation ($38 \pm 3/m^2$). Another study done in November 1994 and 1995 on the Chokchon tidal flat showed that the species number/0.2 m^2 ranged from 10 to 39 (Hong *et al.*, in preparation). However, the nearby Panwol tidal mud flat showed less rich species according to Koh and Shin (1988) because the total number of species was only 26 in a total sampled area of 30 m^2 from the three transects. This extremely underestimated low number of species was incomparable with the other data due to the differences in collection method and probably in the identification of the species present. Overall, the valid mean number of species/0.2 m^2 around the study area may range between 5–30 (approximate confidence level of 95%). The number $/m^2$ may reach up to 50 around these areas, although it varies depending on the sediment type and tidal elevation.

Species richness and biomass on a tidal flat

The result of ANOVA and non-parametric tests could be summarized as follows: (1) difference of species numbers among and within tidal flats and (2) seaward increase of biomass. As previously described, some data were omitted due to their fundamental difference in spatial patterns so robust generalization seemed impossible. The interpretation was based on the assumption that both tidal elevation and substratum effects are major factors that govern macrofaunal communities.

Tidal elevation would not be responsible for the difference in species number among tidal flats because (1) tidal ranges are just the same and (2) significant differences in sediment grain size among tidal flats were instead observed in this study. Hence, the variation may be linked to substratum properties. If sediment characteristics are effective in variation among transects, it can be naturally related to variation within a transect. Similar variation in species numbers is often explained by substratum properties (Rakocinski *et al.*, 1993) while Beukema (1976) observed higher species numbers in intermediate bottom types. The area that was examined exhibited extreme sediment types (gravelly sand or silt bottom) at the uppermost elevation and mixed types at lower elevation.

Because quantitative analysis was not carried out, it was impossible to judge whether the seaward increase in biomass is an identical response to that of the species number or not. We programmed further analysis on this and other problems (*e.g.*, omission of some data in testing species number variation) in another paper. In general, the spatial pattern of biomass found in this study may be related to either physiological stress or food availability (Peterson, 1991; Peterson and Black, 1991). However, Beukema (1976) connected this even to biotic factor (*e.g.*, species number). As matters stand now, a conclusive description seemed not advisable.

Ecological characteristics of some dominant species and communities of tidal flats in Yongjong and Yongyu Islands

Conspicuous zonations of benthic organisms were revealed by Frey *et al.* (1987a) in the Chokchon macrotidal flat in Inchon, Korea. The three zones coincided well with sediment textures and included: (1) the Brachyuran zone, a landward sandy mud flat characterized ecologically by the crabs *Ilyoplax pingi* and *Macrophthalmus japonicus*; (2) the Molluscan zone, a mid-flat of sandy clayey silt typified mainly by the bivalve, *Solen strictus*, and the gastropod, *Umbonium thomasi*; and (3) the Holothurian zone, a seaward flat of sandy silt to silty sand characterized primarily by the holothurian, *Protankyra bidentata*.

Several benthic faunal communities were recognized from this study. Among them, the *Moerella-Mactra* community (Group 1) was observed in the Shinbul tidal flats. The distribution of this community is more or less correlated with sediment grain size on a tidal flat. Their sedimentary habitats showed narrow variations in grain size (4.194 ± 0.199 ϕ in this study; *ca.* 4.0 ~4.3 ϕ in the molluscan zone of Frey *et al.* (1989)). The general characteristics were similar to those of the molluscan zone in the Chokchon tidal flats, and these may be regarded as a substratum-specific community.

The *Leonnates-Heteromastus-Protankyra-Nephtys polybranchia* community (Group 4) resembled the benthic community of the holothurian zone of Frey *et al.* (1987b). Although the associated animals of the holothurian zone were somewhat different from those of the present community, they commonly possessed the best diagnostic synaptid holothurian, *Protankyra bidentata*. As a main cause of biological disturbance by reworking the bottom substrates, this species remains the most important in the lower tidal flat of Chokchon (Frey *et al.*, 1987a; 1989). While this bioturbator limits and regulates the abundance and distribution of certain sedentary species which need stable substrates, *P. bidentata* effects a positive interaction by providing three-dimensional microhabitats. This promotes the presence of smaller invertebrates, which are otherwise absent, and finally influences community structure and species composition. Group 4 included mainly the stations in lower elevations (station 5 in Tokkyo South, 4 and 5 in Tokkyo West and 5 in Ulwang tidal flats). *P. bidentata* occurred on a wider range of bottom types, but the species were generally confined to lower elevations. This community seemed to be sensitively affected by tidal elevation, and thus may be considered as a low elevation-specific community.

A unique station, characterized by two dogielinotid amphipods, *Haustorioides* spp. (recently confirmed as being composed of two different species, *H. koreanus* and *H. indivisus*)-urothoids *Urothoe* spp., was found in the uppermost tidal flat of the Ulwang transect. The sediment was consisted mainly of sand (more than 90%). It is well known that on many temperate shores, talitrid amphipods are commonly found in the upper zones of sandy beaches. The oedicerotid and haustoriid amphipods, on the other hand, dominate the middle flat of sandy beaches (Croker, 1967; Holland and Polgar, 1976; Brown and McLachlan, 1990). It is interesting to note that the two sand-burrowing dogielinotids indicated above were described as species new to Korean waters (Jo, 1988). They are known to possess combined taxonomical characters of the Talitroidea and Phoxocephalidae-Haustoriidae (Barnard, 1969).

Here, two questions have arisen. First, do the *Haustorioides* spp.-*Urothoe* spp. community replace and occupy niches of talitrid or haustoriid amphipod communities usually found in the upper and mid tidal flats? Secondly, is there a niche separation between these species as shown in the haustoriid community in Croker (1967) and Holland and Polgar (1976)? Therefore, further research on these intriguing subjects is needed.

Substratum properties and tidal elevations influenced the resultant eight communities. Through a combination of these factors, the different communities were formed in this low-energy macrotidal regime. Groups 1, 2 and 3 seemed to be substratum-specific communities and Group 4 seemed to be an elevation-specific community. In the other four groups, it was difficult to divide the predominant governing agent due to their presence in extreme sedimentary habitats at uppermost elevations. It was unlikely that same types of sediment in lower elevations would hold similar suites of species. On the other hand, if the effect of tidal elevation solely affected the faunas, those four unique assemblages would not be produced. It seemed valid that mixed effect of the two factors acted upon the comminities.

Based solely on the samples, 60% of target samples was governed by substratum properties, 20% by tidal elevation effect and 20% by mixed effects. From this, sediment grain size had a fundamental influence on soft bottom inhabitants in the area studied. Consequently, prudent concerns have to center on current coastal developments and accompanying environmental perturbations that inevitably cause drastic and invariable changes in the sedimentary environment.

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REFERENCES

Barnard, J. L., 1969. The Families and Genera of Marine Gammaridean Amphipoda. Smithsonian Institution Press, Washington D.C., 535 pp.

Bartlett, M. S., 1937. Some examples of statistical methods of research in agriculture and applied biology. *J. Royal Stat. Soc. Suppl.*, **4**: 137 – 170.

Beukema, J. J., 1974. Seasonal changes in the biomass of the macrobenthos of a tidal flat area in the Dutch Wadden Sea. *Neth. J. Sea Res.*, **8**: 94 – 107.

Beukema, J. J., 1976. Biomass and species richness of the macrobenthic animals living on the tidal flats of the Dutch Wadden Sea. *Neth. J. Sea Res.*, **10**: 236 – 261.

Beukema, J. J., 1989. Long-term changes in macrozoobenthic abundance on the tidal flats of the western part of the Dutch Wadden Sea. *Helgoländer Meeresunters*, **43**: 405 – 415.

Beukema, J. J., G. C. Cadée and H. Hummel, 1983. Differential variability in time and space of numbers in suspension and deposit feeding benthic species in a tidal flat area. *Oceanologica Acta*, Special Issue, Proc. 17th European *Man. Biol. Symp.*: 21 – 26.

Brown, A. C. and A. McLachlan, 1990. Ecology of Sandy Shores. Elsevier Science Publishers B.V., Amsterdam, 328 pp.

Cochran, W. G., 1941. The distribution of the largest of a set of estimated variances as a fraction of their total. *Annals of Eugenics*, **11**: 47 – 52.

Croker, R. A., 1967. Niche diversity in five sympatric species of intertidal amphipods (Crustacea: Haustoriidae). *Ecol. Monogr.*, **37**: 173 – 199.

Folk, R. L., 1968. Petrology of Sedimentary Rocks. Hamphill's, Austin, Texas, 170 pp.

Folk, R. L. and W. C. Ward, 1957. Brazos River bar: A study in the significance of grain-size parameters. *J. Sed. Pet.*, **27**: 3 – 27.

Frey, R. W., J. D., Howard, and J. S. Hong, 1987a. Prevalent lebesspuren on a modern macrotidal flat, Inchon, Korea: Ethological and environmental significance. *PALAIOS*, **2**: 517 – 593.

Frey, R. W., J. D., Howard, S. J. Han and B. K., Park, 1989. Sediment and sedimentary sequences on a modern macrotidal flat, Inchon, Korea. *J. Sed. Pet.*, **2**: 517 – 593.

Frey, R. W., J. S., Hong, J. D. Howard, B. K., Park and S. J. Han, 1987b. Zonation of benthos on a macrotidal flat, Inchon, Korea. *Senckenbergiana marit.*, **19**: 295 – 329.

Holland, A. F. and T. T. Polgar, 1976. Seasonal changes in the structure of an intertidal community. *Mar. Biol.*, **37**: 341 – 348.

Jo, Y. W., 1988. Taxonomic studies on Dogielinotidae (Crustacea, Amphipoda) from the Korean coasts. *Bijdragen tot de Dierkunde*, **58**: 25 – 46.

Koh, C. H. and H. C. Shin, 1988. Environmental characteristics and distribution of macrobenthos in a mudflat of the West Coast of Korea (Yellow Sea). *Neth. J. Sea Res.*, **22**: 279 – 290.

Lance, G. N. and W. T. Williams, 1967. A general theory for classificatory sorting strategies. 1. Hierarchical systems. *Computer Journal*, **9**: 373 – 380.

Le Bris, H., 1988. Fonctionnement des écosystèmes benthiques côtiers au contact d'estuaire: la rade de Lorient et la baie de Vilaine. Thèse de Doctorat, Université de Bretagne Occidentale, Brest, France, 311 pp.

Ludwig, J. A. and J. F. Reynolds, 1988. Statistical Ecology: A Primer on Methods and Computing. John Wiley and Sons, Inc., New York, 337 pp.

McLachlan, A., A. C. Cockcroft and D. E. Malan, 1984. Benthic faunal response to a high energy gradient. *Mar. Ecol. Prog. Ser.*, **16**: 51 – 63.

Park, H. S., 1991. An Ecological Study of the Macrobenthos on a Macrotidal Flat, Inchon, Korea. MS thesis, Inha University, 124 pp. (in Korean with English summary).

Peterson, C. H., 1991. Intertidal zonation of marine invertebrates in sand and mud. *Am. Sci.*, **79**: 236 – 249.

Peterson, C. H. and R. Black, 1991. Preliminary evidence for progressive sestonic food depletion in incoming tide over a broad tidal sand flat. *Est. Coast. Shelf Sci.*, **32**: 405 – 413.

Rakocinski, C. F., R. W. Heard, S. E. Lecroy, J. A. McLelland and T. Simons, 1993. Seaward change and zonation of the sandy-shore macrofauna at Perdido Key, Florida, U.S.A. *Est. Coast. Shelf Sci.*, **36**: 81 – 104.

Reise, K., 1985. Tidal Flat Ecology-An Experimental Approach to Species Interaction. Springer-Verlag, Berlin, 191 pp.

Seo, I. S., 1994. The Community Structure and Distribution Patterns of the Benthic Macrofauna in Chokchon Tidal Mudflats, Inchon. MS thesis, Inha University, 103 pp. (in Korean with Engli-sh summary)

Shin, H. C., J. W. Choi and C.H. Koh, 1989. Faunal assemblages of benthic macrofauna in the inter- and subtidal region of the inner Kyeonggi Bay, West Coast of Korea. *J. Oceanol. Soc. Korea*, **24**: 184 – 193.

Sneath, P. H. A. and R. R. Sokal, 1973. Numerical Taxonomy -The Principles and Practice of Numerical Classification. W.H. Freeman and Company, San Francisco, California, 573 pp.

Tamaki, A. and T. Kikuchi, 1983. Spatial arrangement of macrobenthic assemblages on an intertidal sand flat, Tomioka Bay, West Kyushu. *Publ. Amakusa Mar. Biol. Lab.*, **7**: 41 – 60.

Wentworth, C. K., 1922. A scale of grade and class for clastic sediments. *J. Geol.*, **30**: 377 – 392.

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