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Salinity and Sediment Types as Sources of Variability in the Distribution of the Benthic Macrofauna in Han Estuary and Kyonggi Bay, Korea

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The distribution patterns of the benthic macrofauna of Han Estuary and Kyonggi Bay and the controlling environmental factors were studied at twenty-five stations in spring and fall of 1989. As a result, four biological groups were established as follows : *Crassostrea gigas-Balanus reticulatus* (Group I), *Heteromastus filiformis-Mediomastus californiensis-Lumbrineris* spp. -*Sternaspis scutata-Tharyx* sp. 1-*Diopatra bilobata* (Group II-A), Haustoriids-Phoxocephalids-*Moerella rutila* (Group II-B) and *Nephtys chemulpoensis* (Group II-C in March) and indistinctive group which was composed of common species (II-C in September). Results of the habitat analysis revealed that most of the dominant species showed narrow ranges of habitat niche in March and relatively wide ranges in September. Based on multiple discriminant analysis, the critical environmental factors governing their distributions are salinity in the regions of Yomha and Sokmo Channel in Han Estuary and sediment types in Kyonggi Bay. Also, sediment instability during the rainy season due to run-off was assumed to play a major role in the species composition of the benthic communities and their distribution in the study area.

INTRODUCTION

Han River is one of the five major rivers in Korea, and is located in the midwest portion of the Korean Peninsula. Fifteen million people inhabit the area around the river drainage basin. In 1982 to 1986, the government launched a development program for Han River to restore the proper function, and maximize the effective use of the river. In spite of such a development program, a recent study by Jang (1989) has shown that the sedimentary environments of Han River have changed and altered the natural estuarine ecosystem. Consequently, it was expected that the ecosystems down river in the Han Estuary and in Kyonggi Bay would be affected by changes in sediment flux and anthropogenic inputs experienced upriver.

Until recently, little work on benthic macrofauna has been conducted in this area (Shin *et al.*, 1989; Yoo and Hong, 1996), because the upper part of the study area is designated as demilitarized zone where people cannot get in due to the national security. Shin *et al.* (1989) conducted a 2-year study on the distribution pattern of benthic macrofauna in part of Kyonggi Bay. They defined four biotic types, two at the intertidal and two at subtidal areas based on the composition of benthic communities. Other estuaries in Korea, such as Naktong Estuary (Bae and Yoon, 1988, 1989a, 1989b; Yoon and Bae, 1984; Yoon *et al.*, 1987; Kim *et al.*, 1982) and Keum Estuary (Kim *et al.*, 1985), have also been described in terms of benthic ecology.

This study on the seasonal and spatial distributions of benthic organisms was undertaken to examine the environmental variables that are critical to benthic community structure. This baseline information will be of importance now to detect macrofaunal changes in relation to environmental disturbance in this area in the future.

MATERIALS AND METHODS

Field sampling

Kyonggi Bay is located on the western part of Korea and is mostly composed of extensive tidal flats and subtidal channel regions. Twenty-five stations were established within Han Estuary and part

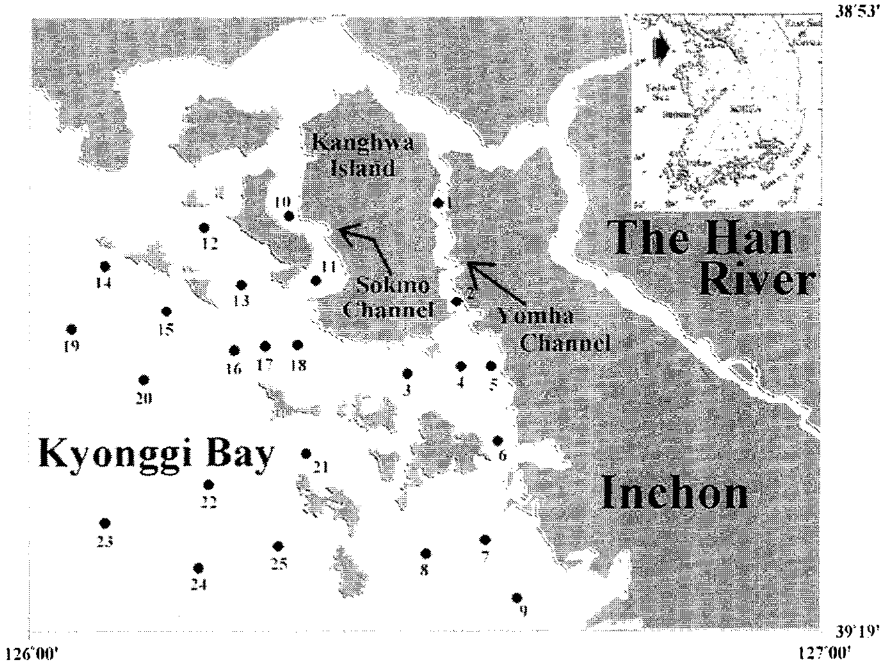

Fig. 1. Location of benthic sampling sites in the Han Estuary and Kyonggi Bay, Korea.

of Kyonggi Bay based on their geographical characteristics (Fig. 1). Samples were collected in March and September of 1989, using a rectangular dredge (Type Charcot, 17×32 cm). The collecting part of dredge is made of durable fabrics with no mesh. Sediments are filled up to approximately 40 *l* and at each station one haul was tried. The samples were washed through a 1.0 mm mesh screen. All animals retained on the screen were collected, sorted, identified to species level whenever possible and preserved in 10% formalin. Animals were counted under a dissecting stereomicroscope. Sediment samples for grain size analysis were also collected at each station. Surface and bottom temperature and salinity were determined using a portable T-S Bridge. Methods and results of grain size analysis and other environmental characteristics are reported and discussed in Yoo and Hong (1996).

Statistical analysis

The measure of community similarity between stations and between species was determined with the relative euclidean distance (Orloci, 1978). Transformed species counts (log (x+1)) were used in numerical classifications to reduce the discrepancies between high and low values (Boesch, 1977; Orloci, 1978). Species with less than 5 individuals were considered as rare species and not included in the cluster analysis. Linkage method used in agglomerative hierarchical cluster analysis was flexible strategy with β=-0.25 (Lance and Williams, 1967; Sneath and Sokal, 1973).

Principal component analysis was used to understand the inter-stationary difference on the basis of environmental factors (*e.g.*, depth, sediment properties, bottom temperature and bottom salinity), and the distribution patterns of dominant species. Habitat analysis was made to determine the critical variables and their seasonal differences in physical environments. The purpose of this analysis is to examine the distributional patterns of dominant species in the physical space, to relate the variations of distributional patterns to those of habitat characteristics. Canonical discriminant analysis was also performed to identify important environmental factors among groups which had been established on the basis of similarities, and the significance of

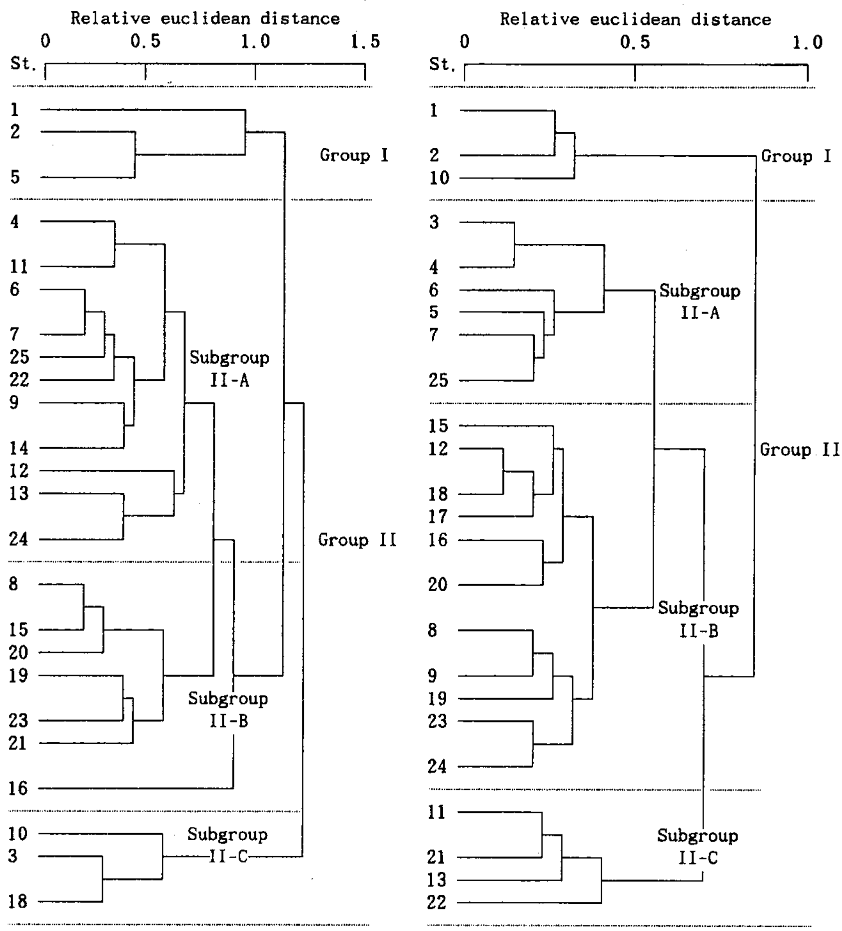

Fig. 2. Biologically truncated 4 groups in March(left) and September(right).

canonical discriminant functions were tested by Likelihood Ratio (SAS, 1987; Cassie, 1972).

RESULTS

Normal classification (Q-mode analysis)

Characterization of the study area was initially done by comparing the species composition among stations. During the separation, there was some tendency of misclassification for Station 16 in March. Hence, the visual inspection of data matrix was made and Station 16 was reallocated into Group II-B (Fig. 2).

Group stations between two sampling periods had similar species composition with the exception of Group II-C. Stations 1, 2 and 5 composed Group I located at Yomha Channel in spring and in fall, Stations 1, 2, 10 were located in the Yomha and Sokmo Channels. Affinity of these three stations were highly influenced by the hard bottom-attached animals, *Balanus reticulatus* and *Crassostrea gigas* which in March and September accounted for 73.1% and 61.5% of their groups total abundance, respectively. However, the relative importance of two mobile and sensitive gammaridean amphipods, *Corophium* sp. and *Nippopisella nagatai*, should be noted also.

A truncation of Group II-A is due to the abundance of the co-occurring mud and sand-mixed bottom-dwelling polychaetes: *Heteromastus filiformis, Mediomastus californiensis, Lumbrineris* spp., *Sternaspis scutata, Tharyx* sp. 1, and *Diopatra bilobata*, which in March accounted for 36.8%, but in September 38.3% of their group abundance. Group II-A is composed of 11 stations which are located on the extended parts of each channel in March, whereas in September only six stations are included in this faunal delimitation. As shown in environmental interpretations(Yoo and Hong, 1996), sedimentary facies displayed distinct seasonal variations and their changes are the major cause of reduction of Group II-A. In March, these stations which were muddier became sandier in September.

In contrast, the local faunal range of distribution of Group II-B showed reverse pattern. It is commonly composed of mobile sand-burrowing amphipods, haustoriids and phoxocephalids, and the tellinid bivalve, *Moerella rutila*, which accounted for 37.9% of the group abundance in March, and 30.6% in September. However, Group II-B had more stations (11 stations) in September which included the inner and extension parts of Kyonggi Bay.

Group II-C had rather a different species composition between the two sampling seasons. In March, most stations were characterized by *Nephtys chemulpoensis* comprising 50.5% of the group's total abundance. In September, the stations of this subgroup changed to be mainly composed of indistinct and common species of *Glycera chirori* and a Mysid sp., which also occurred in other areas.

Inverse classification (R-mode analysis)

Inverse classification was performed for the two seasonal collections to come up with characteristic species groups. Of the 185 species collected in March and 189 in September, 91 and 76 species, respectively, were included in the r-mode analysis. The results are summarized in Table 1 and 2. The faunal groups were clustered amongst the species with similar distributional patterns.

In March, Group I is comprised of the species occurring in Station 7 and 25 and they have narrow distributional ranges and mainly occurred on mud-dominant mixed bottoms. Group II involved intertidal species found in stations with depth of less than 1 m and silty substrate (Station 3 and 4). Species in Group III (Stations 5 and 22) generally had low faunal abundance (<10 individuals) and occurred on sand-dominant mixed bottoms. Group IV (Station 9) was composed of the species having high abundances on sand-dominant mixed bottoms. They occurred in Stations 8, 9, 19 and 22, and occupied the southern part of Kyonggi Bay. Species of Group V also occurred at the lower part of Kyonggi Bay. This area is characterized by mud or mud-dominant mixed bottom (Station 5, 6, 7, 14, 19, and 25). Group VII were mostly abundant and ubiquitous species. Here, the group may be divided into three distinct sub-groups. Subgroup VII-1 are mainly composed of sand bottom dwellers and restricted to the outer part of Kyonggi Bay. Species in Subgroup VII-2 are characterized by wide ranges of distribution (Station 5, 6, 9, 10, 11, 12, 14, 16, 19, 22 and 25) but were more common in Station 6, 19 and 22. The species can be found from the lower salinity regime (estuary) to the outer part of the bay (more saline). Although their peak abundance appeared on silt substratum, they were found to occur in silt to sand-dominant mixed bottom. In Subgroup VII-3, four species were occurring in sand-dominant mixed to sand bottom with low abundance and relatively common in Station 20. Distribution of Group VIII species were restricted to Yomha Channel. Among this group, *Nereis heterocirrata* is known to be associated with oyster beds (Wu *et al.*, 1985).

In September, the species from Group I mainly occurred on mixed sandy bottoms in Kyonggi Bay (Station 6, 18 and 19). The members of Group II are commonly found on sandy bottom (Station 10). Species of Group III frequently occurred on mixed facies in Stations 5, 6, 7, 8 and 25. Species in Group IV were largely restricted to Stations 1 and 5. As previously noted, *Balanus reticulatus* occurred in lower salinity regime and densely populated Station 5. Other species showed similar distributional patterns and occurred from mud to sand-dominant mixed bottoms. Group V species were limited to the shallower stations and referred to as intertidal species. *Magelona japonica* and *Macrophthalmus japonicus* have been reported as frequent and a-

Table 1. Species groups defined from the result of r-mode analysis in March, 1989

Group I.	Group VII-1.
Anthopleura sp.	*Moerella rutiala*
Modiolus elongatus	Phoxocephalids
Sthenelais fusca	Haustoriids
Bivalvia sp. VI	*Nephtys californiensis*
Holothuroidea sp. 1	*Philline argentata*
Terebellides sp.	*Varicinassa varicifera*
Holothuroidea sp. 2	*Diogenes nitidimanus*
Xenophthalmus pinnotheroides	Fish larvae. 1
	Oedicerotids
Group II.	Mysid sp. (unid)
Macrophthalmus japonicus	*Sthenolepis yhleni*
Decorifer insignis	
Stenothyra glabra	Group VII-2
	Anaitides kreana
Group III.	*Glycera chirori*
Heterospionidae sp.	*Nephtys chemulpoensis*
Protankyra bidentata	*Mediomastus californiensis*
Bryozoan colony. 1	*Lumbrineris* spp.
Nemertinea sp. 3	*Glycinde gurjanovae*
	Prionospio paradisea
Group IV.	*Magelona japonica*
Ogyrides orientalis	Nemertinea sp. 2
Phacosoma japonicus	*Scoloplos armiger*
Mactra chinensis	Nemertinea sp. 1
Aglaophamus sinensis	
	Group VII-3
Group V.	*Ophiura kinbergi*
Amphioplus megapomus	*Pinnotheres* cf. *tsingtaoensis*
Anthozoa sp. 1	Arminid opisthobranch?
Melita co. *longiddactyla*	*Anaitides chinensis*
Glycera oomichiensis	
Ophiactis sp. 1	Group VIII.
Eucrate crenata	*Crassostrea gigas*
Neodorippe japonica	*Balanus reticulatus*
	Marphysa sanguinea
Group VI.	*Lygdamis giardi*
Sternapsis scutatua	*Nereis heterocirrata*
Heteromastus filiformis	*Chone teres*
Notomastus sp.	Porifera sp.
Tharyx sp. 1	*Euchone alicaudata*
Cirolana japonensis	*Nippopisella nagatai*
Anthuridae sp.	Gammaridae sp.
Diopatra bilobata	Sipunculida sp.
Ampelisca sp.	*Corophium* sp.
Typhlocarcinops canaliculata	*Ruditapes philippinarum*
Loimia medusa	*Nephtys polybranchia*
Cycladicama cumingii	Sphaeromidae sp.
Dosinia gibba	
Lysilla sp. 1	
Lysilla sp. 2	
Paralacydonia paradoxa	
Nectoneanthes oxypoda	
Lepidasthenia ocellata	
Virgularia juncea	
Amphicteis gunneri	
Haplosydnopsis pilosa	
Praxillella affinis	
Pherusa plumosa	
Ampharete sp.	
Amphiura vadicola	

Table 2. Species groups defined from the result of r-mode analysis in September, 1989

Group I.	Group VII.
Cycladicama cumingii	*Crassostrea gigas*
Jassa falcata	*Corophium* sp.
Phacosoma japonicus	*Melita* cf. *longidactyla*
Sthenolepis japonica	Photidae sp. 1
	Palaemon serrifer
Group II.	Sphaeromidae sp.
Lygdamis giardi	*Alpheus* sp.
Modious elongatus	
Gammaridae sp.	Group VIII-1.
Pinnotheres cf. *tsingtaoensis*	*Ogyrides orientalis*
Sipunculida sp.	Haustoriids
	Phoxocephalids
Group III.	*Glycinde gurjanovae*
Comanthus japonica	*Varicinassa varicifera*
Cirriformia tentaculata	*Aglaophamus* sp.
Ampharete sp.	*Anaitides koreana*
Euchone alicaudata	
Latreute planirostris	Group VIII-2.
Pisidia serratifrons	*Glycera chirori*
	Moerella rutila
Group IV.	Nemertinea sp. 2
Balanus reticulatus	Mysid sp. (unid)
Tharyx sp. 1	*Prionospio paradisea*
Mediomastus californiensis	*Lumbrineris* spp.
Heteromastus filiformis	*Neptys californiensis*
Gycera onomichiensis	*Amphioplus megapomus*
Anthozoa sp. 5	Oedicerotids
Amphicteis gunneri	*Paralacydonia paradoxa*
Chone teres	*Leptochela gracilis*
	Pennatulacea sp. 2
Group V.	
Magelona japonica	Group VIII-3.
Neptys chemulpoensis	*Sternapsis scutata*
Macropthalmus japonicus	*Diopatra bilobata*
Prionospio japonica	*Ophiura kinbergi*
	Anthozoa sp. 2
Group VI.	*Typhlocarcinops canaliculata*
Scoloplos armiger	
Ericthonius sp.	
Echinoidea juv.	
Nephtys polybranchia	
Owenia fusiformis	
Terebella ehrenbergi	
Cultrensis attenuatus	
Nematoda sp.	
Ascorphynchus ramipes	
Photis longicaudata	
Aglaophamus sinensis	
Photis sp. 2	

bundant in nearby Chokchon tidal flats (Park, 1991). Group VI species were frequently found at Stations 3, 4, 8 and 9. They were present in sand-dominant, mixed to slightly gravelly-sand facies but were relatively low in abundance (<10 individuals). The

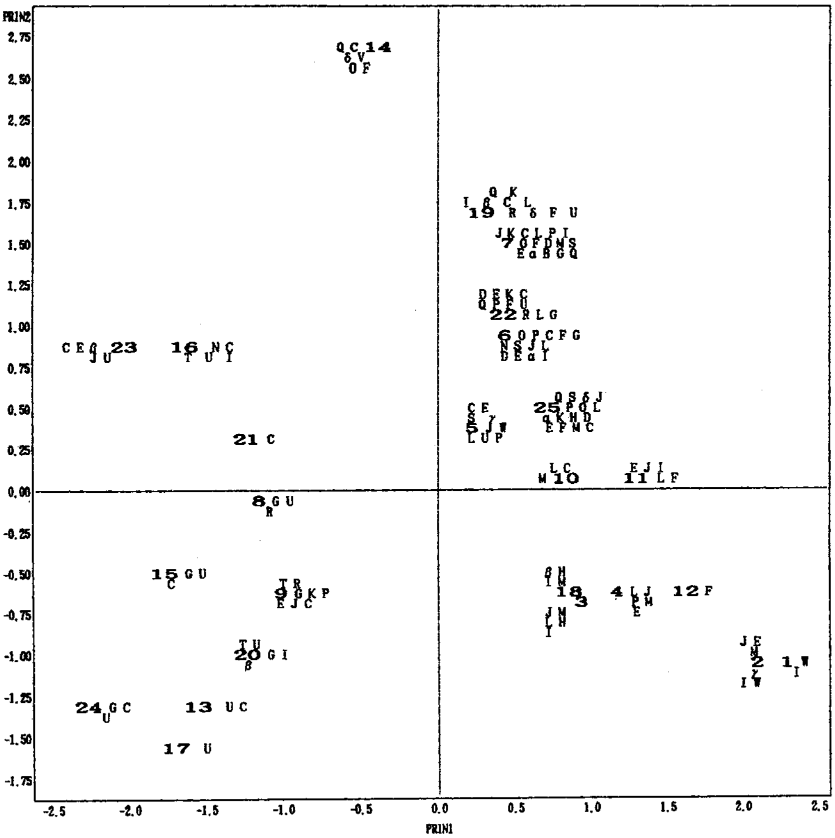

Fig. 3. The distributional patterns of dominant species on the first two principal components of the environmental factors in March, 1989.

※Note that
Scoloplos armiger (A) *Anthopleura* sp. (B) *Glycera chirori* (C) *Sternaspis scutata* (D)
Heteromastus filiformise (E) *Anaitides koreana* (F) *Nephtys californiensis* (G) *Magelona Japonica* (H)
Glycinde gurjanovae (I) *Mediomastus californiensis* (J) *Notomastus* sp (K) *Lumbrineris* sp. (L)
Nephtys chemulpoensis (M) *Prionospio paradisea* (N) *Diopatra sugokai* (O) *Tharyx* sp. A (P)
Cirolana japonensis (Q) *Ogyrides orientalis* (R) Anthurid sp. (S) Haustoriids (T)
Phoxocephalids (U) *Melita cf. longidactyla* (V) *Balanus reticulatus* (W) Oedicerotids (X)
Mysid sp. (Y) *Comanthus japonica* (Z) *Corophium* sp. (*) *Cycladicama cumingii* (α)
Moerella rutila (β) *Crassostrea gigas* (γ) *Amphioplus megapomus* (δ).

species of Group VII were highly abundant and restricted to the channel areas. Group VIII species were dominant in the study area. Similarly to the result in March, Group VIII species were subdivided into three sub-groups which were considerably different in their distributional attributes. The species in Subgroup VIII-1 were mainly found on sandy bottom. In comparison with data collected in March, their range of distribution increased correspondingly with the expansion of the sandy bottom. The Subgroup VIII-2 species had high abundances and wider range of distribution than those of Subgroup VIII-1, and occurred in various habitats. Subgroup VIII-3 species were abundant on the mixed sandy bottom.

Results of r-mode analysis seemed to be affected by their distributional ranges and population sizes. Consequently, it was found that the similarity between two seasonal group clusters is established in estuarine species group (Group VIII in March and VII in September) and in widely distributed dominant species such as that of Group VII in

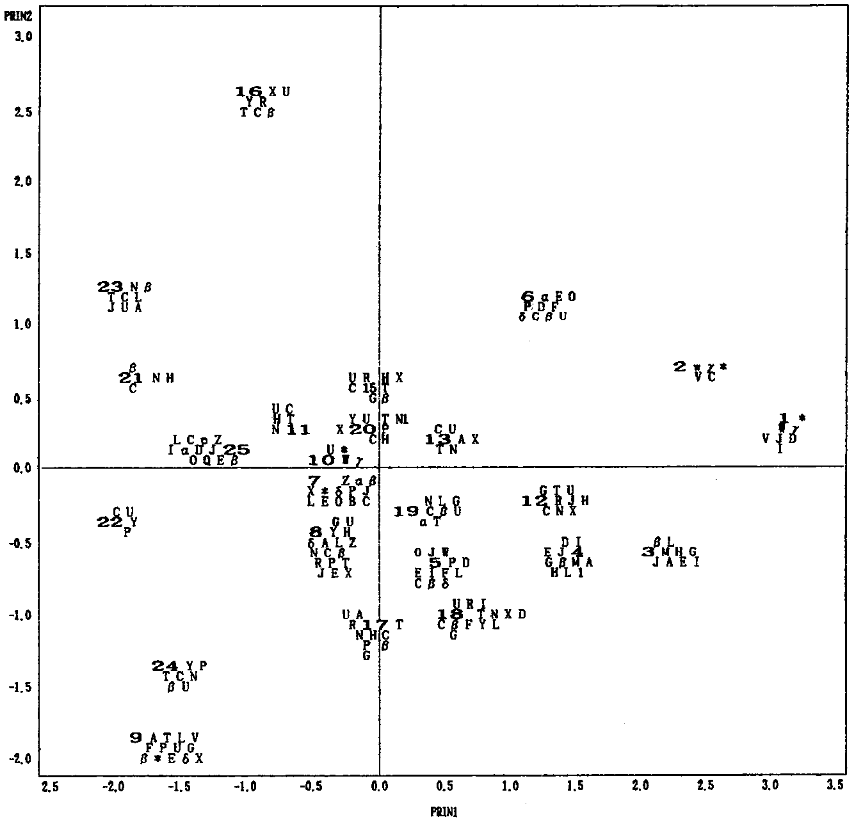

Fig. 4. The distributional patterns of dominant species on the first two principal components of the environmental factors in September, 1989.

March and VIII in September.

Habitat characterization

In March, extreme positives on Component 1 are composed of mud facies and poorly-sorted stations around the channel area. Intermediate positives are of mixed facies and extreme negatives of sand facies and located on the outer part of Kyonggi Bay (Fig. 3). In September, the patterns of compositional properties of loading coefficients were similar to those in March. Principal component analysis showed that habitats characterized by mud facies and low salinities are found on the positive part, while habitats with sand dominant mixed-facies are plotted in the middle part. The habitats with approximately more than 90% of sand contents on the outer part of Kyonggi Bay are found on the negative part along component 1 (Fig. 4). In both seasons, the shapes of plotting patterns are determined by depth which is positively and heavily loaded in Component 2.

The distributional patterns of dominant species are also shown in Fig. 3 and 4. They showed that more species were occurring on mixed bottoms and few of the species were found either on sandy or muddy environments. Habitats occupied by the same species are marked by a symbol to interpret simple habitat niche of the species based on physical and environmental data (Fig. 5, 6). First, *Glycera chirori*, *Glycinde gurjanovae* and two capitellids, *Heteromastus filiformis* and *Mediomastus californiensis* were found in most of the habitats, and could be regarded as common species of relatively wide niches in Kyonggi Bay and Han Estuary (Fig. 5, (a)-(d)). On the other hand, *Nephtys californiensis* was found to inhabit sand to mixed facies habitats while *Anai-*

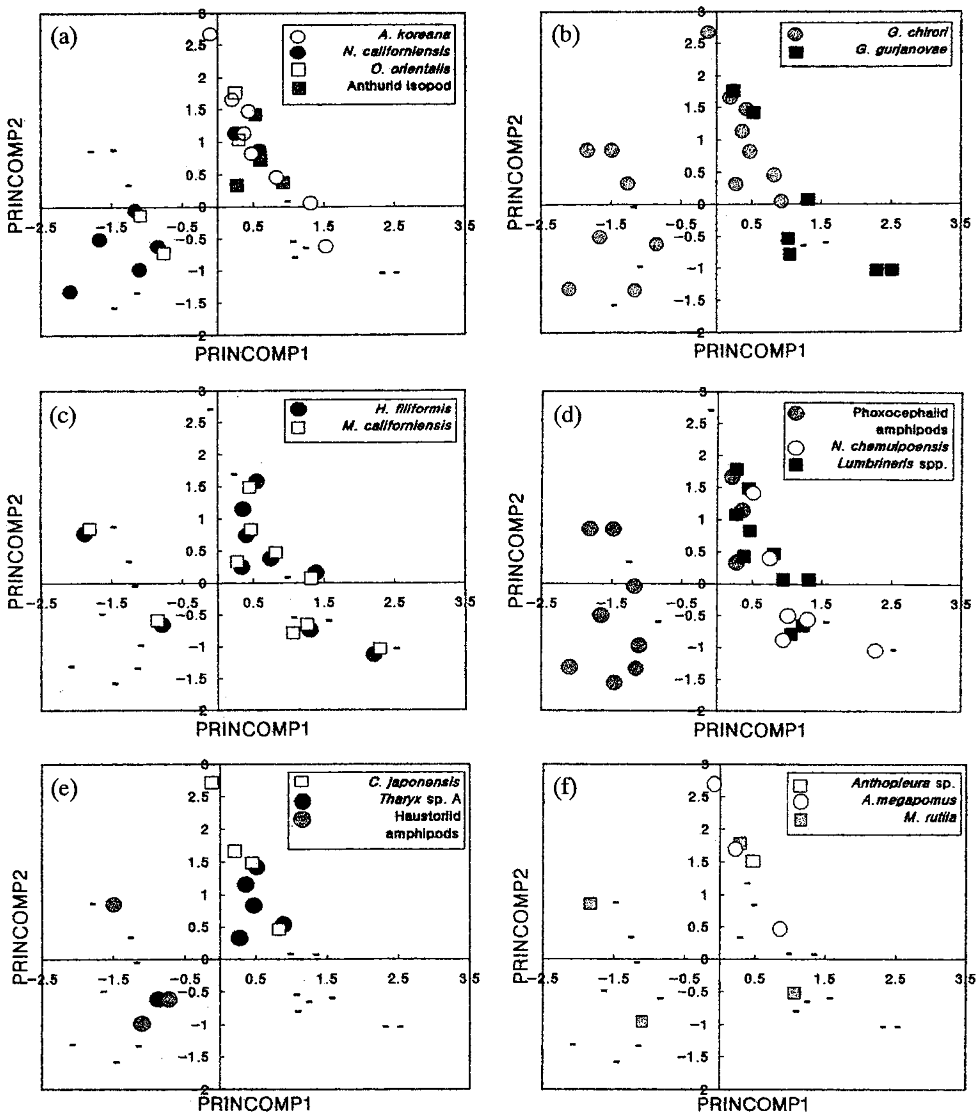

Fig. 5. Occurrence patterns of dominannt species in Kyonggi Bay((a)-(f) in March, 1989).

tides koreana occurred mainly on mud and mixed bottom with minimum abundance at silt and slightly gravel-sandy mud. The maximum abundance of *A. koreana* was observed at Station 19 with sandy silt bottom type (Fig. 5, (a)). Based on the results above, the distributions of the dominant species in both seasons seemed to have been primarily limited by sediment characteristics rather than depth. However, the species distribution patterns in September differed from those in March. Fig. 6(a) is a typical pattern showing that the species range of distribution were strikingly expanded in September.

Such trend holds not only for common species but also for substrate-specific species. For instance, in March, the cirratulid polychaete *Tharyx* sp. 1, which were distributed from silt (with sand content=0.81%) to silty sand (75.48%) with a peak abundance in sandy mud (4.85%), appeared almost in stations with silt (9.48%) to sand (98.11%) with a peak abundance in silt (9.48%) in September. The same was true for gam-

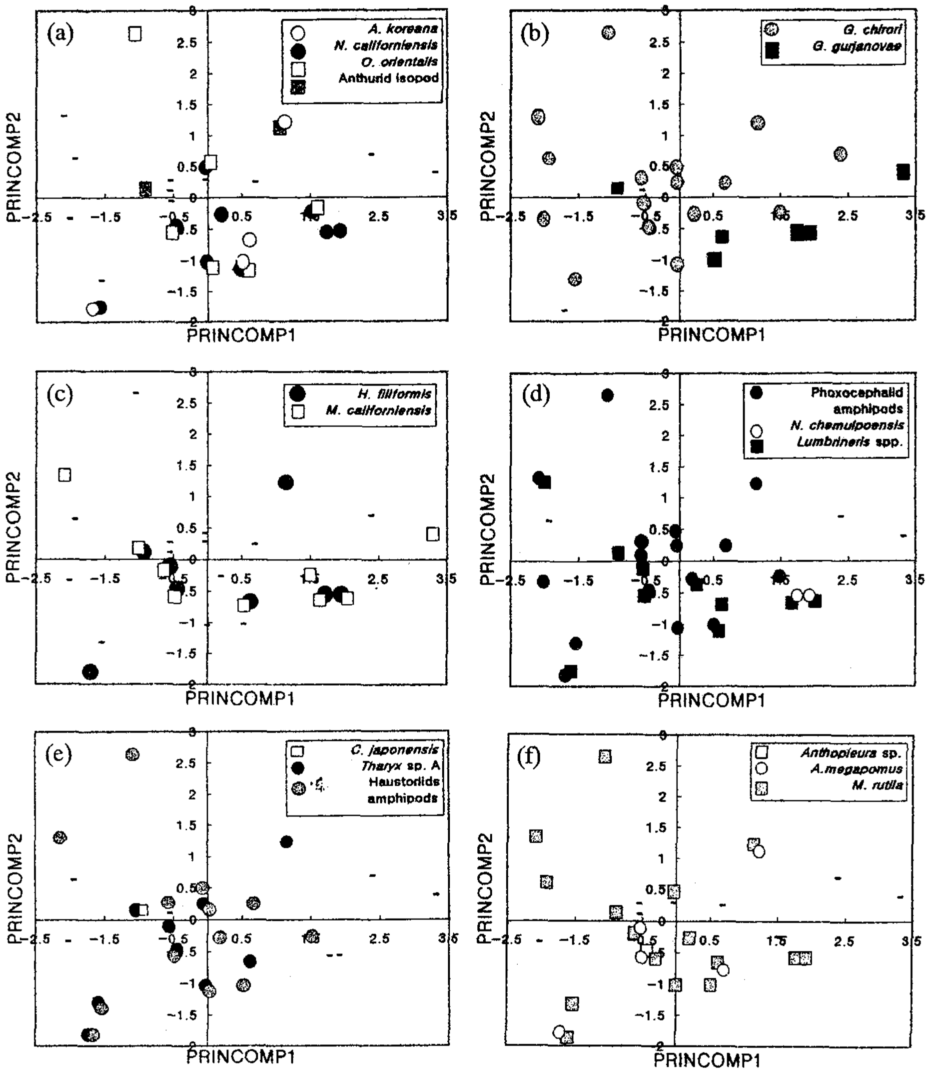

Fig. 6. Occurrence patterns of dominannt species in Kyonggi Bay((a)-(f) in September, 1989).

maridean phoxocephalid amphipod, which were distributed from sandy silt (33.85%) to sand (94.22%) and were represented in 12 stations, mainly located in the outer part of the bay in March. In September, they occurred in silty sand (51.50%) to sandy bottom (98.11%) with increasing frequency (16 stations), including the inner part of the bay.

Environmental discrimination

Multivariate discriminant analysis was applied to evaluate the environmental characteristics. First, in one-way analysis of variance and canonical coefficients, salinity was found to be the only variable that discriminated the two groups (Group I and II) in both seasons. Also, the discriminatory power of CDF (canonical discriminant function) 1 was tested by likelihood ratio and proved to be significant (p= 0.0001 in March and 0.0010 in September) (Table 3). The discriminant function 1 in March had a high positive coefficient of salinity (2.30) and to a lesser degree in coefficients of mean phi (1.31) with a sorting value of -1.13. In September, the discriminant function 1 is also associated with salinity (1.66) but others are insignificant. Fig. 7 showed that each group was considerably distant in terms of group means and thus the discriminant function 1 for both seasons divided the Group into I and II by the contribution of salinity.

The result of subdivision of Group II are shown in Table 3. In both seasons, sedimentological variables (silt in March and sand in September) were proved to be significant from the univariate F-test and their probability levels. For the analysis of Group II-A, II-B and II-C, likelihood ratio test showed that the discriminatory power of canonical function 1 (differences among groups to the discriminant function 1) are considerably appropriate. Likelihood ratio test of function 2 is insignificant in both seasons. In March, function 1 contributed 96.99% (correlation=0.81) and function 2 did 3.01% (0.24) of the separation. In September, function 1 accounted for 97.86% (0.85) and function 2 only 2.14% (0.23). So, the insignificance of function 2 did

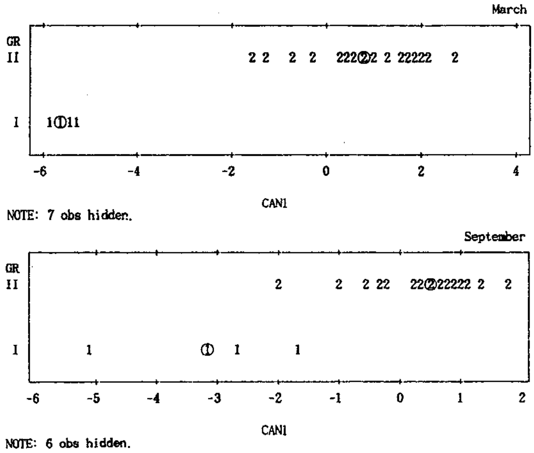

Fig. 7. Groups were seperated by canonical discriminant function 1 in March and September, 1989. Circled character denotes class mean of each group(Group I and II).

Table 3. Results of canonical discriminant analysis(Upper is of Group I and II; Lower is of Group II-A, II-B and II-C)

The result of Canonical Discriminant Analysis on Group I and II

March, 1989

Variable	R-Squared	F	Pr > F	CDF1 Standardized Canonical Coeff.
Salinity	0.6083	35.7256	0.0001	2.3042
Mean	0.0020	0.0458	0.8323	1.3069
Sorting	0.1025	2.6262	0.1187	-1.1282

	Canonical Correlation	Likelihood Ratio	F	Pr>F
CDF1	0.9064	0.1785	32.2139	0.0001

September, 1989

Variable	R-Squared	F	Pr > F	CDF1 Standardized Canonical Coeff.
Depth	0.0046	0.1013	0.7533	-0.2676
Salinity	0.5732	29.5487	0.0001	1.6591
Sorting	0.0253	0.5714	0.4577	0.3044
Silt	0.0718	1.7025	0.2054	-0.0815

	Canonical Correlation	Likelihood Ratio	F	Pr>F
CDF1	0.7781	0.3946	7.2880	0.0010

The result of Canonical Discriminant Analysis on Group II-A, II-B and II-C

March, 1989

Variable	R-Squared	F	Pr > F	CDF1 Standardized Canonical coeff.	CDF2 Standardized Canonical coeff.
Depth	0.2826	3.5460	0.0503	0.5725	-0.3605
Sort	0.1399	1.4638	0.2576	0.5278	1.4748
Silt	0.5113	9.4157	0.0016	-1.6390	-0.9369

	Canonical Correlation	Likelihood Ratio	Approx F	Pr > F	Cumulative Proportion Eigen
CDF1	0.8082	0.3276	3.9842	0.0043	0.9699
CDF2	0.2349	0.9448	0.4962	0.6174	1.0000

September, 1989

Variable	R-Squared	F	Pr > F	CDF1 Standardized Canonical coeff.	CDF2 Standardized Canonical coeff.
Depth	0.0846	0.8314	0.4515	-0.0649	1.0812
Salinity	0.0493	0.4665	0.6345	-0.8182	-0.1537
Sand	0.5739	12.1213	0.0005	1.7970	-0.3210

	Canonical Correlation	Likelihood Ratio	Approx F	Pr > F	Cumulative Proportion Eigen
CDF1	0.8498	0.2629	5.0683	0.0009	0.9786
CDF2	0.2321	0.9461	0.4840	0.6246	1.0000

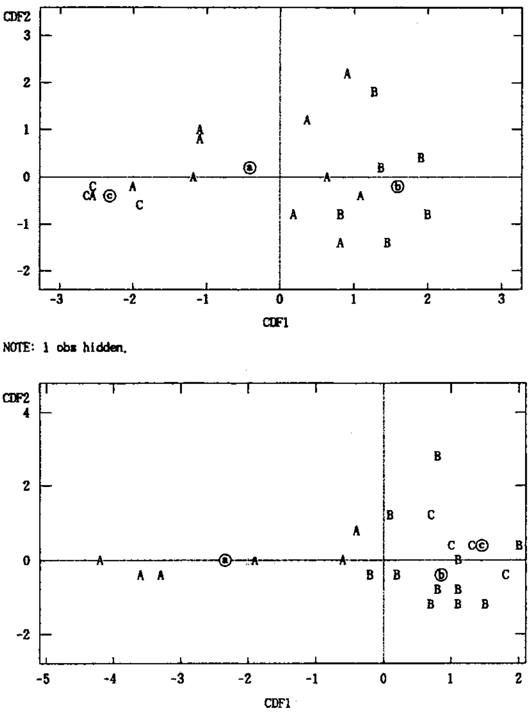

Fig. 8. Groups were seperated by canonical discriminant function 1 and 2 in March and September, 1989. Circled character denotes class mean of each group(Group II-A, II-B and II-C).

not affect the result seriously. Instead of function 2, function 1 could explain most part of variations and discriminations. Detailed results are given in Fig. 8. March groups are in parallel with function 1, chiefly composed of silt contents (-1.64).

The class mean of Group II-A differed from II-B and II-C along function 1. In September, Group II-A, II-B and II-C formed a series along the single significant function 1. There were high canonical coefficients in sand contents (1.80) and to a lesser degree, in salinity (-0.82). The relatively large coefficient of salinity obtained in Group II analysis is a reflection of the effect of expansion of the local range in salinity influx during the rainy season. The results of Group II analysis strongly suggested an absolute contribution of sedimentological variables.

DISCUSSION

Species groups

The results of R-mode analysis have shown rather seasonal variation in species-group composition. The similarity of species composition between March and September was found in estuarine groups together with those composed of dominant species in Kyonggi Bay, Korea. The characteristic species of this estuarine regime are *Balanus reticulatus, Crassostrea gigas* and *Corophium* sp. In September, *Balanus reticulatus* was assigned to Group IV, and it might be ascribed to the high abundance in Station 5 which was influenced by freshwater influx. On the other hand, the characteristic species of Kyonggi Bay were apportioned to three sub-groups : VII-1, VII-2 and VII-3 in March and VIII-1, VIII-2 and VIII-3 in September. First, the presence of sand-dwelling species, phoxocephalid and haustoriid amphipods should be noted. They were usually found in the outer part of Kyonggi Bay, but invaded the inner part in September. The widely distributed species are the errant polychaetes *Glycera chirori, Lumbrineris* spp., *Mediomastus californiensis and Prionospio paradisea* in Subgroup VII-2 in March and Subgroup VIII-2 in September. Other widespread species such as the polychaetes, *Heteromastus filiformis, Notomastus* sp., *Tharyx* sp. 1, *Sternaspis scutata, Diopatra bilobata*, and *Paralacydonia paradoxa* were allocated to Group VI in March. Although widely distributed, they had somewhat different abundance patterns than those of Subgroup VII-2 in March and branched into Group IV, Subgroup VIII-2 and VIII-3 in September.

The differences in benthic macrofauna distribution between seasons could be caused by variations in abundance pattern, distributional ranges and habitat preferences. Similar interpretations have been made by Boesch (1973), where he considered four main types of species groups: predominantly habitat restricted, seasonally restricted, widespread, and epifaunal or microhabitat-restricted. These four main types were also the result of the seasonality and fluctuation of ecological variables (*e.g.*, abundance and dominance, *etc*). In this study, the estuarine species groups (Group VIII in March and VII in September) could be assigned to type 1-the predominantly habitat restricted, or 4-the epifaunal or microhabitat-restricted. Group II and Subgroup VII-1 in March and V and Subgroup VIII-1 in September could be in the predominantly habitat restricted because the former group was largely confined to intertidal habitats and the latter was usually distributed in sand bottom. Group VI and VII-2 in March and IV, VIII-2 and VIII-3 may be categorized into the third type 'widespread'. Others showed strong seasonality, hence they could be designated to the type 2 'seasonally restricted'.

Dominant species distributions

Some of the sandy to mixed bottom-inhabiting species expanded distributional ranges of habitats. However, the ranges or population sizes were much more reduced in the case of mud and mixed bottom-inhabiting species. For example, sessile sea anemones, *Anthopleura* sp., only occurred at station 7 with 35 individuals in March but appeared at the same station with 2 individuals in September. Noticeable variations in sediment composition were observed at station 7 (slightly gravelly sandy mud (37.7% in sand) in March and slightly gravelly to muddy sand (72.3% in sand) in September). It is known that the influx of suspended sediments showed strong seasonal variations in this study area (Jang and Oh, 1991). Consequently, it is possible that the changes of the suspended sediments influx may cause the seasonal variations of sedimentary facies for certain stations. Another example is the fourth ranked dominant polychaete *Anaitides koreana*, which mainly inhabited 10 stations of mixed bottom in March. However, they were represented in 4 stations with an abundance of 5 individuals. An anthurid isopod was also found on mixed bottoms of 4 stations in March and their peak abundance was recorded from station 6 (gravel=2.3%, sand=4.9%, and mud=92.9%). In September, they occurred in total abudance of 4 individuals at four stations visited in March. Amongst the four stations, station 6 was conspicuously changed in sedimentary composition (gravel=3.7%, sand=48.5%, and mud=48.0%). This pattern was also recognized in other dominant species such as *Nephtys chemulpoensis* and *N. californiesis* which mainly distributed on mud-bottom and mixed-bottom. From the results of habitat analysis, it was confirmed that the distributions were dependent spatially and seasonally on the variations of sedimentary facies.

Environmental discrimination and disturbance

The study area was clearly divided into four different station groups. Group I included characteristic species, whose distributional ranges were strictly limited to Yomha and a part of Sokmo channel (station 1, 2, 5, 10). The critical environmental factor in this area was found to be salinity in the multiple discriminant analysis. The distribution pattern of benthic macrofauna in Kyonggi Bay was largely different from Group I probably due to sedimentological characteristics and salinity variation ranges. The three station groups (Group I, Group II-A, and II-B) exhibited similar pattern in species composition in both seasons. However, Group II-C in March and September were significantly different in their internal attributes. Group II-C in March was isolated from its characteristic species composition (*Nephtys chemulpoensis* comprised of 50.5%) and resulting from lower depths and high mud content. In the rainy season, it was disintegrated and the habitats were assimilated into other groups with the reduced traces of characteristic species.

On the other hand, in September Subgroup II-C showed extremely poor biocoenosis. Absalao (1991) in a study of the Patos Lagoon estuary insisted that sedimentology was influenced locally by fine terrigenous sediments through the estuary. The combined reaction of terrigenous sediments (sand and muds) inputs from the adjacent river and periodic resuspension of sediment during storms induced the settlement of opportunistic species, such as a mactrid bivalve *Mactra isabelleana*, and thus played a major role in qualitative and quantitative structure of benthic community. The resulting variations in communities due to unstable sediments can be applied to this study based on the following two points: first, the importance of spatial and temporal variations of sedimentary facies was proved in our previous study (Yoo and Hong, 1996); and second, the result of habitat analysis have shown that some of the dominant species were damaged due to unstable sediment.

A close relationship between the composition of the benthic communities and the sedimentary environment has been generally accepted for most latitudes and habitats. Sanders (1958) stated that differences in species composition among various sediment types were primarily induced from their different trophic modes. Later, Rhoads and Young (1970) revealed that deposit-feeders actively inhibited suspension-feeders and thus emphasized the biological interaction of trophic group amensalism. These results show the indispensible relationships between sedimentary mass properties and their influence on biological processes. However, another important factor, sediment instability can be deduced from this study and its effect as a disturbance may have resulted from the fluctuation of the physical environment. Boesch (1973) stated that factors regulating species distribution and diversity were those pertaining to the substrate. A possible factor which he found was the suitability of substrate and a quick silting phenomenon of mud bottom. Similarly, Rhoads *et al.* (1978) studied the effect of dredge-spoil to estuarine benthic animals; first, he compared the communities that were affected by natural disturbance (resuspension by tidal scour and storm disturbance) with those at the dumping site. They revealed that the naturally disturbed environment recovered more quickly than the dumped site environment did. Therefore, from their study it must be inferred that the disturbance here caused by sediment instability is a naturally induced catastrophic event.

The preferences of some major groups of benthic organisms for a certain sediment type has been well described. The physical influence of the tidal current and wave regime in different parts of the Han Estuary and Kyonggi Bay may explain the different sediment characteristics and, in turn, the pattern of benthic distribution. This is particularily true in an estuary under naturally unstable physical condition. From the results of our study, we deduce that in

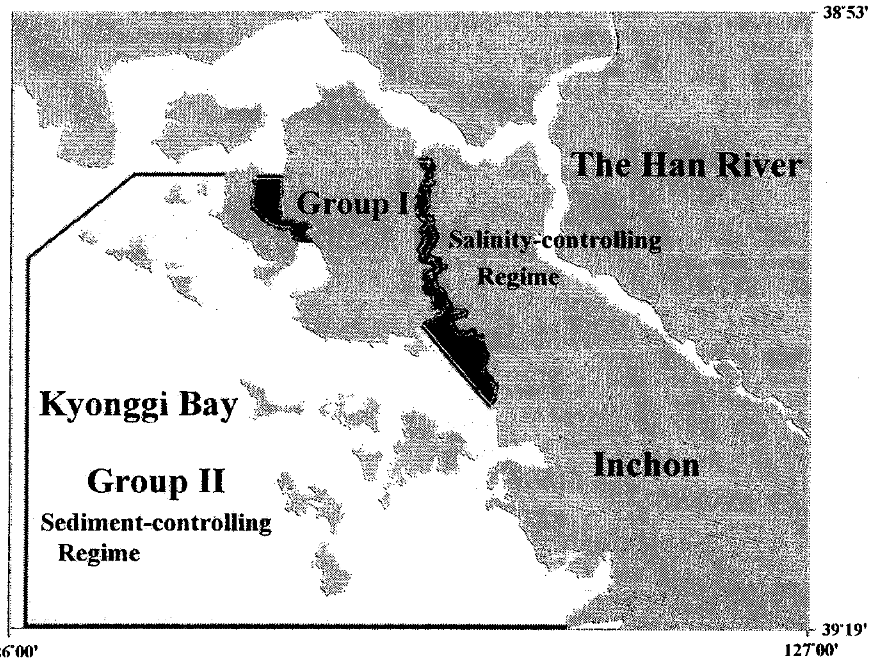

Fig. 9. The faunal assemblages in the study area were divided into two groups, the salinity-controlling regime(Group I) and sediment-controlling regime(Group II).

terms of the sources of variability with regards to the distribution patterns of benthic macrofauna, the salinity-fluctuating regime is limited to the channel part of the Han Estuary. In contrast, the distribution of benthic communities in Kyonggi Bay area is under the influence of sediment-controlling regime (Fig. 9). In fact, many studies of benthic communities that identify environmental factors, show that salinity and sediment type are among the most important natural factors that determine benthic infaunal relationships in estuaries (Flint and Kalke, 1985; Rabalais, 1990). Because Korean estuarine environments experience heavy rains from cyclonic depression or monsoons, the variations of sedimentary facies in Kyonggi Bay are likewise regulated by increased river discharge. Consequently, mortalities of benthic invertebrates resulting from heavy rainfall and the effects of freshets from typhoon during summer are another factor that may determine the distribution pattern of benthic macrofauna in this region.

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