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# A Revisit on Zonal Macrobenthic Communities in Chokchon Tidal Flat, Incheon, Korea, After the Survey in 1986

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An investigation on the zonal communities in Chokchon macrotidal flat, Incheon, Korea, was carried out on July 1994, eight years after the initial survey done by Frey *et al.* (1987a and b). A survey transect (4 km long) was established with 41 stations having an equi-interval of 100 m. Macrofaunas were sampled in July 1994. R-mode cluster analysis and ordination analysis (detrended correspondence analysis or DCA) were performed. The aims of the investigation were to: (1) observe the distribution and abundance patterns, including zonation of benthic macrofaunal communities in the area; and (2) gain information about faunal changes between two different periods. The primary feature of distribution was corresponded with Frey's zonation, and this was shaped by three level-specific species groups. Significant changes in dominant species were detected when compared with the faunal assemblages of 1986. The bivalve mollusk, *Meretrix petechialis,* seemed to have disappeared. Two newly arrived organic pollution indicator species, *Theora fragilis* and *Capitella capitata,* were regarded as impregnable proof of response to eutrophication, although the concrete evidence on the eutrophication source was not found.

## INTRODUCTION

The Chokchon macrotidal flat is located in the southwestern part of Incheon, Korea. In 1986, Frey *et al.* (1987a, b) investigated this area and reported tripartite zonation of macrofaunal assemblages, a brachyuran zone in landward part, a molluscan zone in middle part, and a holothurian zone in seaward part. Those were the principal study on the macrofaunal zonation of the tidal flat. Based on their division of communities, several studies on faunal composition, diversity, governing agents, secondary production, and temporal variation were performed in this area (Park, 1991; Seo, 1994; Yoo, 1998, *etc.*). However, the authors wondered that the suggestion of Frey *et al.* (1987a, b) could be possibly varied because it was solely based on qualitative observation. Thus, statistical determination on that phenomenon was required.

Other potential factors could be sources of changes in faunal suite or zonation pattern. Since the exploratory study, a lot of environmental events transpired in the coastal area of Incheon. Recently published articles introduced potential impact sources upon the marine ecosystem. These sources included the infamous Shihwa dike (Choi *et al.*, 1997; Hong *et al.*, 1997), seawall around Songdo LNG receptor base (Ahn and Choi, 1998), and eutrophication and warming trends in Kyeonggi Bay (Yoo *et al.*, 1999a, b). Chokchon tidal flat *per se* has experienced a destructive development activity since 1984, and now there is even a large city being built. The comparison of samples taken between 1986 and 1994 was expected to reveal stories about faunal changes and other information on impact-related responses.

Sampling was done in almost the same conditions (*i.e.*, location, design, methods, and season) as those in Frey *et al.* (1987 a, b). This study aims to: (1) show elementary and snapshot features of macrofaunal communities in Chokchon tidal flat, 1994; (2) reaffirm Frey's zonation by a quantitative statistical analysis; and (3) discuss the change of distribution and structure of macrobenthic communities after 8 years.

## MATERIALS AND METHODS

### *Field sampling*

During low tides on 23-24 July 1994, one transect

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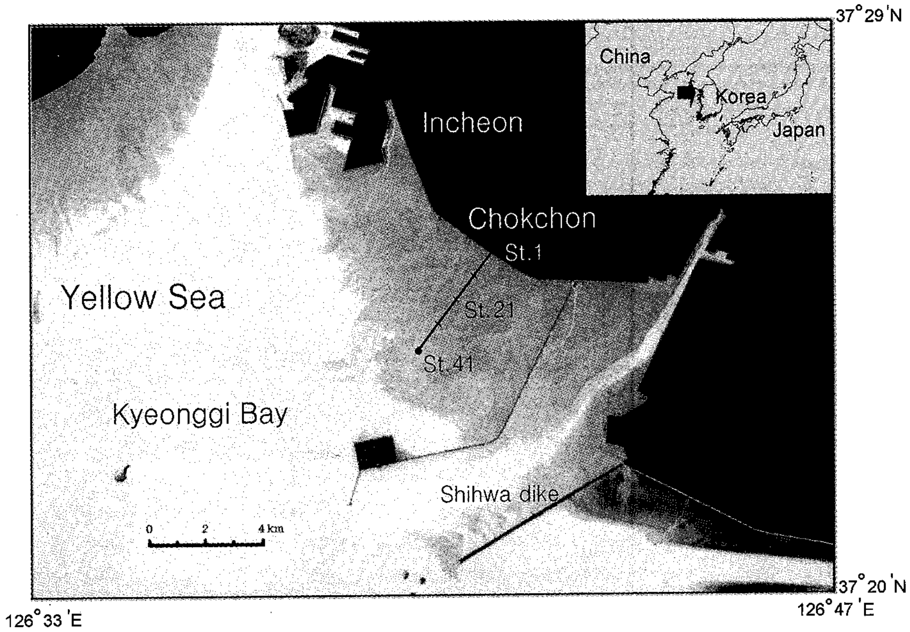

**Fig. 1.** A survey transect established on the Chokchon macrotidal flat (a width of 4 km), Incheon, Korea by Frey *et al.* (1987a and b) was revisited in this study.

running from land to sea was established in the Chokchon macrotidal flat with 41 stations, and the distance between the two stations was approximately 100 m long (measured by rope) (Fig. 1). Biological and sediment samples were collected simultaneously at each station. Macrobenthos above the size of 1 mm were collected by using a can core (volume: $15\times20\times30$ cm$^3$; surface area: 0.03 m$^2$) and sieve. A surface area of around 0.2 m$^2$ was sampled at each station by six replicates of the sampler.

### *Laboratory analysis*

Surface sediments were taken to the laboratory for grain size analysis. Other analyses were made through dry sieving, pipetting methods of Wentworth (1922) and Folk (1968), and granulometric equations of Folk and Ward (1957).

Faunal samples were sorted, identified to species level if possible, and counted under a dissecting stereomicroscope. Biomass was measured in wet weight (g) using an electronic balance.

Dominant species ranking, based on abundance and wet weight data, was calculated using the Le Bris index, *D'ij* (Le Bris, 1988). *Fij* is occurrence frequency, and *Dij* is abundance term. *D'ij* is expressed by the product of *Fij* and *Dij*.

R-mode analysis (classification of species) was done by employing chord distance and flexible strategies with $\beta$=-0.25 (Ludwig and Reynolds, 1988). In ordination analysis, DCA was carried out and a joint plot of species and sites was made on an ordination diagram. A down-weighting option was used to minimize the influence of rare species. For an effective interpretation of species distribution, dominant species plots were fitted by a gaussian response surface. Species optima and circles were drawn in an ordination space. The circles are contours where the expected abundance is 60% of the maximum expected abundance (ter Braak, 1987).

## RESULTS

### *Surface sediment textures*

Mean grain size of sediment was fine in the higher tidal level and coarse in the lower tidal level and changed downshore gradually (Fig. 2). Silt and clay contents decreased and sand showed an inverse trend when going down the transect. The values varied between 3.31 and 7.15$\phi$. Sorting coefficients showed a similar trend (r=0.91) and the variation range was 0.56 and 2.39. Sediments were classified into three types, silt, sandy silt and silty sand from higher to lower level.

### *Dominant species*

Selection of dominant species was based on their densities and biomass (Tables 1 and 2). In Table 1, the most dominant species among 113 species was the molluscan bivalve, *Mactra veneriformis* (fre-

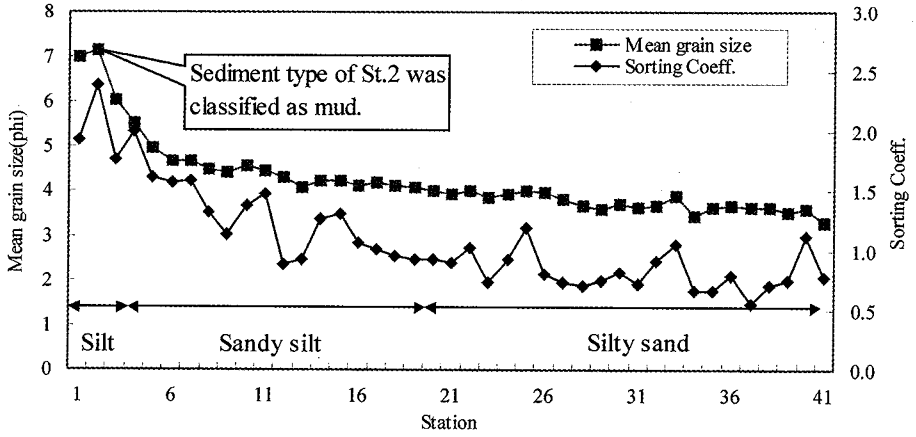

**Fig. 2.** Granulometric parameters and types of surface sediment in the study area.

**Table 1.** Density-based top 30 dominant species in the Chokchon tidal flat.

| Rank | Taxon | Species | Fij | Dij*100 | D'ij |
|---|---|---|---|---|---|
| 1 | MBi | *Mactra veneriformis* | 85.4 | 4563.0 | 389523.0 |
| 2 | APl | *Heteromastus filiformis* | 90.2 | 1348.7 | 121711.7 |
| 3 | APl | *Cirrophorus furcatus* | 80.5 | 223.1 | 17953.3 |
| 4 | MBi | *Theora fragilis* | 46.3 | 318.5 | 14760.6 |
| 5 | APl | *Aricidea pacifica* | 68.3 | 171.2 | 11694.0 |
| 6 | EHo | *Protankyra bidentata* | 48.8 | 180.3 | 8795.0 |
| 7 | APl | *Magelona* sp. | 48.8 | 179.8 | 8769.4 |
| 8 | MBi | *Solen strictus* | 53.7 | 157.2 | 8436.3 |
| 9 | APl | *Glycera decipiens* | 63.4 | 112.6 | 7141.1 |
| 10 | APl | *Glycinde gurjanovae* | 63.4 | 109.2 | 6924.4 |
| 11 | MBi | *Moerella iridescens* | 48.8 | 136.1 | 6638.6 |
| 12 | APl | *Nephtys californiensis* | 75.6 | 87.3 | 6600.0 |
| 13 | APl | *Nephtys chemulpoensis* | 17.1 | 382.0 | 6522.2 |
| 14 | MBi | *Borniopsis tsurumaru* | 41.5 | 136.7 | 5667.5 |
| 15 | CAm | *Monoculodes koreanus* | 46.3 | 110.0 | 5097.1 |
| 16 | MGs | *Reticunassa festiva* | 48.8 | 89.8 | 4380.6 |
| 17 | CCu | *Diastylis paratricincta* | 46.3 | 87.3 | 4045.6 |
| 18 | APl | *Nephtys polybranchia* | 63.4 | 53.0 | 3361.3 |
| 19 | APl | *Magelona japonica* | 26.8 | 107.8 | 2891.1 |
| 20 | CDB | *Macrophthalmus japonicus* | 26.8 | 101.5 | 2722.7 |
| 21 | MGs | *Eulima* sp. | 39.0 | 64.9 | 2533.0 |
| 22 | APl | *Minuspio japonica* | 29.3 | 85.3 | 2496.3 |
| 23 | OPh | *Phoronis* sp. | 19.5 | 113.3 | 2211.4 |
| 24 | APl | *Aricidea assimilis* | 36.6 | 50.7 | 1853.2 |
| 25 | MBi | *Tugonia sinensis* | 17.1 | 96.2 | 1641.9 |
| 26 | APl | *Pseudopolydora kempi* | 43.9 | 30.5 | 1340.9 |
| 27 | CAm | *Eohaustorius longidactylus* | 22.0 | 45.1 | 989.1 |
| 28 | MBi | *Potamocorbula laevis* | 31.7 | 31.2 | 988.7 |
| 29 | CDB | *Ilyoplax pingi* | 22.0 | 42.7 | 937.9 |
| 30 | CDB | *Asthenognathus inequipes* | 26.8 | 30.7 | 824.7 |

*Note: APl: Annelida, Polychaeta; MBi: Mollusca, Bivalvia; MGs: Mollusca, Gastropoda; CDB: Crustacea, Decapoda, Brachyura, CAm: Crustacea Amphipoda; CCu: Crustacea, Cumacea; EHo: Echinodermata, Holothuroidea; OPh: Others, Phoronids.

**Table 2.** Biomass-based top 30 dominant species in the Chokchon tidal flat.

| Rank | Taxon | Species | Fij | Dij*100 | D'ij |
|---|---|---|---|---|---|
| 1 | MBi | *Mactra veneriformis* | 85.4 | 4416.4 | 377011.9 |
| 2 | EHo | *Protankyra bidentata* | 48.8 | 1440.3 | 70257.6 |
| 3 | CDB | *Macrophthalmus japonicus* | 26.8 | 1027.1 | 27555.8 |
| 4 | APl | *Heteromastus filiformis* | 90.2 | 254.6 | 22975.8 |
| 5 | MBi | *Moerella iridescens* | 48.8 | 386.4 | 18848.5 |
| 6 | MGs | *Reticunassa festiva* | 48.8 | 322.1 | 15713.8 |
| 7 | MBi | *Phacosoma japonicum* | 19.5 | 396.2 | 7731.2 |
| 8 | MBi | *Solen strictus* | 53.7 | 77.2 | 4142.1 |
| 9 | MBi | *Tugonia sinensis* | 17.1 | 216.0 | 3688.3 |
| 10 | APl | *Glycera decipiens* | 63.4 | 57.7 | 3657.4 |
| 11 | MBi | *Cyclina sinensis* | 9.8 | 320.0 | 3122.3 |
| 12 | APl | *Lumbrineris heteropoda* | 19.5 | 159.6 | 3113.7 |
| 13 | MBi | *Theora fragilis* | 46.3 | 53.5 | 2478.8 |
| 14 | CDB | *Macrophthalmus dilatatus* | 19.5 | 126.8 | 2474.4 |
| 15 | APl | *Diopatra bilobata* | 9.8 | 133.9 | 1306.0 |
| 16 | MGs | *Eulima* sp. | 39.0 | 31.9 | 1243.2 |
| 17 | CDB | *Ilyoplax pingi* | 22.0 | 53.6 | 1177.3 |
| 18 | MBi | *Ruditapes phillipinarum* | 19.5 | 57.6 | 1123.5 |
| 19 | APl | *Nephtys californiensis* | 75.6 | 14.4 | 1091.6 |
| 20 | MBi | *Borniopsis tsurumaru* | 41.5 | 20.6 | 853.8 |
| 21 | MGs | *Bullacta exarata* | 12.2 | 60.4 | 736.0 |
| 22 | APl | *Nephtys chemupoensis* | 17.1 | 35.0 | 597.2 |
| 23 | CDB | *Asthenognathus inequipes* | 26.8 | 14.0 | 374.9 |
| 24 | APl | *Glycera subaenea* | 29.3 | 12.8 | 374.5 |
| 25 | APl | *Aricidea pacifica* | 68.3 | 5.4 | 371.5 |
| 26 | OCn | Anthozoa sp. | 4.9 | 68.9 | 336.0 |
| 27 | OPh | *Phoronis* sp. | 19.5 | 17.1 | 334.6 |
| 28 | APl | *Glycinde gurjanovae* | 63.4 | 5.1 | 325.7 |
| 29 | APl | *Cirrophorus furcatus* | 80.5 | 4.0 | 322.5 |
| 30 | APl | *Magelona* sp. | 48.8 | 5.1 | 246.7 |

quency=85.4%), followed by the polychaete, *Heteromastus filiformis* (frequency=90.2%). For the third dominant species (*Cirrophorus furcatus*), high frequencies of over 80% were recorded. The subdominant species were mainly composed of polychaetes and molluscs. Among other taxonomical groups, holothurian echinoderms, *Protankyra bidentata,* and crustaceans, amphipod, *Monoculodes koreanus,* and ocypodid crab, *Macrophthalmus japonicus,* were ranked in the dominant species group.

Among the biomass-based species, the most dominant was bivalve, *M. veneriformis* (Table 2). Other species showed some rise and fall in their ranks. The next dominant species were *P. bidentata* and *M. japonicus*. Mollusc species occupied a higher rank and other dominants were mainly composed of polychaetous annelids, *Glycera decipiens, Lumbrineris heteropoda, Diopatra bilobata, Nephtys californiensis, N. chemulpoensis, Glycinde gurjanovae, Cirrophorus furcatus,* and *Magelona* sp., among others.

### *R-mode analysis*

Some 50 dominant species were used in r-mode analysis (Fig. 3). Three species groups were formed in a higher level of dissimilarity (chord distance 1.7), and each group was divided into three subunits.

Each of the groups could be categorized as a higher, middle, and lower level inhabiting species group. The higher level species were crabs, *M. japonicus*; polychaetes, *N. chemulpoensis* and *Capitella capitata*; and molluscs, *Moerella iridescens, Theora fragilis,* and *Potamocorbula amurensis.* The middle level species were molluscs, *Umbonium thomasi, M. vener-*

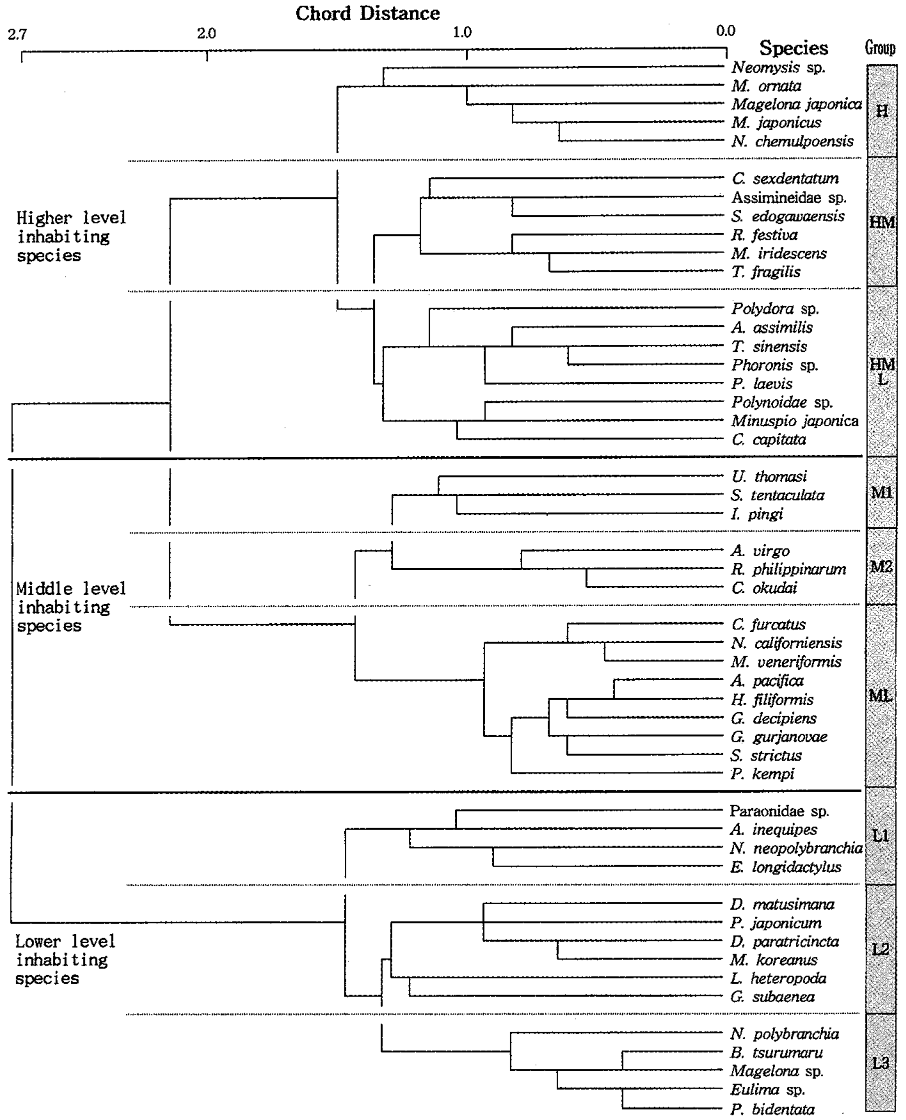

**Fig. 3.** The result of r-mode classification by chord distance and flexible strategy.

*iformis*, and *Solen strictus*; and polychaetes, *Cirrophorus furcatus, H. filiformis,* and *Nephtys californiensis*. The lower level inhabitants were holothurians, *Protankyra bidentata*; molluscs, *Phacosoma japonicum, Borniopsis tsurumaru, Decorifer matusimana,* and *Eulima* sp.; and polychaetes, *Nephtys polybranchia, Magelona* sp., and *Lumbrineris heteropoda.* All these species in the three levels were divided into nine subgroups, according to their distributional attributes, level-specific species (H, M1, M2, L1, L2, and L3) and relatively wider distributors (HM, HML, and ML).

The authors simplified the result of the r-mode analysis (Fig. 4). Group H was a higher-level specific species, and the HM species inhabited a higher to middle level. The HML species was distributed from a higher to a lower level. Some of the HML species did not exactly inhabit from the uppermost level but from the upper middle level. The middle level specific species groups were M1 and M2, and they differed in their densities from a medium to a low density. The ML species group was the dominant in the study area. The lower level species groups were L1, L2, and L3. They showed the most conspicuous specificity, although an exceptional case was found in cumaceans, *Diastylis paratricincta.*

### *Ordination analysis*

Stations and species were bi-plotted, and dominant species were marked with their scientific names (Fig. 5). Communities were classified into three, and each of them was converged in an eye-fitted circle (Fig. 5a). The grouping of scattered stations in hyperspace was coincided with the classificatory result of Yoo

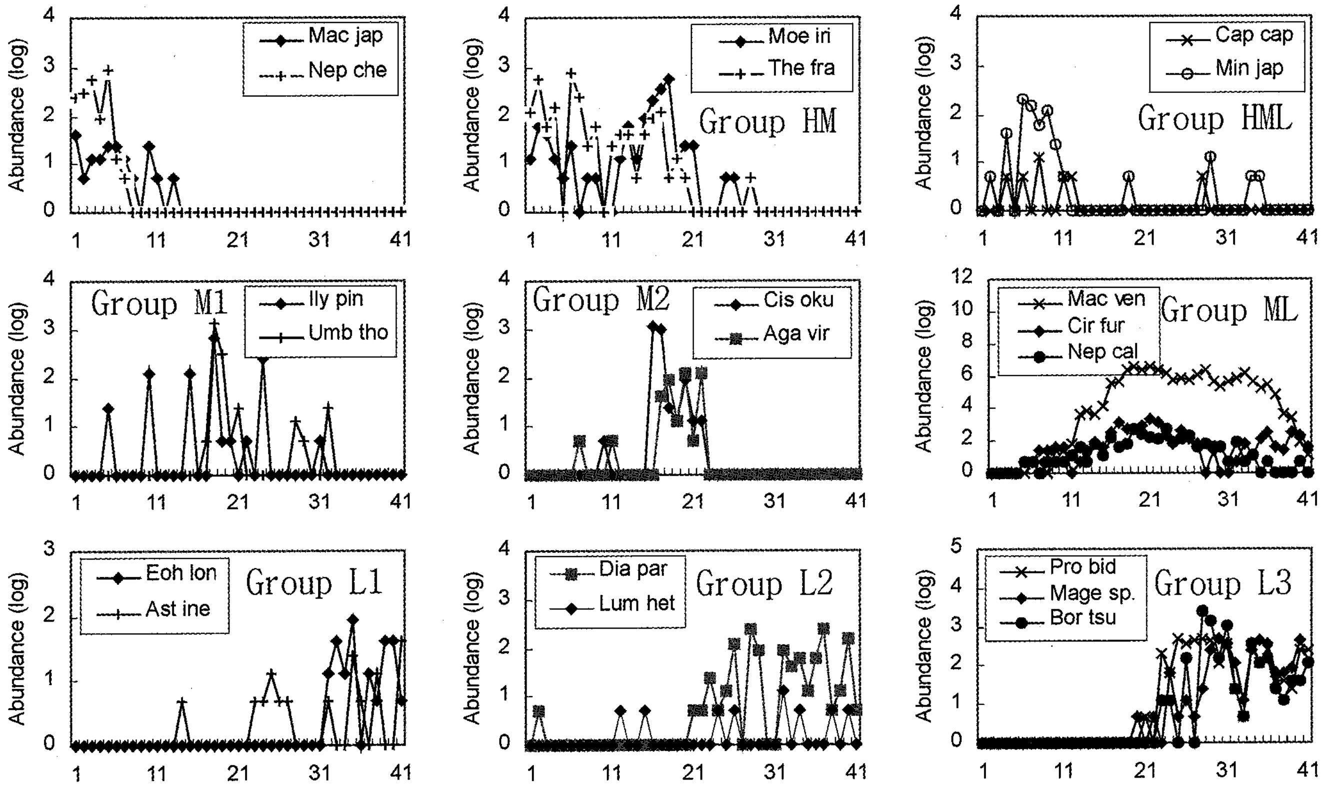

**Fig. 4.** Distribution and abundance of macrofaunas along the transect. Characteristic species that show their distributional attributes were chosen from the r-mode analysis and were labelled by their abbreviated codes (refer to the lists in Table 1 and 2).

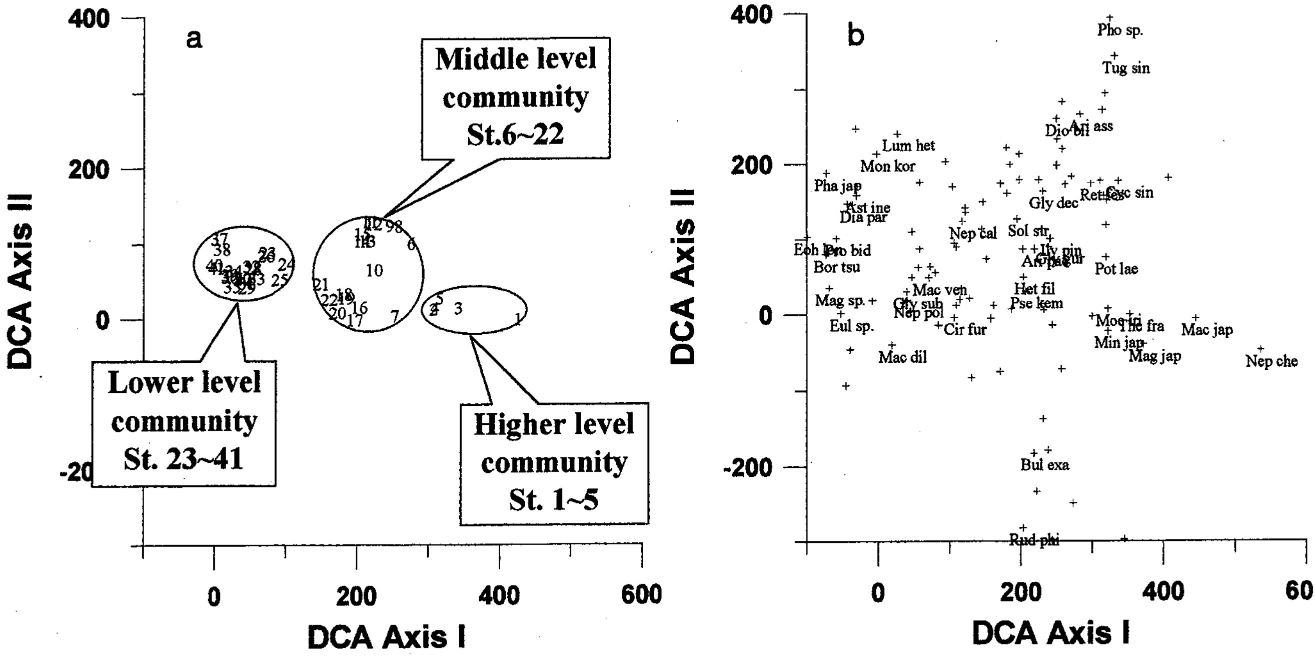

**Fig. 5.** DCA ordination diagram of the Chokchon macrotidal flat data. Scatter plot by case is (a) and by species (b). Dominant species were labelled by their abbreviated codes (refer to the lists in Table 1 and 2).

(1998). The higher-level community was composed of stations 1-5; mid-level, stations 6-22; lower level, stations 23-41. The stations were arranged along DCA axis 1. The mid-level community showed a slight dis-

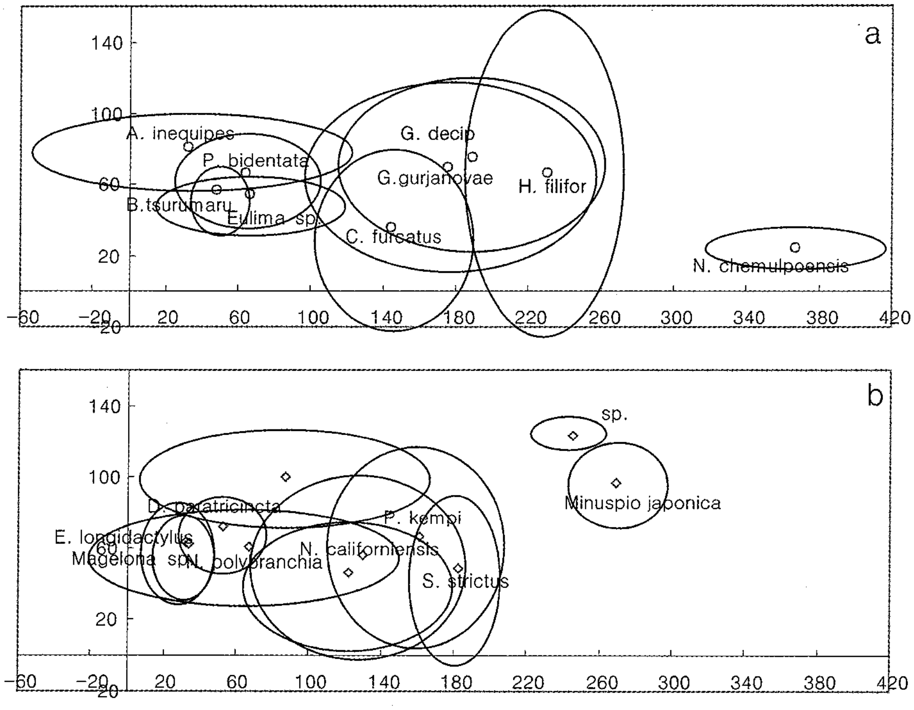

**Fig. 6.** Gaussian response surface fitted on the dominant species. Circles represent species optima and 60% of the maximum expected abundance.

persion along DCA axis 2. It might be ascribed to a weak departure of the centre of distribution among the species groups HML, M1, and M2. On the other hand, the lower level community showed relatively higher within-group similarities (*i.e.*, small circle with relatively large number of station). Species were scattered around their preferred stations (Fig. 5b). They showed not a flocked but rather a continuous pattern along axis 1. Higher diversity was found around mid-level stations. Species along negative and positive parts of DCA axis 1 displayed narrow variations, and relatively wide variations were observed at the intermediate part of axis 1.

Fig. 6 is the result of gaussian response curve fitting for dominant species in two dimensions of DCA ordination space. As described above, circles represent 60% of the maximum expected abundance, and thus they may be regarded as reflecting optimal habitat niche in the study area. In Fig. 6a, middle level species, *H. filiformis, Glycinde gurjanovae,* and *Glycera decipiens* showed wide niches; the latter two showed almost the same habitat niches. For *H. filiformis,* niche breadth was underestimated because it displayed peak abundances in mid-level communities. The higher and lower level inhabiting species had narrow niches (*e.g., N. chemulpoensis, Borniopsis tsurumaru, Eulima* sp., and *P. bidentata*). Especially, *B. tsurumaru, Eulima* sp., and *P. bidentata* are known to be in a commensal relationship. In Fig. 6b, *Nephtys californiensis*, *Pseudopolydora kempi, N. polybranchia, M. veneriformis* and *Monoculodes koreanus* showed relatively wide niches, and *Phoronis* sp, *Minuspio japonica,* and *Diastylis paratricincta* had narrow niches.

## DISCUSSION

### *Zoned communities in the Chokchon macrotidal flat*

From the result of ordination and cluster analysis, three-banded zonation was found (Fig. 7). The range of each zone roughly corresponded with that of Frey *et al.* (1987a, b). The higher level community ranged between 0 and 500 m, and the "Brachyuran zone" of Frey *et al.* (1987a, b) was between 0 and 900. The middle level community was between 600 and 2200 m, and the "Molluscan zone" was between 900 and 2100 m. The lower level community was between 2300 and 4100 m, and the "Holothurian zone" was between 2100 and 3900 m. The authors considered these minor differences in ranges to be negligible, considering that the result of Frey *et al.* (1987a, b) was based on qualitative observation. This was supported by the fact that the distributional ranges of three dominant species, *Solen strictus, Protankyra bidentata,* and *M. venerformis* were nearly similar with the results in June 1986, although the density of *M. veneriformis* was increased. Interestingly, based on its relative abundance in 1986, it was classified

| Biological zonation | Brachyuran zone | Molluscan zone | Holothurian zone |
|---|---|---|---|
| Diagnostic species | *Macrophthalmus japonicus*<br>*Moerella iridescens*<br>*Nephtys chemulpoensis* | *Mactra veneriformis*<br>*Umbonium thomasii*<br>*Nephtys californiensis*<br>*Solen strictus*<br>*Ilyoplax pingi* | *Protankyra bidentata*<br>*Borniopsis tsurumaru*<br>*Nephtys polybranchia*<br>*Asthenognathus inequipes*<br>*Lumbrineris heteropoda*<br>*Magelona* sp. |

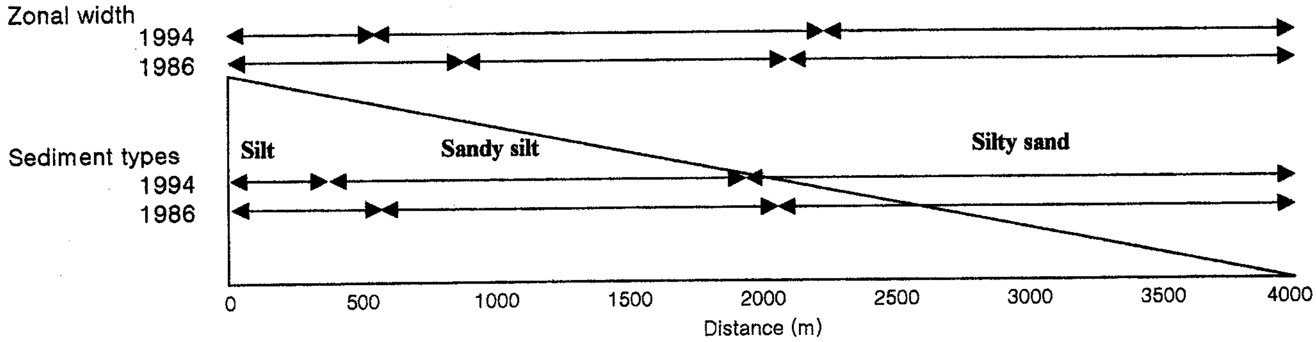

**Fig. 7.** Zonation and its diagnostic species in Chokchon macrotidal flat. Zonal boundaries and surface sediment types from this study and Frey *et al.* (1987a, b) were compared.

into an uncommon species distributing between 900 and 3500 m. In July 1994, *M. veneriformis* with a great many densities of 5–3535 individuals/ was distributed from 600–4100 m. Near the opposite end of the distribution ranges (600–900 m, and 3900–4100 m), a very low abundance was reported from this study.

In the r-mode analysis, some characteristic patterns were observed when species groups were divided into two types: (1) narrow-range (H, M1, M2, L1, L2 and L3) and (2) wide-range (HM, HML and ML) distributing species groups. Peterson (1991) demonstrated the specificity of species to a level through transplant experiments and noted a finding consistent with the hypothesis that physiological sensitivity to increasing stresses of higher elevation contributes to clam zonation in a sandy shore. However, the authors couldn't find a reason to remove the possibility of selectivity of substratum that might be contributed to the specificity because a gradient of sedimentary facies was more remarkable and the sediments were mainly divided into three types that fitted well with the tripartite zonation in this macrotidal flat. Anyway, it was found that the zonation was organized by the level-specific groups, though the right cause of zonation was not revealed in this study.

The interruption of distribution was detected in several species groups. For example, polychaete, *Aricidea assimilis*, was contiguously distributed in the middle level, and ranged to the lowest level stations. However, the interruption occurred in the lower level and the interval was *ca.* 1.5 km. In case of species with low densities, it might be ascribed to infrequency and an inappropriate sampling size for sampling. However, interruptions in abundant species like the L2 species group could be linked to the result of biological interactions (see Fig. 4). In altitudinal distribution of terrestrial plant species, a similar phenomenon was interpreted as representing a good proof of competition by Mueller-Dombois *et al.* (1981). A clear bimodal pattern was not found, which strongly suggests the presence of a biological interaction (Huston, 1994). Though not introduced in tidal flat ecology yet, this kind of spatial pattern raised the necessity for testing competitions.

## *Some proofs of change in macrobenthos faunal assemblages*

Within the limit of comparison ascribed to the long-time span between the two samples, only tentative conclusions could be drawn on the changes of faunal assemblages. The authors intended to detect the influences from potential factors of anthropogenic activities (*e.g.*, building seawall of LNG receptor base and dyke of Shihwa), increasing eutrophication, and rising temperatures. Though a correlative study was not performed, populations or communities would respond to one of these potential and consistent effects in possible ways from which some remarkable patterns could be found and interpreted.

Ahn and Choi (1998) recently proposed a hypothesis that directional variation of tidal flat faunas was linked to gradual coarsening surface sediment after the seawall construction. The surface sediment of this area had no remarkable changes when compared with those of Kim (1983) and Frey *et al.* (1989). Borderlines among sediment types (silt-sandy silt-silty sand) showed slight variation in 1986 and 1994 (Fig. 7). In Kim (1983), mean grain size of the sediment varied between 3.7 and 6.3ϕ from land to seaward. Frey *et al.* (1989) reported the size between 3.7–6.5ϕ. In this study, it varied between 3.3–7.0ϕ. In a fixed station of Chokchon tidal flat, mean grain size showed neutral trend with variation ranges of *ca.* 0.4ϕ in muddy sand bottom and *ca.* 1ϕ in silt bottom for six years (Yoo *et al.*, 1999b). Hence, there were no significant changes in the sediment textures in the study area.

Previous workers reported the effect of temperature rise (Beukema, 1992; Barry *et al.*, 1995) and eutrophication (Beukema and Cadee, 1986; Jensen, 1986) on macrobenthos faunal assemblages. In Yoo *et al.* (1999a), a time-series analysis on water temperature between 1980 and 1996 was tried and a +2°C increasing trend was observed. Summer temperatures had no trend, but winter temperatures showed some rising trend after the late 1980s and were predicted to rise consistently until 1995. However, a prevalence of southerly species in this study could not be found.

Remarkable changes were detected in two bivalve populations, *Meretrix petechialis* and *Theora fragilis*. *M. petechialis* was mainly found on the lower sand bottom and *T. fragilis* on the upper silt bottom. In the early 1980s, total yearly catches of *M. petechialis* ranged from 24997 to 70313 kg (data gathered from Chokchon fishing village cooperatives). However, the population size sharply declined from 1984, and after 1986, *M. petechialis* was not caught presumably because of the extremely low potential stock of the natural population. Several factors may be the culprit (*e.g*, parasite endemism, temperature, eutrophication, *etc.*). No studies were carried out to elucidate the exact causal factors. Temperature rise could not be related with the collapse because the species' southern distribution range extends to Hadong, Chollanam-do (Yoo, 1991). By contrast, the organic pollution indicator species, *T. fragilis*, has showed an increasing trend as time goes by. From 1986 to 1991, the number of *T. fragilis* might have been under a detectable limit; however, from the late spring of 1992, 1 individual/m$^2$ was reported by Seo (1994) and in the present study, density ranged between 5 and 85. This trend seemed to be a response to the increasing degree of eutrophication in and around this coastal area. The appearance of another pollution indicator species, *Capitella capitata*, should be noted also, which has never been observed before, although it was detected under 20 individuals/m$^2$. Except for the case of *M. petechialis*, two other species' response was presumably attributed to eutrophication.

Probable responses of macrofauna to direct and indirect effects of temperature rise and other factors seemed to be equivocal at this scale of comparison. The newly observed species and their obvious increase in abundance should be noted and regarded as an impregnable proof of increasing trend of eutrophication, although the authors could not identify the source of this eutrophication.

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