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Abundance of Polychaetes in Lake Shihwa, Korea

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This study examined the relationship between the sediment pollution and the occurrence of polychaetes in a heavily polluted saltwater lake, Lake Shihwa on the west coast of Korea, separated from the sea by a dike in 1994. The species composition of polychaete assemblage was compared with that found off the lake in Kyeonggi Bay. Environmental variables investigated both in and off the lake were the grain size distribution, chemical oxygen demand (COD) and metal concentrations (Al, Fe, Mn, V, Co, As, Pb, Cr and Cu) in the sediment. We sampled sediments at 10 stations in the lake and 25 stations in Kyeonggi Bay using a modified van Veen grab. The levels of COD, chromium, and copper in sediments were much higher in Lake Shihwa than in Kyeonggi Bay. Differences in the species composition were found along the pollution gradient. An azoic zone was observed in the most heavily polluted area at the upper reach of the lake and the *Polydora ligni* zone in the center of the lake. Bottom fauna were diverse in Kyeonggi Bay; however, *Heteromastus filiformis* predominated in the organically enriched sediment. The density of dominant species differed along the pollution gradient. The highest density of *H. filiformis* was found at the COD level of around 5.8 mg/g. The COD level in the sediment where *P. ligni* predominated was tow-fold higher than that where *H. filiformis* occurred in large numbers. The chromium and copper contents at which *P. ligni* showed a maximum abundance were 120 mg/kg and 127 mg/kg, respectively. The density of *H. filiformis* was highest at concentrations of 56 mg/kg chromium and 13 mg/kg copper.

INTRODUCTION

Coastal areas of the Korean peninsula have long been exposed to industrial use for the rapid achievement of economic growth since 1970's. In the early stage of the industrialization, industrial complexes were largely established around bays on the east and south coasts, but have been expanded even to the west coast especially since the mid 1980's. Coastal use on the west coast has involved reclamation of tidal flats that broadly developed seaward along the coast. Land earning was the prime interest and, therefore, tidal flats have frequently been barriered and landfilled (RDC, 1995).

Lake Shihwa is one of the typical areas reclaimed for industrial purposes on the Korean coast. The central government has launched in 1987 a project constructing a dike across the tidal flat that has been developed in the tidal inlet near Shihwa. A 12.7-km long barrier was completed in the beginning of 1994. The land earned from this project amounts to about 200 km^2. One third of the reclaimed tidal flat is being used for industrial purposes and the rest is left for agriculture (RDC, 1995). Lake Shihwa, which covers an area of about 56.5 km^2, now forms a channel that remains after the reclamation, and it is to be filled with freshwater after flushing the saltwater. The amount of water retained in the lake is about 0.2 billion metric tons.

The dike construction has caused the problem of pollution in the lake. A large amount of sewage about 3 million tons per day is discharged into the lake from Ansan, a city near the lake with a population of 0.5 million (Lee, 1997). Industrial wastewater of 1.8 million tons per day also flows from the Panweol industrial complex into the lake. Only about 50% of the total discharge receive primary treatment that removes floatable and suspended solids before it reaches the lake (Lee, 1997). Rapid accumulation of hazardous substances and its resultant faunal changes have been expected as the consequence of industrial pollution. Before the dike construction, however, suspended materials could be dispersed widely to outer Kyeonggi Bay (Lee *et* *al.*, 1985). The embanked area was a tidal inlet originally connected to Kyeonggi Bay and belonged to a macrotidal regime. Sediment transportation by tidal current as well as surface distribution and geochemical properties of sediments was reported by Lee *et al.* (1985).

Faunal records on the Panweol tidal flat near Panweol industrial complex in 1984 indicated no signs of pollution effects on the benthic community (Koh and Shin, 1988). However, Ahn *et al.* (1995) the recently reported a sharp decrease in the species number of tidal flat fauna from 22 in 1984 to 4 in 1992 and increases in the concentrations of copper (from 33 to 70—323 mg/kg) and lead (from 31 to 33—83 mg/kg) in sediments. The large increase in the number of industrial plants from 442 in 1984 to 1157 in 1992 was thought to be a factor responsible for those changes, although the area was under the influence of tidal fluxes. This area receives the industrial effluents as before, and it is all the worse because of the absence of tidal mixing due to the dike construction. Faunal characteristics has intensively been reported after the dike construction (Hong *et al.*, 1997; Lee and Cha, 1997; Ryu *et al.*, 1997). However, those reports have largely concentrated on the distribution of bottom fauna in an aspect of the concentration of organic matters. The present study attempted to describe the faunal occurrence with respect to heavy metal levels in the sediment.

The present study aims to assess the level of accumulation of pollutants (heavy metals and others) in the bottom sediment of Lake Shihwa and their impact on faunal composition in the sediment after the barrier construction. Sediment samples were collected from the lake as well as surrounding waters off the lake. Occurrence of polychaetes is compared with the pollution level, especially the heavy metals concentration in sediments. The outer region of Lake Shihwa, Kyeonggi Bay, was also investigated to compare the fauna and the level of pollutants with those within the lake.

MATERIAL AND METHODS

Study area

Lake Shihwa is located between 37°10' and 37° 17'N and 126°35' and 126°50'E in the central eastern part of Kyeonggi Bay (Fig. 1). The lake area was connected to Kyeonggi Bay before its separation from the sea by the dike. The velocities of tidal currents in the surface water had a range of 110 cm/s at spring tide and 46 cm/s at neap tide before the dike construction (Lee *et al.*, 1985). The maximum velocity at the near-bottom of the water column reached 70 cm/s during the flood.

The filling of the artificial Lake Shihwa with freshwater began in 1994 just after the completion of the barrier. However, the lake has received little freshwater input other than runoff from a few small creeks to the east. The main source of freshwater is drainage from the city of Ansan and the industrial complexes to the north of the lake. A slightly lower salinity of 31.4 to 32.6‰ than that measured from the coastal waters outside the dike indicates there is little change in the freshwater volume of the lake by the land runoff. The Shihwa industrial complex has been developed on new ground reclaimed after the dike construction, but the Panweol industrial complex has been in full operation since 1979.

Kyeonggi Bay, located outside of Lake Shihwa, is a tide-dominated environment with spring tides up to 9 m high (Yi, 1972). Tidal currents is predominate in the NE-SW direction and range up to 3.4 knots in the channel areas. The variation in water temperature reaches a maximum of 24.7°C in sum- mer and a minimum of 5.4°C in winter.

The morphology of Kyeonggi Bay has been changed largely by reclamation of the tidal flat. A 10-km long dike from the Namdong Industrial Complex to a LNG deposit established in 1993 runs parallel to the dike of Lake Shihwa 3 km south of the dike (Fig. 1). The accumulation of pollutants in the channel between these two dikes was also expected, since industrial effluents from the Namdong industrial complex flow into it.

The northern part of Kyeonggi Bay receives freshwater from the Han River that joins the main tidal channel of Kanghwa Suro. Fluctuations in salinity were reported to be in the range of 26.9 to 32.4‰ at the mouth of the Han River (Choi and Shim, 1986). Freshwater discharge amounts to 18×10^6 m^3 per day. The anthropogenic substances discharged to Kyeonggi Bay through the Han River are 135 metric tons per day of organic substances, which was equivalent to 50.4 metric tons per day of nitrogen. The Han River runs through the capital city of Seoul, which has a population of more than 10 million. Organic materials loaded from the Han River to Kyeonggi Bay were estimated to be 60% of the total discharge. Urban runoff from Incheon counted to about 35% of the total (IMC, 1993).

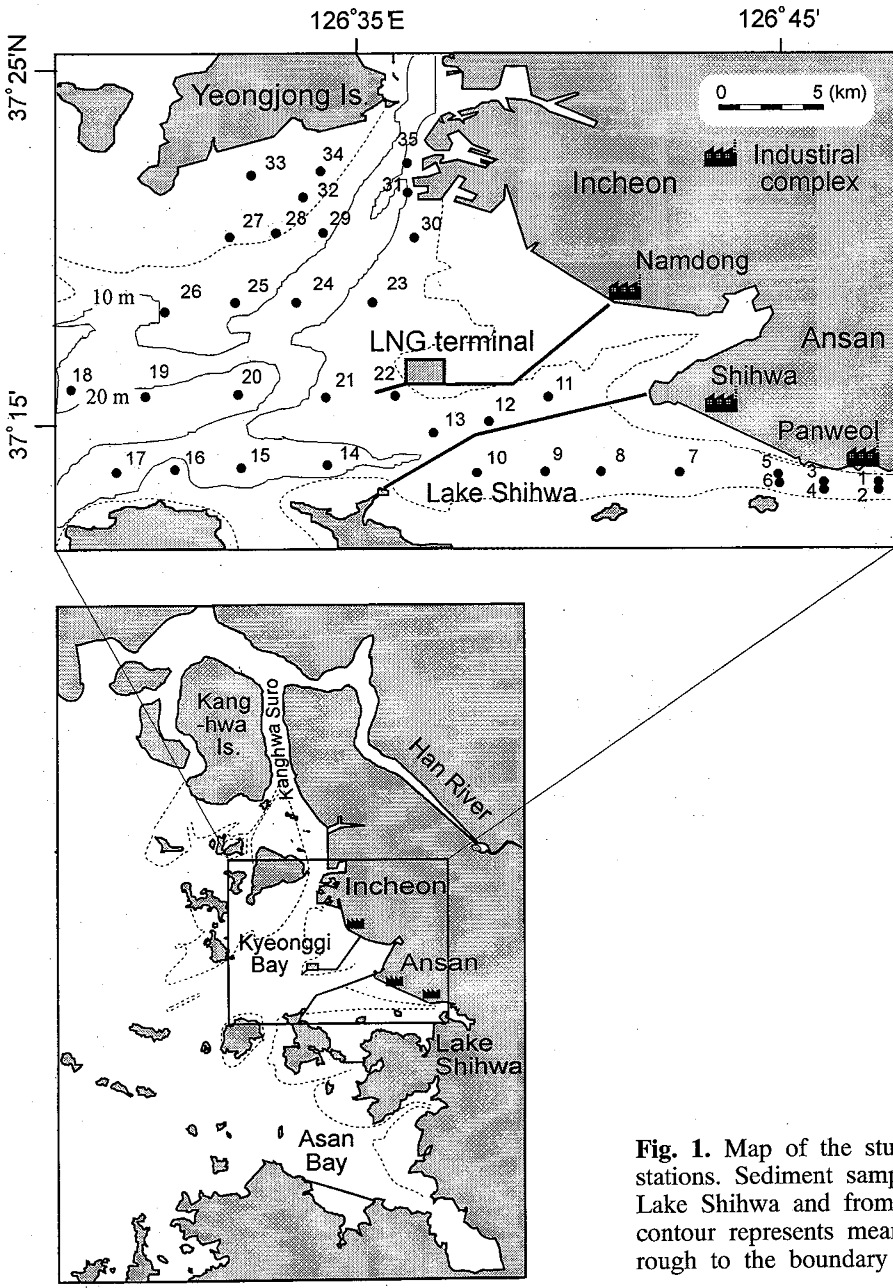

Fig. 1. Map of the study area with locations of 35 sampling stations. Sediment samples were taken from 10 stations in Lake Shihwa and from 25 stations in Kyeonggi Bay. Dotted contour represents mean level of low waters and corresponds rough to the boundary of Lake Shihwa with the dike.

Sample collections and analysis

Bottom sediments were taken tow-fold from 10 stations along the former channel area in Lake Shihwa in October 1994 and from 25 stations in Kyeonggi Bay in June 1994, using a modified van Veen grab with 0.1 m^2 sampling area. The sediments were screened through a 1-mm mesh sieve, and organisms retained on the sieve were fixed in 10% buffered formalin. The animals were then identified to the species level and enumerated in the laboratory. The number of species, their abundance, and the dominant species as well as species diversity (H': Shannon and Weaver) were determined and then compared between stations in Lake Shihwa and in Kyeonggi Bay.

At the time of sediment collection, about 100 g of surface sediment was sub-sampled to measure grain size, chemical oxygen demand (COD), and the concentrations of metals (Al, Fe, Mn, V, Co, As, Pb, Cr and Cu). The grain size was analyzed using the standard dry sieve and pipette method. COD was determined by oxidation of surface sediments with $KMnO_4$. For the determination of metal concentrations in the sediment, aliquots of oven-dried and powdered sediments of ca. 0.5 g were digested with a mixed solution of concentrated nitric (HNO_3, 6 ml), hydrofluoric (HF, 4 ml), and perchloric ($HClO_4$, 2 ml) acids in screw-capped Teflon beakers on a hot plate at 175°C for 4 hours (Kitano and Fujiyoshi, 1980). The samples were oxidized tow-fold and then dried via evaporation to remove excess acids, and residues were dissolved in 1 N HNO_3. After centrifuging at 4500 rpm, the supernatant was diluted to 1 ml 1 N HNO_3. The concentration of heavy metals was determined using ICP-AES. The reference sediment used for the calibration was NRC BEST-1 (NRC of Canada).

RESULTS

Heavy metal concentration in the sediment

Environmental characteristics of sediments in and off Lake Shihwa are presented in Fig. 2. Fine-grained sediments representing silty to muddy facies were dominant in the bottom of Lake Shihwa. The phi values ranged from 6.0 ϕ to 7.8 ϕ. These sediments were enriched with organic matter: COD values ranged from 8.0 to 18.1 mg/g of dry sediments. High concentrations of copper and chromium were observed from sediments collected in the central area of the lake. High values of 338 mg/kg of copper and 321 mg/kg of chromium were recorded at Station 1. Plots of metal concentrations versus grain size clearly showed an anthropogenic accumulation of copper and chromium in the lake sediments (Fig. 3). Most of the metal elements showed a linear relationship with grain size. The metal concentrations became higher with increasing phi value of the grain size. An exception was the case of manganese, which showed higher values at large grain sizes. The levels of copper and chromium in lake sediments were far higher than those expected from the regression lines.

The sediments off the lake, in Kyeonggi Bay, were composed of coarser grains, mostly sand to silty sand (Fig. 2). The phi values ranged from 1.5 ϕ to 6.2 ϕ. There was a decreasing tendency in grain size from the sea to the dike. The mean grain size of sediments just outside of the lake was 5.5 to 6.2 ϕ (Stations 11 to 13). Fine-grained sediments of 4.4 to 5.4 ϕ were also observed around Incheon Harbor (Stations 30, 31, and 35). COD values in sediments collected from Kyeonggi Bay ranged from 0.3 to 5.8 mg/g of dry sediment. The mean value was about one-third of the level observed in the lake sediments. Concentrations of trace metals including copper and chromium were lower in Kyeonggi Bay: the highest concentration of 13.8 mg/kg of copper was found at Station 11 located at the entrance of the Namdong Industrial Complex. The level of chromium was also highest at Station 11 (56 mg/kg). However, these levels of copper and chromium were not higher than the equivalents derived from the regression lines of those concentrations against the grain size. A linear relationship between the levels of copper and chromium and the sediment grain size was clearly shown in Kyeonggi Bay (Fig. 3).

Occurrence of polychaetes

Altogether, 62 species of polychaetes, 11 crustaceans, 8 mollusks, and 7 other species of inver-

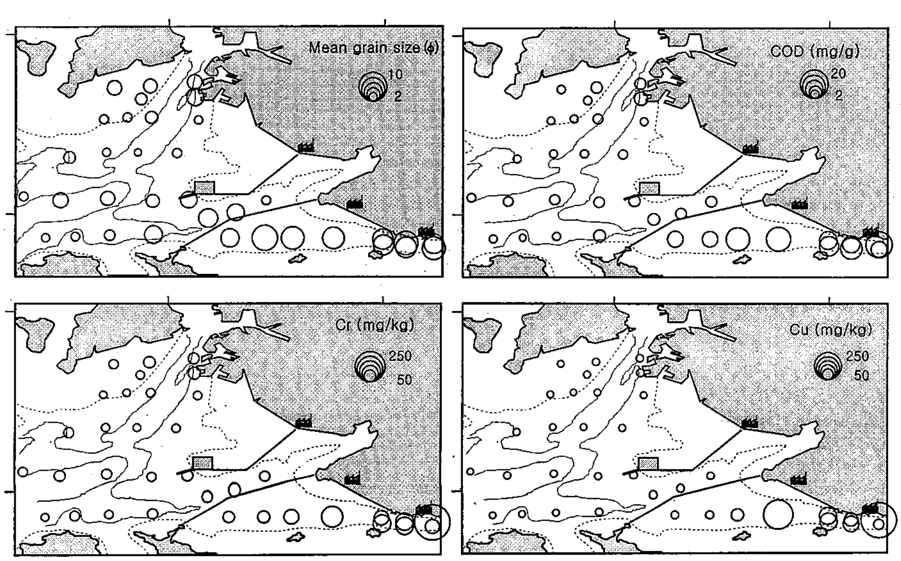

Fig. 2. Maps showing the mean grain size of sediment and the levels of chemical oxygen demands (COD), chromium (Cr) and copper (Cu) in sediments of the study area.

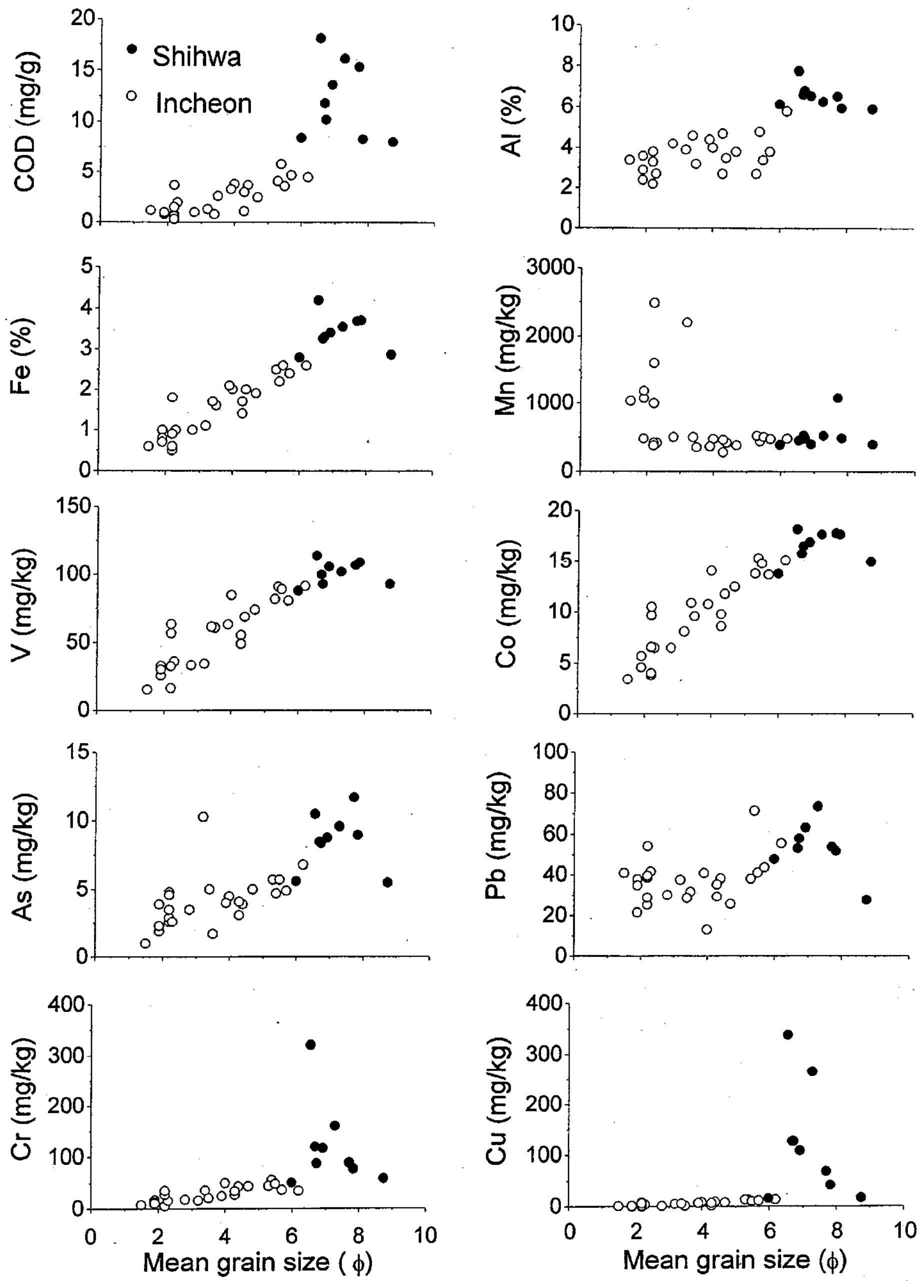

Fig. 3. The relationship between the concentration of metals in sediments and the sediment mean grain size. The level of metal concentrations is plotted against the mean grain size.

tebrates were collected during this study. The total count amounted to 10065 individuals and the mean density per station was 288 ± 433 (mean $\pm$ SD). The number of individuals for each species ranged from 5 to 2080 individuals per square meter. Polychaetes were the dominant group in respect to the abundance as well as the number of species. The polychaetes group with which we were concerned during this study occupied more than 85% of the total count and 70% of the total number of species. A number of polychaete species were aggregated at Station 20 (26 species) and Station 19 (18 species) located around the main channel (Fig. 4). However, the center of the density did not coincide with that of the number of species. The highest density of polychaetes was found at Station 6 in Lake Shihwa (2085 individuals/m^2). Another high density of polychaetes was observed at Station 31 near Incheon Harbor in Kyeonggi Bay (1520 individuals/m^2).

In Lake Shihwa, some species of polychaete (10 species) were identified from the sediment samples. There was even an azoic zone at the upper reach of the lake (Stations 1 to 4) where no animals were found (Table 1). The central area of the lake

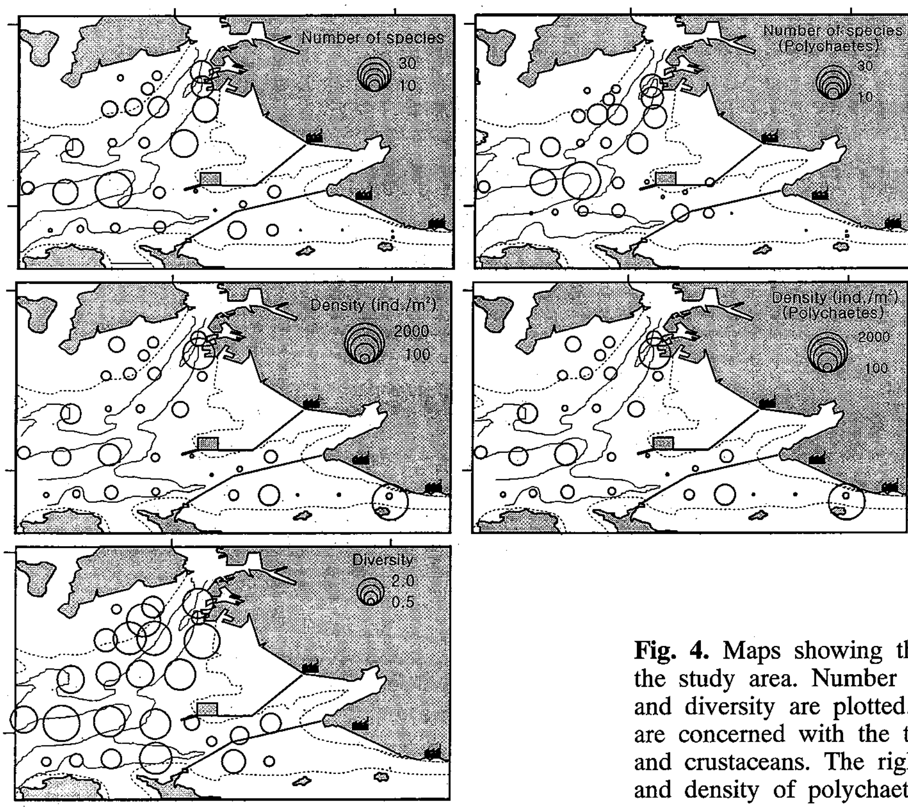

Fig. 4. Maps showing the values of ecological indices in the study area. Number of species, density (individuals/m^2) and diversity are plotted. The left-side figures from the top are concerned with the total community including molluscs and crustaceans. The right-side figures are number of species and density of polychaetes counted from the same samples.

Table 1. Individual numbers of dominant species counted at tow-fold samplings (0.2 m^2 areal coverage) in Lake Shihwa and Kyeonggi Bay (Numbers in parentheses indicate numbers of stations where polychaetes occurred among the total of 35 stations)

Species name	Total counts	Individual numbers counted at tow-fold samplings Lake Shihwa							Kyeonggi Bay
		St.1-4	St. 5	St. 6	St. 7	St. 8	St. 9	St. 10	
Polydora ligni	538 (6)		416	11	2	1	108	1	
Heteromastus filiformis	338 (15)							6	332 (14)
Nephtys polybranchia	108 (20)							2	106 (19)
Sternaspis scutata	89 (9)							5	84 (8)
Prionospio cirrifera	72 (9)								72 (9)
Chaetozone setosa	70 (8)								70 (8)
Mediomastus sp.	63 (16)						1	3	59 (14)
Glycinde sp.	59 (15)						8		51 (14)
Tharyx sp.	48 (12)								48 (12)
Aricidea sp.	30 (7)								30 (7)
Aricidea jeffreysii	26 (8)							4	22 (7)
Glycera chirori	23 (9)							2	21 (8)
Goniada sp.	9 (8)							1	8 (7)
Magelona sp.	8 (4)								8 (4)
Nephtys ciliata	8 (3)								8 (3)
Sigambra sp.	7 (2)						2		2 (1)
Prionospio pygmaea	6 (4)						1	1	4 (2)
Pseudopolydora kempi	5 (2)		2				2		1 (1)
Capitella capitata	4 (1)							4	

(Stations 5 to 8) was populated by the spionid polychaete *Polydora ligni* with a low density of 5 to 55 individuals/m^2. However, high density of this species was found at Station 6 (2080 individuals/m^2). The only other species occurring in the central area was the spionid polychaete, *Pseudopolydora kempi* (10 individuals/m^2 at Station 6). The bottom sediments collected from Stations 9 and 10 near the dike were inhabited by polychaetes with relatively higher species number and abundance. The species numbers of polychaetes (7 at Station 9 and 12 at Station 10) were approximately equal to the mean number of species (10±6, mean±SD) identified from Kyeonggi Bay. The numbers of individuals were 135 and 625 at Stations 9 and 10, respectively.

A total number of 55 species of polychaetes recorded in Kyeonggi Bay was greater than that in Lake Shihwa (10 species). The average number of species per station was also larger in Kyeonggi Bay (9±6, mean±SD) than that of Lake Shihwa (2±4) ($p<0.001$). The average count of individuals per station (228±315 individuals/m^2, mean±SD) was not greatly different from that of Lake Shihwa (292±625)($p=0.71$). A feature of the abundance distribution in Kyeonggi Bay was that individual numbers at each station deviated far less from the mean compared with those in the lake area. The most abundant species in Kyeonggi Bay was the deposit feeding polychaete, *Heteromastus filiformis*, which was found at 14 of the 25 stations (Table 1). However, this species was most abundant at Station 31 (1200 individuals/m^2) at the entrance of the Incheon Harbor, where the bottom sediment was most highly enriched by orgamic matters among

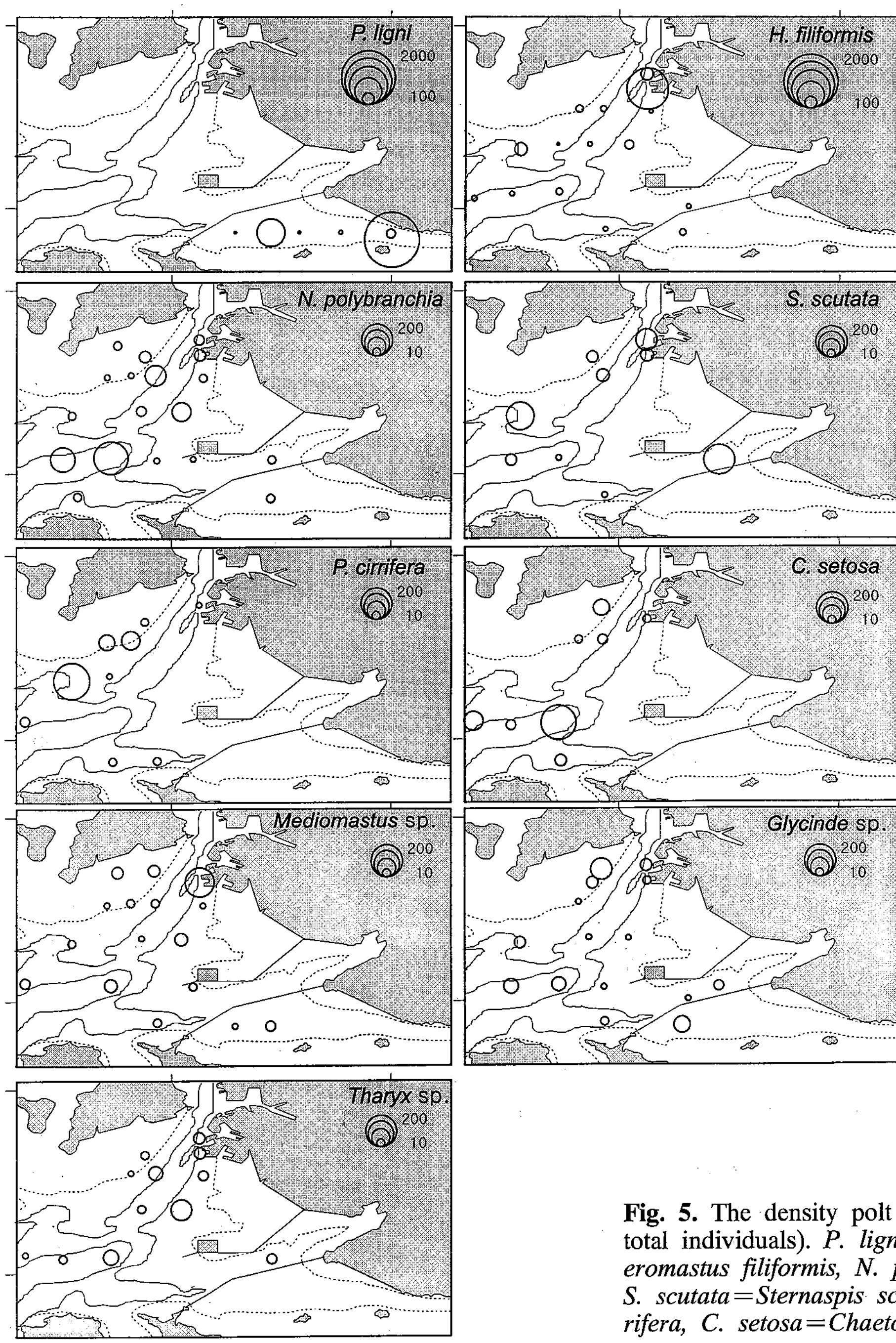

Fig. 5. The density polt of dominant species (>2% of the total individuals). *P. ligni*=*Polydora ligni*, *H. filiformis*=*Heteromastus filiformis*, *N. polybranchia*=*Nephtys polybranchia*, *S. scutata*=*Sternaspis scutata*, *P. cirrifera*=*Prionospio cirrifera*, *C. setosa*=*Chaetozone setosa*.

stations in Kyeonggi Bay. The COD level at Station 31 was 5.8 mg/g dry sediment. The mean value of COD except Station 31 was 2.1±1.4 mg/g dry sediment.

Other common polychaete species were *Nephthys polybranchia, Sternaspis scutata, Prionospio cirrifera, Chaetozone setosa, Mediomastus* sp., *Glycinde* sp., and *Tharyx* sp. (Table 1; Fig. 5). All of these species recorded the abundance greater than 2% of the total count. The first four of the above seven species were most abundant at the edge or in the center of the channel where coarse-grained sediment predominated. *S. scutata* and *P. cirrifera* showed the highest density at Station 26 (33% of all abundance) and Station 11 (58%), respectively. *N. polybranchia* (32%) and *C. setosa* (53%) were most abundant at Station 20. Although the second dominant species, *N. polybranchia*, had a high density at deep-water stations (Stations 19 and 20), this species was more common than *S. scutata, P. cirrifera*, and *C. setosa*. These species occurred at eight to nine of the twenty-five stations in Kyeonggi Bay. *Mediomastus* sp. was also common (14 among 25 stations), but its distribution is peculiar in terms of having a great density at Station 31 near Incheon Harbor. *Glycinde* sp. and *Tharyx* sp. did not show high densities at any stations but displayed rather uniform distribution patterns all over Kyeonggi Bay.

Plots of the nine most dominant species against environmental variables, which showed an anthropogenic accumulation of metals in Lake Shihwa (Figs. 2 and 3), provided distributional evidences to ascertain habitat characteristics (Fig. 6). Taxa from top to bottom in Fig. 6 are arranged so that the median values of environmental variables on which the center of occurrence shifts to the right along the gradient of variables. Mean grain size was also included to examine on any preference to sediment types.

Some correlation among the various environmental variables and the dominant polychaetes was noted. The most common species associated with the finest sediment grains were *P. ligni* and *H. filiformis*. *Mediomastus* sp. would also be considered as a species that prefers fine-grained sediment, but its density was about ten-fold or even twenty-fold lower than the mentioned two species. *P. ligni* differed from others by showing an extremely high density at higher levels of COD, chromium and copper in sediment. The pollution levels over which each taxon was found discriminated by contaminants. With the exception of *P. ligni*, almost all the dominant species were found in sediments with an upper maximum of about 20 mg/kg of copper. The range of chromium in which polychaete growth was tolerant was generally wider than that of copper (maximum of about 70 mg/kg).

DISCUSSION

Extremely high accumulation of heavy metals was shown in the bottom sediment of Lake Shihwa. The content of chromium in nearshore sediments of the Korean peninsula ranges from 33 to 68 mg/kg (Cho, 1994), whereas its concentration ranges between 51 and 321 mg/kg in the present study. The level of chromium in the center of the lake was even higher than that in the intertidal sediment (69 to 194 mg/kg) collected in June of 1992 from the tidal flat located north of Station 1 (Ahn *et al.*, 1995). An increase in the concentration of copper in the lake sediment was also shown. The copper concentration in the sediment around Station 1 in 1984 was 33 mg/kg (Lee *et al.*, 1985; Lee *et al.*, 1992) and 73 mg/kg in the lower intertidal zone of the upper inlet east of Station 1 in 1986 (Jung *et al.*, 1996). However, in the present study, the highest concentration found was 338 mg/kg. The range of the copper content in the Korean coastal sediments was 7 to 22 mg/kg (Cho, 1994).

A significantly lower number of species and the less diversity of infauna in Lake Shihwa ($p<0.001$) relative to those of Kyeonggi Bay (Fig. 4) are found and thought to be related to the accumulation of pollutants in the lake sediment. Rygg and Skei (1984) reported that the number of species was roughly halved for each ten-fold increase in the copper concentration in Norwegian fjords. In the present study, even an azoic zone was found around Stations 1 to 4, where the mean copper concentration (143 mg/kg) was approximately twenty-five times higher than that of outer Kyeonggi Bay. The total of 9 species recorded at Stations 5 to 9 in Lake Shihwa was only one eighth of the total counted in outer Kyeonggi Bay. This decrease is striking when compared with that reported by Rygg and Skei (1984). The mean concentration of copper (121 mg/kg) at Stations 5 to 9 was about twenty-fold higher than that of outer Kyeonggi Bay.

High concentrations of organic matter, chromium, and copper in the lake sediment were reflected by the species composition and the abundance. Before the dike construction, the tube-building polychaete

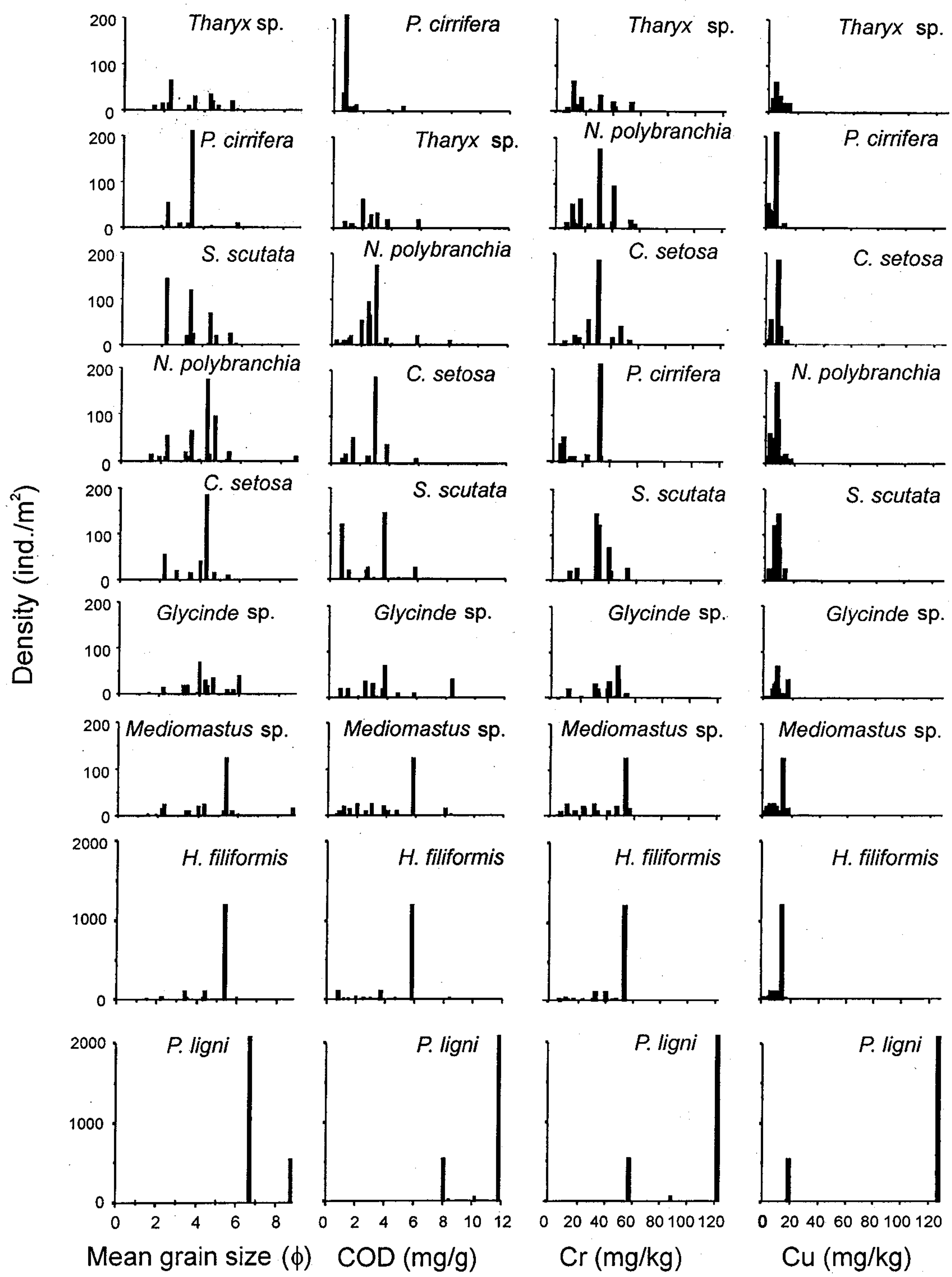

Fig. 6. The density of 9 dominant species are plotted against the mean grain size ((), chemical oxygen demands, chromium, and copper. Abbreviations of the species names are same as in Fig. 5.

Laonome tridentata and the small suspension-feeding bivalve *Potamocorbula amurensis* were dominant (43800 and 19250 ind./m^2, respectively) in the channel area near the Station 1 (Koh and Shin, 1988). Ahn *et al.* (1995) reported an occurrence of *H. filiformis* with its density range from 62 to 395 ind./m^2 in sediment near the channel in June 1992. This species was the most abundant polychaete, accompanied by the nereid polychaete *Perinereis aibuhitensis*. In the present study, however, no animals were found around Stations 1 to 4 and instead, a highly populated zone of *P. ligni* occurred in the central area (Station 5). The predominance of *P. ligni* in the area enriched with organic matters was already reported in the lake Shihwa (Hong *et al.*, 1997; Lee and Cha, 1997).

It is noteworthy that the capitellid polychaete *H. filiformis* was widely distributed in Kyeonggi Bay, but none was found in Lake Shihwa. The frequency of occurrence was 60% in Kyeonggi Bay (14 among 25 stations). The highest density of this species (1200 ind./m^2) was found at Station 31 near Incheon Harbor where organic matter was highly accumulated and COD level was the greatest (5.8 mg/g dry sediment) among the stations in Kyeonggi Bay.

Rygg (1985) reported twenty-three species tolerant to the high concentration of copper exceeding 200 mg/kg. Three species, *P. ligni, H. filiformis,* and *C. setosa* were designated as very tolerant species. In the present study, however, the highest concentration of copper for *H. filiformis* and *C. setosa* to tolerate was lower than one tenth of that reported from the Norwegian coast (Rygg, 1985). The only species showing characteristics comparable to Rygg's results was *P. ligni*, showing a maximum abundance at around 130 mg/kg copper content in the sediment. However, *P. ligni* was absent at Stations 1 to 4, although the level of copper concentration was low (42 mg/kg at Station 1). The level of copper lower than Rygg's maximum tolerance for *H. filiformis* and *P. ligni* in the study area (Fig. 6) is difficult to interpret. A high concentration of chromium would act combined with copper concentration, or a deficiency in dissolved oxygen (Hong *et al.*, 1997) in bottom water could affect the occurrence. The binding effect of sulfur with heavy metals (Jung *et al.*, 1996) would exclude the bio-effect, but the subject remains for further study.

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