Journal of Environmental Biology **July 2008,** 29(4) 559-566 (2008)

Effects of sediment disturbance caused by bridge construction on macrobenthic communities in Asan Bay, Korea

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(Received: March 08, 2007; Revised received: December 21, 2007; Accepted: December 27, 2007)

Abstract: *Changes in soft-bottom macrobenthic communities and the effects of anthropogenic disturbances were studied. We compared biological and environmental samples during and after bridge construction (DBC and ABC). Significant differences were detected in sediment composition at three stations, although hydrographic conditions were similar for DBC and ABC samples. From DBC to ABC, the number of species and density of macrobenthic fauna tended to decrease, whereas biomass increased. Non-metric multidimensional scaling (MDS) analysis identified two sampling period groups from eight temporal samples, plus three station groups and one station from 12 spatial samples, which corresponded to macrobenthic faunal assemblages and their characteristic species. In addition, contributions of variables to similarity showed that the DBC and ABC samples differed significantly in the distribution of characteristic species and proportion of polychaete trophic groups, suggesting that the macrobenthic community structure was a factor affecting sediment disturbance caused by bridge construction.*

Key words: *Bridge construction, Sediment disturbance, Macrobenthos, Trophic group*
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Introduction

Human activities cause varying degrees of impact on marine benthic habitats, and the current rate of habitat degradation is alarming. Human activities that negatively impact benthic habitats include marine aquaculture (Edgar *et al.,* 2005), dumping (Stronkhorst *et al.,* 2003), sand mining (De Groot, 1979), and industrial exploitation (Ogbeibu and Victor, 1989; Lewis *et al.,* 2002; Dauvin *et al.,* 2006).

Studies of macrobenthic communities are useful for assessing short- and long-term changes in marine ecosystems and thus for discriminating between natural and human-induced disturbances (Olsgard and Gray, 1995). Macrobenthic animals are relatively sedentary or immobile, have relatively long life spans, are abundant and diverse in most marine benthic habitats, and display interspecific differences in environmental stress tolerance (Pearson, 1975). Structural changes of macrobenthic communities caused by environmental disturbance can be understood by examining species distributions and diversity in time and space (Sanders, 1958).

The impacts of sedimentary disturbance on macrobenthic communities caused by anthropogenic activities, such as reclamation and dredging, have been extensively studied. Anthropogenic sediment removal can expose the underlying sediment, redeposit suspended material onto the substratum (including organic particles that are often bound to sediment grains; De Groot, 1986), and elevate sedimentation rates and suspended sediment levels in coastal waters (Hewitt *et al.,* 2003). On the broader scale of macrobenthic communities, in particular, this can influence species composition, density, biomass, diversity, and colonization by opportunistic species (Warwick, 1988; Kenny and Rees, 1994).

Historically, Asan Bay, Korea, was a spawning and nursery ground for various commercial fishes (Lee and Hwang, 1995). However, during two decades of human exploitation in the bay, a well-developed tidal flat and two major influx streams were replaced by industrial complexes and huge artificial lakes. In addition, from 1993 to 2000, reclamation and dredging activities were undertaken for the construction of the Seohae Grand Bridge, across the middle part of the bay. Due to continuous exposure to these situations, the marine benthic ecosystem inevitably experienced environmental disturbances such as sedimentary change, which can strongly affect benthic animals (Boyden and Little, 1973).

The macrobenthic faunal composition of coastal areas may vary considerably at different spatial and temporal scales. Such variability in faunal distributions may be further modified by localized natural and human disturbances of different magnitude. Accordingly, predicting directional changes in the macrobenthic fauna in coastal areas is difficult (Gray and Christie, 1983). Long-term monitoring studies, including pre- and post-event comparisons, are essential for defining protracted trends. Unfortunately, few studies have considered long-term changes in soft-sediment macrobenthic communities in Korean coastal areas (Lim and Hong, 1994; Hong *et al.,* 1997; Choi *et al.,* 2006). Furthermore, the macrobenthic community structure in Asan Bay is unknown, although studies have documented the plankton community (Choi and Park, 1993; Sharma and Cyril, 2007; Park and Shin, 2007), fish community (Lee and Hwang, 1995), and water content (Moon *et al*., 1993) of the bay.

We examined the macrobenthic community during and after bridge construction in Asan Bay to assess the key variables affecting spatial and temporal changes. The main objectives of the study were to compare certain environmental variables, macrobenthic faunal composition, and community structure during and after bridge construction.

Materials and Methods

Asan Bay (36°55' N, 126°50' E) is the largest mega-tidal bay on the west coast of Korea (Fig. 1). The average tidal range is about 6.1 m for the spring tide, with a peak of up to 9 m. This 80 km^2 bay opens to the eastern part of the Yellow Sea through a narrow channel (2-4 km wide and about 12 km long). In the inner portion of the bay, the Asan and Sabkyo embankments are located on either side.

The distribution of macrobenthic fauna was determined from two seasonal surveys conducted in 1995 (during bridge construction, DBC) and again in 2001 (after bridge construction, ABC). Sampling was carried out using a 0.05-m^2 Smith-McIntyre grab, and four replicate samples were taken at the same six stations in each year. The samples were sieved through a 0.8-mm mesh sieve, and the remaining fraction was kept in 5% formalin solution with Rose Bengal stain. In the laboratory, all the organisms were sorted, counted and identified in terms of species levels under a dissecting microscope (Leica MZ16 A) using standard references (Polychaeta: Paik, 1989; Decapoda: Kim, 1973; Mollusca: Min, 2004). Biomass was determined as wet weight (wwt) recorded to two decimal places.

Samples for sediment content analysis were taken with a spatula to a depth of about 5 cm from a separate grab sample at each station. Wet sieving (Buchanan, 1984) was used to determine the sand (>62.5 μm particle size) and silt-clay (<62.5 μm particle size) fractions of the sediment. Surface water temperature and salinity were measured with a portable temperature-salinometer at 1 m depth beneath the surface. The temperature of the bottom sediment was measured by inserting a thermometer into the intact sediment in a grab at each station.

Macrobenthic community structure was analyzed using both univariate and multivariate data analysis techniques. Several univariate community measures were calculated: number of species, number of individuals, wet weight, and the Shannon-Wiener species diversity index (*H'*).

For multivariate analyses, the spatial and temporal community patterns were tested using the analysis of similarity (ANOSIM) test. Non-metric multidimensional scaling (MDS) was used to investigate faunal similarity among samples (data were fourth-root transformed). Species responsible for similarities and differences between sample groups were investigated using the similarity percentages routine (SIMPER; Clarke, 1993). All multivariate analyses were performed using the PRIMER package (version 5.3).

Differences in the sediment content between DBC and ABC were tested by one-way analysis of variance (ANOVA). Polychaete species were classified into three trophic groups (carnivores, suspension feeders, and deposit feeders) according to Fauchald

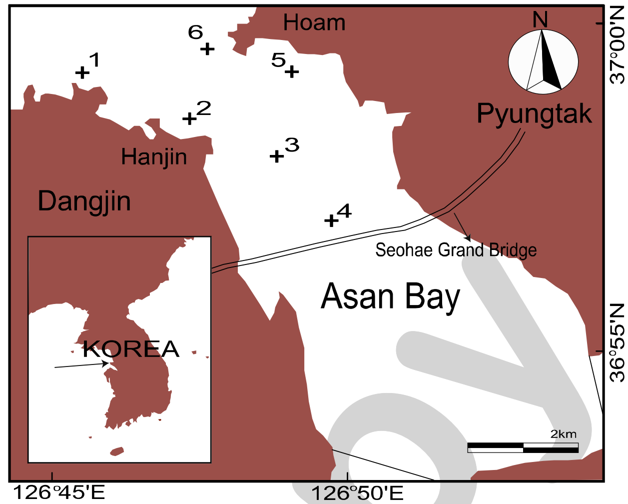

Fig. 1: Asan Bay, showing the locations of the six sampling stations

and Jumars (1979). The effect of pollution stress was assessed using geometric species abundance class plots (x 2 scales; Gray and Pearson, 1982).

Results and Discussion

Depth, surface water and bottom sediment temperature, salinity, and sediment content at the sampling stations are shown in Table 1. Hydrographic conditions were similar in the DBC and ABC sampling periods (Table 1). However, the depth at the stations varied between DBC and ABC due to different tidal levels at the sampling times. A total of 12 sampling stations were divided into three sediment types: sandy mud, muddy sand and homogeneous sand (Table 1). We found no significant differences in sand content at stations 1, 3, and 4 between DBC and ABC; sand content significantly increased at Station 2 ($p<0.01$) and significantly decreased at Station 5 ($p<0.001$) and 6 ($p<0.001$). At Station 3 and 4, located in the mid-water channel of the bay with homogeneous sand sediment (>98.0% sand content), we found no evidence of a sediment change, probably because of the strong tidal current. Dredge and reclamation activities in a coastal area resulting from industrialization, such as harbor development and road and bridge construction, may lead to changes in sediment composition (increasing turbidity and enhancing sedimentation) or hydrological conditions (current velocity; Ogbelibu and Victor, 1989; Dauvin *et al*., 2006). Here a notable change in sediment composition was detected at all stations except stations 3 and 4, reflecting the tidal current disturbance and suspended sediment caused by a temporary dam built for bridge construction.

In total, 206 macrobenthic species contained 99 species of polychaetes, 52 species of crustaceans, 28 species of mollusks, 10 species of echinoderms and 17 species belong several taxonomic groups (Nemertina, Actinaria and Tubellaria) were recorded from the study area: 134 species from DBC samples and 125 species from ABC samples. DBC samples contained 61 species of polychaetes (45.5%), 42 species of crustaceans (31.3%), 16 species of mollusks, seven species of echinoderms, and several other species. ABC

Table - 1: Summary of depth, physical parameters of sea water and sediment characteristics at the six sampling stations in Asan Bay during (DBC) and after (ABC) bridge construction (** = p < 0.01, *** = p < 0.001)

Period	Station	Depth (m)	Temperature (°C)		Salinity (psu)	Silt-clay content (%)	Sand content (%)
			Surface water	Sediment			
DBC	1	9.2	11.7 (±11.2)	11.7 (±11.1)	29.4 (±1.8)	65.9 (±1.9)	34.1 (±1.9)
	2	9.7	11.8 (±10.8)	11.9 (±10.7)	30.4 (±1.8)	74.8 (±1.2)	25.2 (±1.2)**
	3	6.2	12.7 (±11.1)	12.1 (±11.0)	29.8 (±1.6)	0.4 (±0.2)	99.6 (±0.2)
	4	8.9	12.3 (±11.2)	12.1 (±11.1)	30.1 (±1.6)	1.9 (±2.4)	98.1 (±2.4)
	5	16.0	12.6 (±11.6)	12.3 (±11.1)	29.9 (±1.9)	69.3 (±1.3)	30.7 (±1.3)***
	6	15.5	12.7 (±11.5)	12.6 (±11.4)	30.0 (±2.1)	35.2 (±1.1)	64.8 (±1.1)***
ABC	1	6.0	12.9 (±8.9)	12.4 (±9.4)	30.2 (±1.8)	61.0 (±6.4)	39.0 (±6.4)
	2	5.3	13.0 (±9.1)	12.6 (±9.3)	29.9 (±2.0)	56.1 (±11.6)	43.9 (±11.6)**
	3	7.8	12.9 (±8.9)	12.4 (±10.0)	29.7 (±2.1)	0.4 (±0.4)	99.6 (±1.4)
	4	6.4	13.2 (±9.3)	12.6 (±9.9)	28.8 (±3.0)	0.2 (±0.2)	99.8 (±0.2)
	5	8.0	13.2 (±9.3)	12.7 (±9.2)	29.2 (±2.4)	88.1 (±3.6)	11.9 (±3.6)***
	6	18.0	12.9 (±9.1)	12.4 (±9.2)	29.4 (±2.4)	57.3 (13.0)	42.7 (±13.0)***

Table - 2: Number of individuals (m^{-2}) of characteristic species that contributed to > 55% of the dissimilarity in sample groups between during (DBC) and after (ABC) bridge construction in Asan Bay

Species	DBC group	ABC group
Capitella capitata (P)	331	265
Anaitides koreana (P)	90	5
Hemipodus yenourensis (P)	95	16
Tritodynamia sp (D)	-	45
Protankyra bidentata (H)	-	35
Sternaspis scutata (P)	57	81
Tharyx sp (P)	45	-
Dorvillea cerasina (P)	-	29
Tylorrhynchus heterochaetus (P)	35	-
Nepthys polybranchia (P)	39	8

(P): Polycaheta, (D): Decapoda

samples contained 68 polychaete species (54.4%), 20 crustacean species (16.0%), 19 mollusk species, five echinoderm species, and several others. Only 53 species occurred simultaneously in both samples. The relative number of crustacean species decreased, whereas that of polychaetes was similar in DBC and ABC samples. Overall, the average macrobenthic species density and biomass were estimated to be 840 individuals m^{-2} (DBC: 1013 individuals m^{-2}, ABC: 668 individuals m^{-2}) and 54.5 g wwt m^{-2} (DBC: 41.7 g wwt m^{-2}, ABC: 67.3 g wwt m^{-2}). Polychaetes were the most abundant taxonomic group, contributing over 80% of the total density.

Spatial variation in the number of species, density, species diversity, and biomass are shown in Fig. 2. Spatial variation was similar in the DBC and ABC samples, except at Stations 5 and 6. Station 5 showed notable changes in the number of species, species

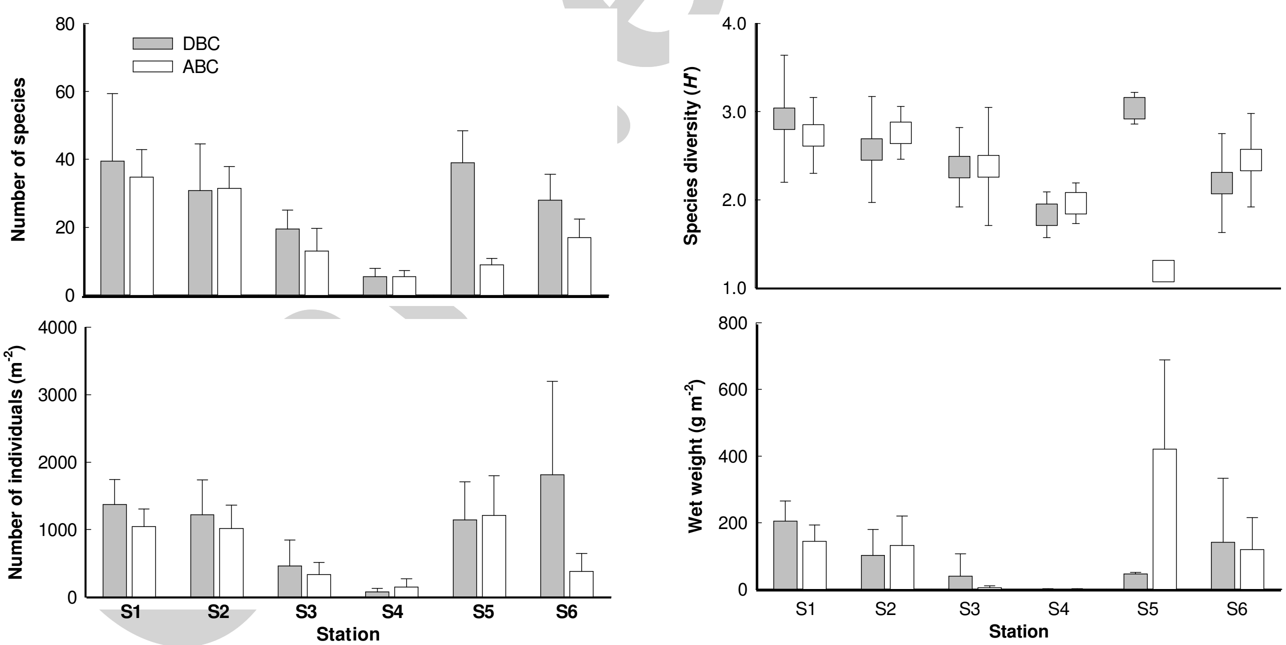

Fig. 2: Species number, individual density, species diversity, and biomass (mean ± SE) of macrobenthos at the six sampling stations during (DBC, grey bars) and after (ABC, white bars) bridge construction in Asan Bay

Table - 3: Number of individuals (m^{-2}) of species that contributed to > 55% of the dissimilarity in sample groups between during (DBC) and after (ABC) bridge construction in Asan Bay

Species	Group A	Group B	Group C	Station 4
Capitella capitata (P)	398	393	10	-
Sternaspis scutata (P)	36	121	2	-
Hemipodus yenourensis (P)	114	25	1	-
Anaitides koreana (P)	107	7	-	-
Dorvillea cerasina (P)	-	-	69	-
Tylorrhynchus heterochaetus (P)	36	-	-	25
Tritodynamia rathbuni (D)	-	67	-	-
Protankyra bidentata (H)	-	58	-	-
Tharyx sp (P)	54	-	-	-

(P) : Polycaheta, (D) : Decapoda, (H) : Holothuroidea

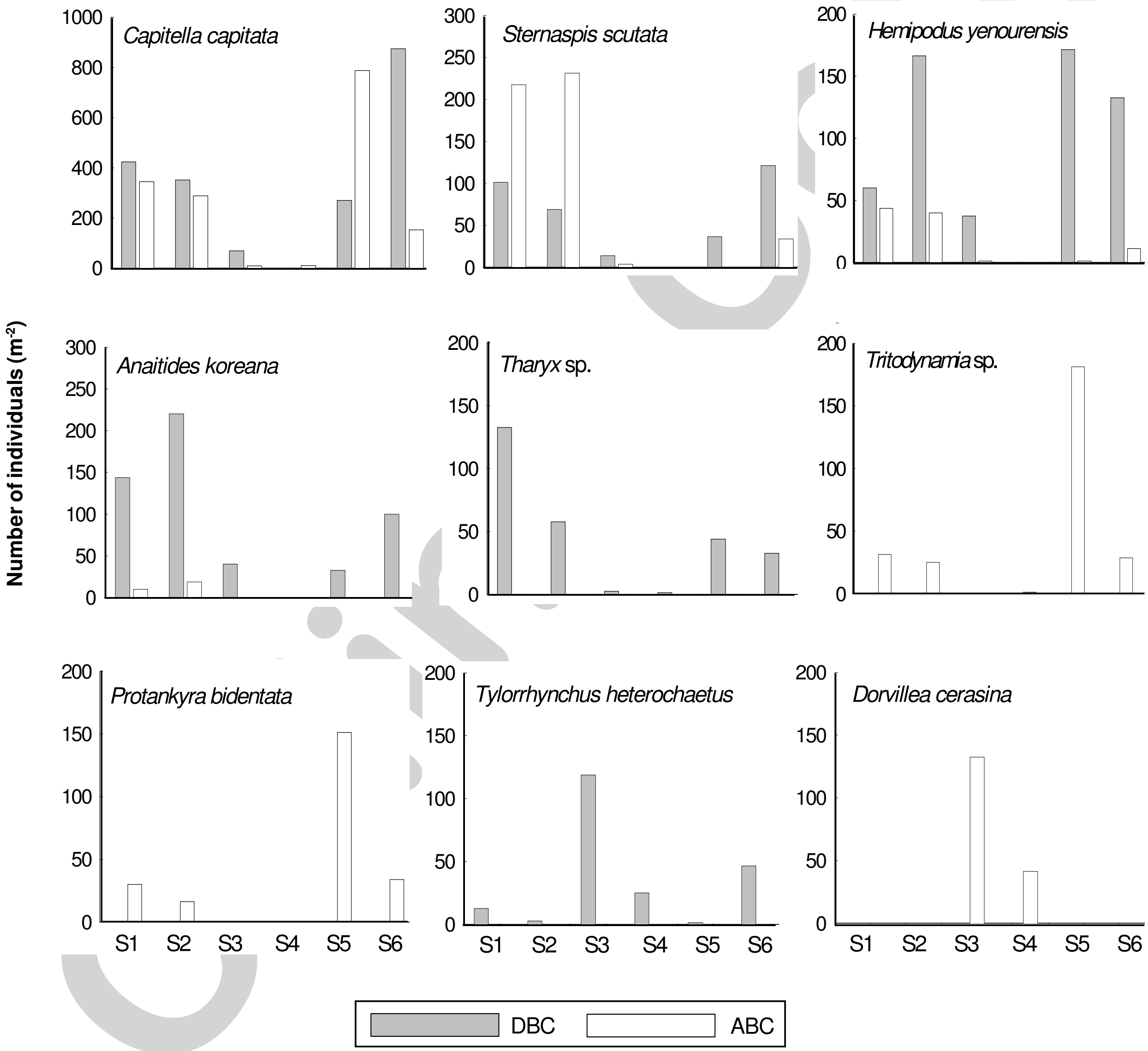

Fig. 3: Density of the dominant and the characteristic species (based on contribution to average similarity within stations) at the six sampling stations during (DBC, grey bars) and after (ABC, white bars) bridge construction in Asan Bay

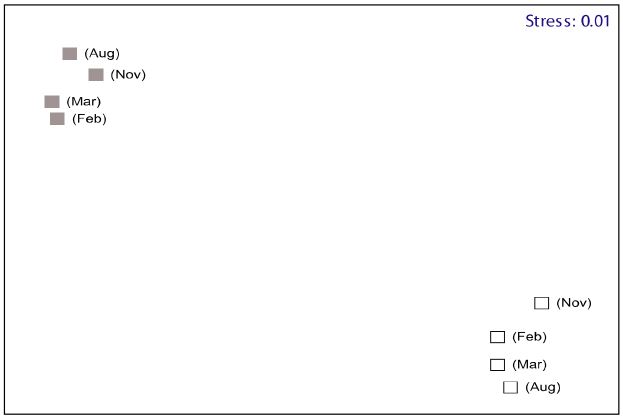

Fig. 4: MDS ordination of fourth-root transformed species abundance data at the four sampling season during (DBC, grey squares) and after (ABC, white squares) bridge construction in Asan Bay

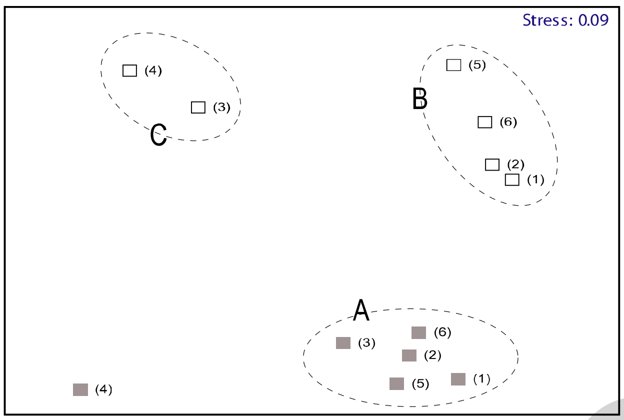

Fig. 5: MDS ordination of fourth-root transformed species abundance data at six sampling stations during (DBC, grey squares) and after (ABC, white squares) bridge construction in Asan Bay

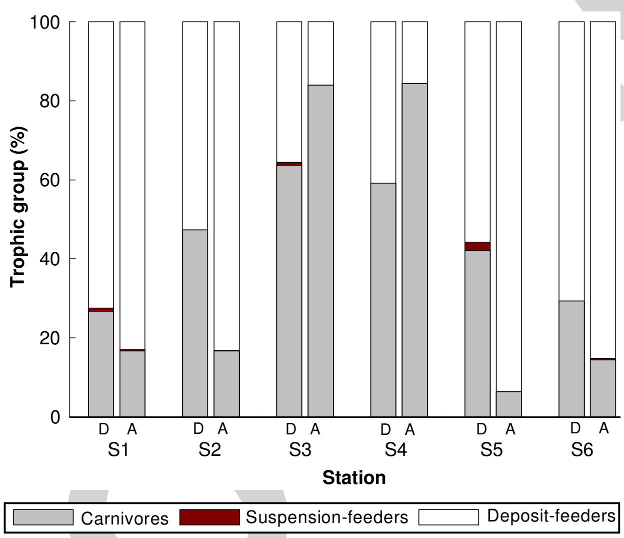

Fig. 6: Proportions of each polychaetes trophic group at six sampling stations during (D) and after (A) bridge construction in Asan Bay

diversity, and biomass between DBC and ABC samples. A sudden decrease in the number of species at Station 5 may have influenced the decrease of species diversity, although the density was similar in the two periods. Furthermore, the polychaete *Capitella capitata*, holothuroid *Protankyra bidentata,* and decapod *Tritodynamia* sp., which were the dominant species at Station 5, showed an increasing trend in ABC samples (Fig. 3). The sudden increase of biomass at Station 5 was due to the predominance of *P. bidentata*. At Station 6, the sudden decrease in overall density was due to the major decrease of *C. capitata* (Fig. 3). A relationship between soft-bottom macrobenthic communities and sediment types has been noted (Gray, 1974). Species diversity is higher in heterogeneous than in homogeneous sediment (Boyden and Little, 1973), and an extremely strong or very weak current can cause particle size fraction homogeneity. Furthermore, species diversity in these habitats is commonly reduced (Nakao, 1982). In this respect, the results from the homogeneous sand sediments at stations 3 and 4 are quite reasonable. The dominant species, *C. capitata*, is a well-known indicator of organic and other forms of pollution (Grassle and Grassle, 1974; Pearson and Rosenberg, 1978; Hong and Lee, 1983). Thus, the spatial and temporal distribution patterns of this species can be explained by the organically enriched habitats in Asan Bay. This species was more dense and had higher temporal variation at stations 5 and 6 (Fig. 3). In particular, this species primarily accounted for the decrease in diversity of station 5 samples from DBC to ABC.

The second-most dominant species, *Sternaspis scutata*, was the most common polychaete in muddy sediment (Lim and Hong, 1997; Labrune *et al.,* 2007). Stations 1 and 2 showed an increasing trend in the density of this species from DBC to ABC (Fig. 3). The sediment-dwelling species *P. bidentata* plays an important role in benthic habitats where bottom sediment is reworked (bioturbation) by limiting and regulating the distribution of sedentary species (Hong *et al.,* 1999). *P. bidentata* is generally accompanied by commensal bivalves and crustaceans (Kim, 2000); in this study, the small decapod *Tritodynamia* sp. occurred with it.

Two-dimensional configuration plots of MDS ordination visually represent the dissimilarity in the macrobenthic community structure between DBC and ABC samples (Fig. 4). SIMPER analysis showed that DBC samples were dominated by *C. capitata*, *Anaitides koreana*, *Hemipodus yenourensis*, *S. scutata*, *Tharyx* sp., *Nepthys polybranchia*, and *Tylorrhynchus heterochaetus* (Table 2). In ABC samples, *C. capitata* and *S. scutata* were also among the dominant species, but the overall species composition and major dominant species were clearly different. *Tritodynamia* sp., *P. bidentata*, and *Dorvillea cerasina* appeared, whereas *Tharyx* sp. and *T. heterochaetus* disappeared from ABC samples (Table 2). Moreover, ANOSIM results showed significant differences in the community structure (global R=1, p=0.029) of DBC and ABC groups. Thus, the macrobenthic communities clearly underwent conspicuous changes between DBC and ABC sampling.

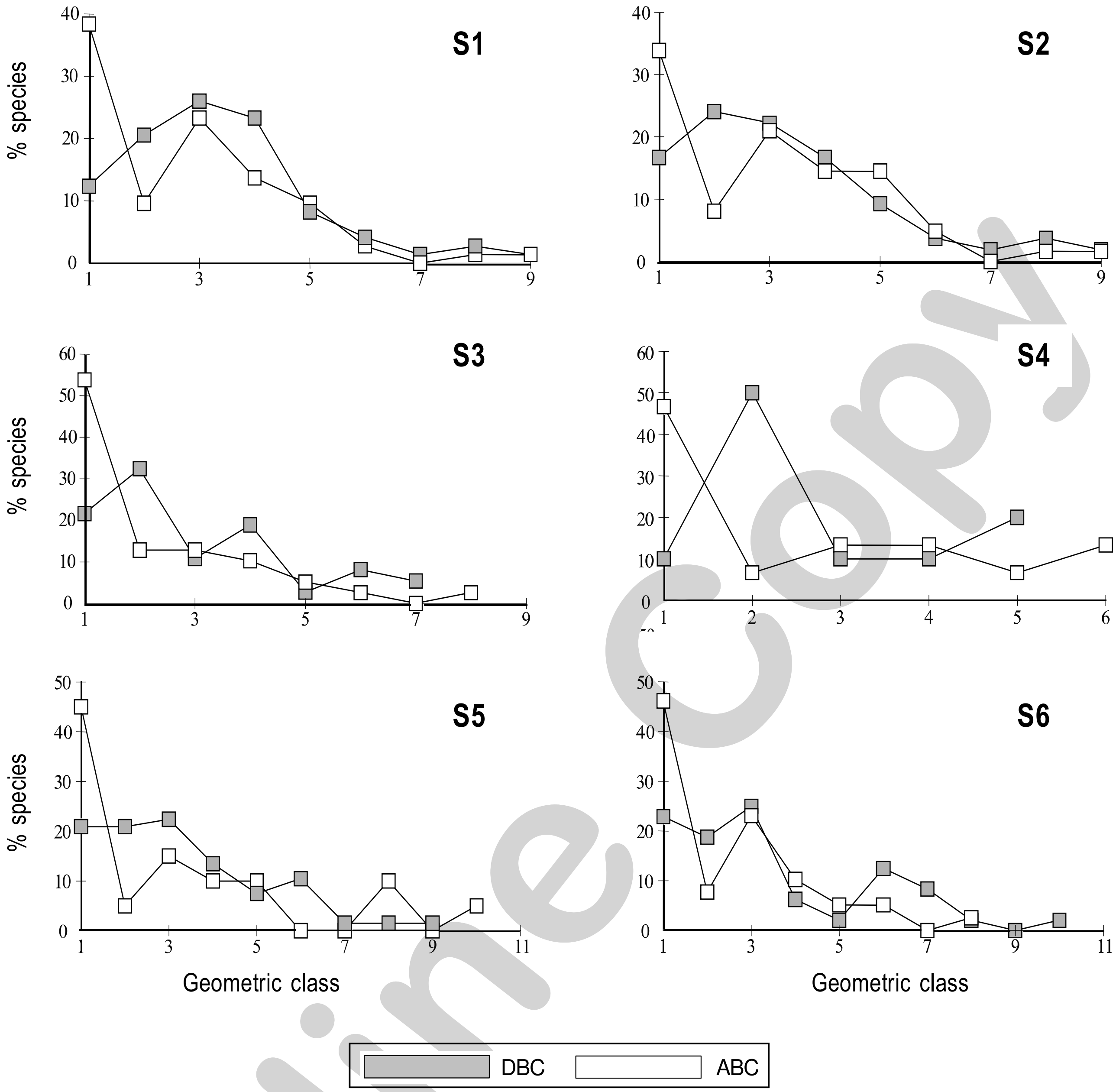

Fig. 7: Plot of geometric species abundance classes at six sampling stations during (DBC, grey squares) and after (ABC, white squares) bridge construction in Asan Bay

The MDS ordination plot of the DBC and ABC samples designated three groups and one station (Fig. 5). Group A (Stations 1, 2, 3, 5, and 6) was formed by the DBC samples and Group B (Stations 1, 2, 5, and 6) by the ABC samples. Group C (Stations 3 and 4) was formed by homogeneous sandy sediment samples from DBC. Three polychaetes species (*C. capitata*, *H. yenourensis*, and *A. koreana*) contributed more than 55% to the similarity of Group A; two polychaete species, *C. capitata* and *S. scutata*, did the same in Group B, as did *Tharyx* sp. and *D. cerasina* in Group C. ANOSIM tests showed that the three groups and station were significantly different (global R=0.981, p=0.001), mainly due to spatial and temporal differences in abundance, as well as the exclusion and appearance of characteristic species by SIMPER analysis (Table 3). The differences between Group A and B were caused by the decrease in density of *H. yenourensis*, *A. koreana*, *T. heterochaetus*, and *Tharyx* sp., and the increase in density of *S. scutata*, *Tritodynamia* sp., and *P. bidentata* (ANOSIM, global R=0.956, p=0.008; Table 3). Two carnivorous polychaetes, *H. yenourensis* and *A. koreana*, commonly occur in sandy mud sediments in Korean coastal areas (Shin *et al.,* 1992; Hong and Yoo, 1996), but the ecology of these species is not known. On the other hand, numerous investigations have shown that the dominance of *Tharyx* species can be evidence of ecologically stressed conditions (Shin and Koh, 1998; Belan, 2003). Group C and Station 4, which comprised the homogeneous sandy sediment area, were mainly distinguished by the appearance or disappearance of two sediment-burrowing polychaetes, *D. cerasina* and *T. heterochaetus*, respectively (ANOSIM, global R=1, p=0.033; Table 3). Nanami *et al.* (2005) demonstrated that the deposit-feeder *T. heterochaetus* is more abundant in sites with high salinity and small grain sizes. Sediment type is among the factors influencing the spatial distribution of feeding types of macrobenthic species (Rhoad and Young, 1970; Gray, 1974). For example, suspension feeders are more abundant on sandy flats where water velocity prevents detritus accumulation on the bottom, and stronger currents carry more potential food to suspension feeders. In contrast, deposit-feeders are more abundant on muddy bottoms, where weak currents allow organic matter to settle (Sanders, 1958). However, our study does not support these conclusions, as *T. heterochaetus* was more abundant in homogeneous sand sediment stations, albeit mostly as juveniles. Thus, this species was highly represented, but the biomass at this station was lower than that at other stations. These results may be due to opportunistic settlers on temporally disturbed sediment, due to the bridge construction. Carnivorous *D. cerasina*, a member of a genus that became dominant in urban and industrial areas of the Canadian Pacific coast (Levings *et al.,* 1985), occurred mostly in Group C. The sudden decrease or increase of these characteristic species from DBC to ABC is difficult to interpret. However, with long-term monitoring and some sediment data (organic content), these species could be used as indicators of anthropogenic presence.

Frouin (2000) documented that deposit-feeders dominate in fine sediments with high organic content, whereas carnivores are dominant in coarse sediments with low organic content. We found that overall carnivorous polychaetes (*D. cerasina* and *G. chirori*) tended to increase in the homogeneous sand sediments of Station 3 and 4 (Fig. 6). On the other hand, stations with sandy mud and muddy sand sediments showed an increase in deposit-feeding (*C. capitata* and *S. scutata, L. longifolia*) polychaetes. Thus, we suggest that finer sediments with higher organic content in Station 1, 2, 5, 6 may have negative affected the abundance of carnivorous polychaete (*H. yenourensis* and *A. koreana*), and have positive affected in deposit-feeding polychaete (*Tharyx* sp) during the study period.

Gray and Pearson (1982) recommended plotting the number of species in geometric abundance classes to detect the effects of pollution stress on communities. In unpolluted situations, the mode of the plot is well to the left. Polluted situations contain fewer rare species and more abundant species, with the higher abundance classes shifting the mode to the right. Our abundance class distribution showed that rare species were present in smaller numbers at all stations in DBC compared to ABC samples, indicating a polluted habitat (Fig. 7). Classes 3–5, which are intermediate in abundance, are the most sensitive to pollution-induced changes and may best illustrate the differences between polluted and unpolluted areas (Gray and Pearson, 1982). From this viewpoint, DBC stations overall represent a polluted situation, but we cannot define ABC samples as representing an unpolluted environment. Despite the rarer species occurring in ABC samples, some stations showed lower levels of abundance in classes 3–5, shifting the mode of the higher abundance classes. Accordingly, we judge the ABC samples to be in a recovery situation.

Acknowledgments

This research was supported partly by Daegu University Research Grant (2006) and the research program of KORDI (PE97701). We thank Dr. Do Hyung Kang and Dr. Ok Hwan Yu for critical reading of the manuscript and providing valuable comments.

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