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Impact of Environmental Variables on the Diversity and Distribution of the Megabenthos in the South Sea of Korea

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Abstract : *Megabenthos samples were collected using 10-min trawls towed at 17 stations from 2015 to 2016. The dominant species (>1% of the total density) were Stegophiura sterea (10.4%) and two subtropical species, Mactrinula dolabrata (9.0%) and Acila divaricate (8.3%), respectively. The community structure of the megabenthos fell into four groups: the southeast, the southernmost region off Jeju Island, the frontal zone of the South Sea with C3, and a diagonal area from the south coast to the western side of Jeju Island. The total numbers of species, diversity, density and biomass were higher in the C3 region of the South Sea. Environmental factor analysis showed that differences in the megabenthos community were related to depth, gravel contents, and sorting value (σ). These results indicate that changes in the marine environmental conditions in the South Sea of Korea affect the megabenthos species' composition and diversity.*

Key Words : *South Sea, Frontal zone of South Sea, Megabenthos, Benthic community, Environmental variable*

1. Introduction

Benthic animals live on the bottom of the ocean, including soft areas, such as places of mud and sandy sediment, and hard areas. Depending on their size, benthic animals are divided into megabenthos, macrobenthos, meiobenthos, and microbenthos. They play a decisive role in marine ecology as secondary producers and have an important role in the recycling of nutrients because they resuspend nutrient-rich bottom sediments into the water mass (Daan, 1973; Snelgrove, 1998; Volkenborn et al., 2007; Pratt et al., 2014; Sibaja-Cordero et al., 2016). In addition, macrobenthic animals can be an important means of understanding ecosystem changes and environmental characteristics because of their slow mobility and long lifecycle (Sanders, 1968; Pearson and Rosenberg, 1978; Reisss and Kröncke, 2005; Burd et al., 2008). Macrobenthos communities appear diversely according to sediment characteristics within a sediment type and adaptations of organisms in response to various environmental changes (Gray, 1981; Rakocinski et al., 1997; Paik et al., 2007; Choi, 2016). For example, species composition varies depending on the grain size and sorting values of sedimentary facies, among other environmental factors (Weston, 1988; Amri et al., 2014). Megabenthos are larger than 1 cm in size and include starfish, sea cucumbers, crabs, and shrimp, and have value as a resource for fisheries. Megabenthos have greater mobility than macrobenthos, and can respond to the habitat and environment. Therefore, the community structure and distribution patterns may vary greatly. Most studies have focused on the epibenthic megafauna in the deep-sea. Several studies reported that the density and distribution of megabenthos are related to depth (Jones et al., 2007; Linse et al., 2013), and the distribution of the megabenthic fauna community is related to topography, substratum, sediment conditions, and food resources (Jones et al., 2007; Ramirez-Llodra et al., 2010; Yu et al., 2014).

Consequently, the study of the megabenthos community structure according to the environmental variables of a surveyed area can facilitate understanding of their biodiversity and distribution.

The South Sea of Korea is affected by three currents: the high-temperature, high-salinity Jeju Warm Current; the low-salinity Yangtze River discharge flow from China; and the cold-water bottom currents of the Yellow Sea. Changes in the environment such as debris and low salinity from the Yangtze River have great impact on the pelagic ecosystem in the East China Sea and the South Sea of Korea (MOF, 2006; Kim et al., 2006; Liu et al., 2019). Seasonal flow differences from various water flows drive

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environmental variability in these regions. As a result, the study area has high biodiversity (Hur et al., 1999; Jang et al., 2011). The East China Sea, Jeju Island, Ieodo coast and South Sea of Korea is a haven for fisheries given a variety of fishery resources along with the diversity of marine environment (MLTL, 2011; MLTL, 2012; Yoon, 2013). In particular, the East China Sea is an important area for understanding the impacts of the subtropical ecosystem on global warming (Yu et al., 2008; MLTL, 2010). However, there are very few studies on the benthic ecosystem (Aller and Aller, 1986; Yu et al., 2008).

Under the influence of the subtropical current, the South Sea is expected to include appearances of tropical‐subtropical megafaunal species. However, the study of the benthos inhabiting this study area, where various environmental changes occur, is very limited. Previous studies have been conducted only on the species composition of the macrobenthos and macrobenthic community in the East China Sea and the Korea Strait affected by pelagic organisms (Yu et al., 2008). A study on only the distribution of macrobenthos according to the benthic environment of the East China Sea has been performed (Rhoads et al., 1985). However, information on the diversity and species composition of megabenthos in the South Sea has still not been collated. Therefore, this study aims to analyze the species diversity and distribution of megabenthos in the South Sea and Jeju Island region.

2. Materials and methods

In June and November 2015 and April 2016, sampling was conducted at 17 stations in the South Sea and Jeju Island, Ieodo coast of Korea, to identify the impact of environmental variables on the diversity and distribution of the megabenthos in the South Sea of Korea (Fig. 1, Table 1). The April 2016 survey was conducted around the frontal zone of the South Sea. Megabenthos (> 1 cm) samples were collected using 10-min trawls (width: 1.0 m) at each station. The samples were immediately refrigerated on the research vessel. After transporting them to the laboratory, the megabenthos samples were sorted under a stereomicroscope (Leica MZ16A), counted, identified to the lowest possible taxonomic level, and then fixed in 70 % ethanol. The samples were recalculated to 100 m^2, and the number of species, density, and amount of biomass were determined.

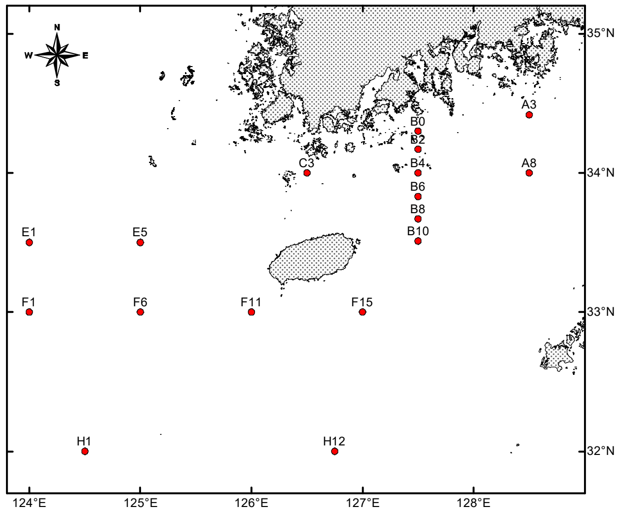

Fig. 1. Sampling sites in southern sea and Jeju Island · Ieodo coast of Korea.

To analyze the environmental factors at each sampling site, the temperature, salinity, and dissolved oxygen (DO) were measured with a CTD during sampling periods, and surface sediment samples (one time per site) were collected in a 50 mL conical tube for analysis of the sediment grain size. The sediment samples were classified into coarse-grained sediment and fine-grained sediment after the removal of organic matter and $CaCO_3$. The sediment samples were dried for 48 hours at 50℃ before applying 10% hydrogen peroxide on 1 g of samples to get rid of carbon with 0.1 N of hydrochloric acid, and heated to > 100℃ to evaporate the hydrogen peroxide, and then washed > 3 times with distilled water to remove organic matter and salts. The sediment grain size composition was determined using a dry sieving method with a Ro-Tap sieve shaker (< 4 phi; W.S. Tyler) along with a laser diffraction method. The mean grain size was calculated according to Folk and Ward (1957).

The megabenthos samples were photographed with a Nikon D5500 camera, and multifocal images were made using a Helicon remote with the Helicon Focus 6 program (Helicon Soft Ltd.) to compensate for the shortcomings of the existing two-dimensional images.

The species diversity index (H′) (Shannon and Wiener 1963) was calculated based on the density. Cluster analysis was carried out using the Bray‐Curtis similarity measure (Somerfield, 2008) based on the fourth root-transformed density data and group average linkage. Multidimensional scaling analysis was also performed. The similarity percentage (SIMPER) analysis was

Table 1. Sampling site and information in the study area

Station No.	Longitude (degree)	Latitude (degree)	Depth(m)	Sampling times		
				Jun 2015	Nov 2015	Apr 2016
A3	128.50	34.42	68	1		
A8	128.50	34.00	104	1	1	
B0	127.50	34.30	24			1
B2	127.50	34.17	38			1
B4	127.50	34.00	75	1	1	1
B6	127.50	33.83	88			1
B8	127.50	33.67	94			1
B10	127.50	33.51	90	1	1	
C3	126.50	34.00	48	1	1	
E1	124.00	33.50	66	1	1	
E5	125.00	33.50	78	1		
F1	124.00	33.00	48	1	1	
F6	125.00	33.00	80	1		
F11	126.00	33.00	109	1	1	
F15	127.00	33.00	103	1	1	
H1	124.50	32.00	37	1	1	
H12	126.75	32.00	109	1	1	

conducted to quantify the contribution of each species to the similarity/dissimilarity of those groups. The BIO-ENV test was performed to determine the environmental factors influencing the megabenthos community structure with 95% or higher correlations when analyzing. Spearman rank correlation analysis was conducted to determine the correlations between environmental variables and the benthic community. This analysis was performed in PRIMER v.6 (Plymouth Routines in Multivariate Ecological Research-e) (Clarke and Warwick, 2001).

3. Results

3.1 Environmental analysis

The study area had an average depth of 74 m, depth range of 24 to 109 m, and maximal depths deeper than 100 m in the southern area of Jeju Island and A8 (Table 1). In June 2015, the average bottom temperature was 13.8°C (range: 10.5 – 14.8°C). In November 2015 and April 2016, the mean bottom temperatures were 16.9°C (range: 12.0 – 22.1°C) and 14.5°C (range: 13.8 – 15.4°C), respectively (Fig. 2). The temperatures of E1 and E5 northwest of Jeju Island were 10.4°C and 11.4°C, respectively, lower than the average temperature in June 2015. The temperatures of F1 and H1 southwest of Jeju Island were 20.8°C and 22.1°C, respectively, about 4°C higher than the average and 10°C higher than E1 in November. The mean salinity of the bottom water was 33.7 psu (range: 32.0 – 34.5 psu) in June 2015, 33.8 psu (range: 32.3 – 34.6 psu) in November 2015, and 34.2 psu (range: 33.8 – 34.6 psu) in April 2016. There were no significant differences in salinity, but the frontal zone of the South Sea had higher salinity than the other stations. Bottom DO was in the range of 5.1 – 7.5 mg/L in June 2015, 4.0 – 6.8 mg/L in November 2015, and 6.4 – 8.8 mg/L in April 2016. Sediment grain size averaged 4.6 ø and varied within 2.3 – 8.1 ø among the stations. B0, B2, and B4 in the South Sea had very fine-grained sediment that was mainly muddy.

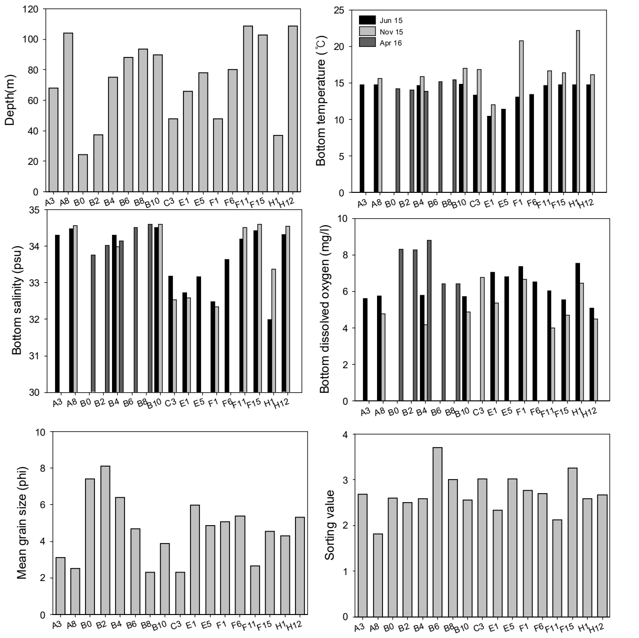

Fig. 2. Environmental variables at each station.

3.2 Species composition

In total, 307 species were identified during the survey period. Arthropod crustaceans represented the most abundant taxon with 118 species (38 %), followed by others phyla with 71 species (23 %), mollusks with 55 species (18 %), echinoderms with 44 species (14 %), and annelid polychaetes with 19 species (6 %). An average of 29 species were recorded. The highest number of species (116) was found at C3, and the lowest number (5) was identified at H12, south of Jeju Island (Fig. 3).

The mean density of megabenthos was 28.7 ind/100 m^2 with values of 25.1 ind/100 m^2 in June 2015, 33.0 ind/100 m^2 in November 2015, and 29.5 ind/100 m^2 in April 2016. In June 2015, the density was highest at C3 (89 ind/100 m^2), in the South Sea, and the values were less than 5 ind/100 m^2 at F11, H1, and H12, southwest of Jeju Island. In November 2015, the density was highest at E1 (93.6 ind/100 m^2), west of Jeju Island, and density was lowest (< 5 ind/100 m^2) at F5 and H12, south of Jeju Island. In April 2016, the density was highest at B2 (100 ind/100 m^2), located at the frontal zone of the South Sea. During the survey period, the density ranking by taxonomic group was mollusks (31 %), arthropod crustaceans (25 %), echinoderms (22 %), other phyla (19 %), and annelid polychaetes (4 %).

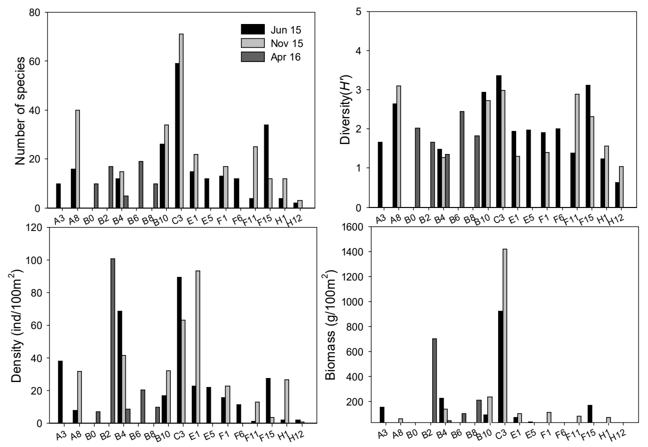

Fig. 3. Number of species, diversity (H'), density (ind./100 m^2) and biomass (g/100 m^2) of megabenthos in the study area.

During the survey period, the mean biomass of megabenthos was 181.1 g/100 m^2 (range: 2.2 – 1422.2 g/100 m^2). There were significant differences among stations. The mean biomass values in June 2015, November 2015, and April 2016 were 135.4 g/100 m^2, 224.3 g/100 m^2, and 213.4 g/100 m^2, respectively. In June 2015, the biomass was significantly higher at C3 (924.6 g/100 m^2) and lower at F11, H1, and H12 (< 5 g/100 m^2), off the southwest coast of Jeju Island. In November 2015, the biomass was significantly higher at C3 (1422.2 g/100 m^2) and lower at F15 (< 10 g/100 m^2), south of Jeju Island. In April 2016, the biomass was highest at B2 (704 g/100 m^2) and lowest at B0. During the survey period, the biomass ranking of megabenthos by taxonomic group was echinoderms (40 %), mollusks (25 %), other phyla (25 %), and arthropod crustaceans (10 %), respectively.

The H′ value in the study area was 2.0, and the highest H′ of 3.0 was found at C3 and F15 in June 2015 and A8 and C3 in November 2015. The lowest H′ was 0.6 at H12 in June 2015.

3.3 Dominant species

The dominant species (> 1 % of total density) during this study were the ophiuroid *Stegophiura sterea* (10.4 %), bivalves *Mactrinula dolabrata* (9.0 %) and *Acila divaricata* (8.3 %), anthozoan *Hormathia andersoni* (8.2 %), gastropods *Zeuxis siquijorensis* (4.7 %) and *Siphonalia fuscolineata* (3.7 %), decapod *Pandalus gracilis* (3.1 %), holothuroid *Pentacta doliolum* (2.1 %), anthozoan *Flabellum distinctum* (1.8 %), decapods *Parapenaeopsis hardwickii* (1.7 %) and *Charybdis bimaculata* (1.7 %), echinoid *Coelopleurus undulatus* (1.5 %), decapods *Palaemon gravieri* (1.5 %), *Paguristes ortmanni* (1.3 %), and *Paguristes digitalis* (1.2 %), holothuroid *Pseudocnus* sp. (1.1 %), and polychaete *Neoleanira areolata* (1.1 %) (Table 2, Fig. 4). *Stegophiura sterea*, the most

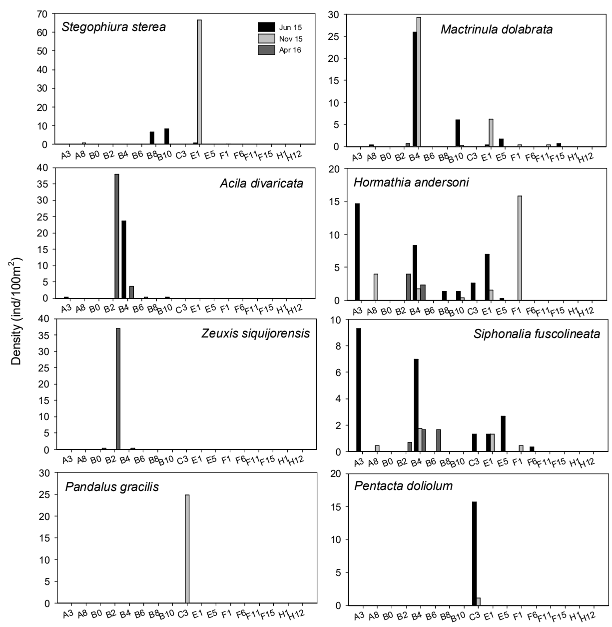

Fig.4 Dominant species of megabenthos at each stations

Table 2. Dominant species ranking based on density

Rank	Taxa	Species	% of total density	Freq.(%)
1	EOp	*Stegophiura sterea*	10.4	21.4
2	MBi	*Mactrinula dolabrata*	9.0	42.9
3	MBi	*Acila divaricata*	8.3	21.4
4	Others	*Hormathia andersoni*	8.2	50.0
5	MGs	*Zeuxis siquijorensis*	4.7	10.7
6	MGs	*Siphonalia fuscolineata*	3.7	46.4
7	CDe	*Pandalus gracilis*	3.1	3.6
8	EHo	*Pentacta doliolum*	2.1	7.1
9	Others	*Flabellum distinctum*	1.8	25.0
10	CDe	*Parapenaeopsis hardwickii*	1.7	7.1
11	CDe	*Charybdis bimaculata*	1.7	50.0
12	EEc	*Coelopleurus undulatus*	1.5	7.1
13	CDe	*Palaemon gravieri*	1.5	25.0
14	CDe	*Paguristes ortmanni*	1.3	14.3
15	CDe	*Paguristes digitalis*	1.2	10.7
16	EHo	*Pseudocnus* sp.	1.1	14.3
17	APo	*Neoleanira areolata*	1.1	14.3

(APo, Polychaeta; MBi, Bivalvia; MGs, Gastropoda; CDe, Decapoda; EHo, Holothuroidea; EOp, Ophiuroidea)

dominant species, appeared with a density of 66.7 ind/100 m^2 at E1 in November 2015. *Mactrinula dolabrata* appeared with 26.0 ind/100 m^2 in June 2015 and 29.3 ind/100 m^2 in November 2015 at B4 in the frontal zone of the South Sea. *Acila divaricata* appeared at a density of 23.7 ind/100 m^2 in November 2015 and 3.7 ind/100 m^2 in April 2016 at B4, and 38 ind/100 m^2 in April 2016 at B2.

3.4 Community structure

A cluster analysis of the Bray - Curtis similarity matrix based on the density of the megabenthos divided the study area into four groups by species contributions: Group A in the frontal zone of the South Sea and C3, Group B in the southeast of Jeju Island, Group C consisting of the southernmost stations, and Group D located diagonally from the south coast to the region west of Jeju (SIMPROF test, $P < 0.05$) (Fig. 5). The average similarity of Group A was 9.84 %, and poriferans, *Munida japonica*, *Paguristes ortmanni*, and *Flabellum distinctum* contributed 10.40 %, 8.78 %, 8.50 %, and 6.94 %, respectively (Table 3). The average similarity of Group B was 9.08 %, and *Solenocera melantho*, *Mactrinula dolabrata*, *Leioptilus fimbriatus*, and *Flabellum distinctum* contributed 33.35 %, 24.22 %, 22.58 %, and 7.40 %, respectively. The average similarity of Group C was 25.11 %, and *Leptochela sydniensis* contributed 100 %. The average similarity of Group D was 25.43 %, and *Ormathia andersoni, Siphonalia fuscolineata, Charybdis bimaculata*, and *Mactrinula dolabrata* contributed 28.44 %, 19.39 %, 11.75 %, and 11.50 %, respectively.

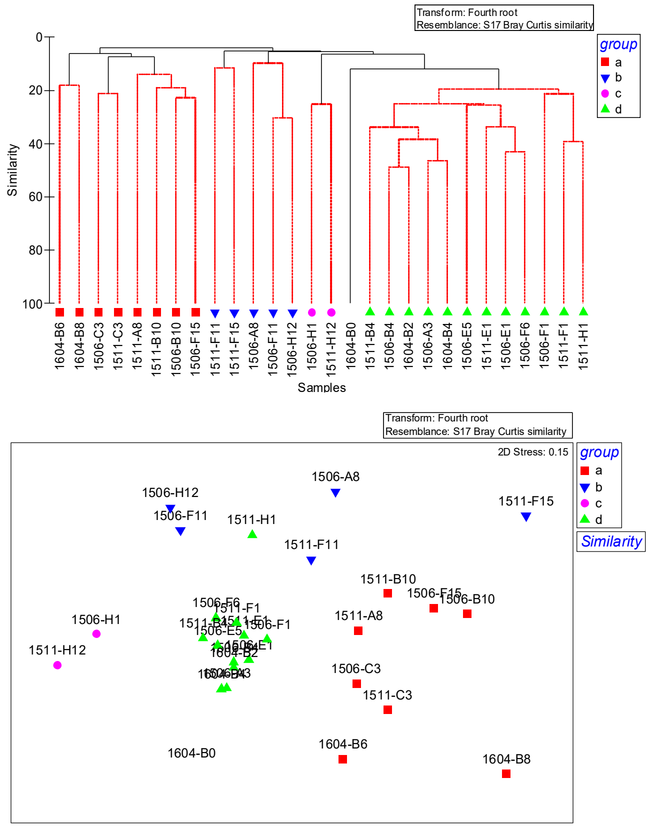

Fig. 5. Dendogram and 2-dimensional plot using macrobenthic faunal abundance data by Bray-Curtis similarities calculated on the fourth-root transformed abundance data in the South sea of Korea.

Table 3. SIMPER analysis of megabenthic fauna, listing the main characterising species at each group

	Species	Average Abundance (log)	Contribution %	Cumulative %
Group a Average similarity: 9.84 %	Porifera	0.60	10.40	10.40
	Munida japonica	0.52	8.78	19.18
	Paguristes ortmanni	0.60	8.50	27.68
	Flabellum distinctum	0.65	6.94	34.62
Group b Average similarity: 9.08 %	*Solenocera melantho*	0.37	33.35	33.35
	Mactrinula dolabrata	0.50	24.22	57.57
	Leioptilus fimbriatus	0.47	22.58	80.15
	Flabellum distinctum	0.40	7.40	87.55
Group c Average similarity: 25.11 %	*Leptochela sydniensis*	0.72	100	100
Group d Average similarity: 25.43 %	*Hormathia andersoni*	1.28	28.44	28.44
	Siphonalia fuscolineata	0.96	19.39	47.83
	Charybdis bimaculata	0.66	11.75	59.58
	Mactrinula dolabrata	0.95	11.50	71.08

Table 4. BIO-ENV test to analyze the effect of environmental variables on the megabenthic community structure

Number of variables	correlation (%)	Best variables
3	0.353	depth, Gravel %, sorting value(σ)
2	0.344	depth, sorting value(σ)
3	0.337	depth, Silt %, sorting value(σ)
4	0.332	depth, Gravel %, Silt %, sorting value(σ)

The BIO-ENV analyses of the megabenthos and environmental variables showed that depth, gravel content, and sorting value (ø) showed the highest correlations with the megabenthic community (Rho = 0.353, $P < 0.01$) (Table 4). The correlations between the total number of species, diversity, density, biomass, and dominant species with environmental factors were determined (Table 5). The diversity showed a positive correlation with sand content and a significant negative correlation with silt content. The mean density of megabenthos decreased with increasing depth, and biomass increased with increasing gravel content. The major dominant species, *Stegophiura sterea*, showed a negative correlation with salinity. *Zeuxis siquijorensis* showed a significant negative correlation with sand content and showed significant positive correlations with silt content, clay content, MZ (ø), and DO. Pandalus gracilis had a significant positive correlation with gravel %. *Pentacta doliolum* also showed a significant positive correlation with gravel content and a negative correlation with MZ (ø).

4. Discussion

The bottom temperature in June 2015 was relatively lower than in November 2015. Especially, E1 was a low temperature at 10.4 ℃ (Fig. 2). These patterns are caused by the summer cold-weather bottom currents of the Yellow Sea (KIOST, 2018). The bottom temperature in November 2015 considered to be relatively high at the H1 due to the influence of the high-temperature Kuroshio Current driving northward.

During the study period, the total number of megabenthos species, density (ind/100 m^2), and biomass (g/100 m^2) were 307 species/9900 m^2, 28.7 ind/100 m^2, and 81.1 g/100 m^2, respectively. The species diversity was 2.0. The density of megabenthos decreased with increasing depth, and the biomass increased with increasing gravel content (Table 5). Rex et al.(2000) reported that benthic animals decreased with increasing water depth. Jones et al.(2007) found that the megafaunal assemblages showed a significant correlation with depth, but no correlation between the

Table 5. Spearman rank correlation within the environmental variables and dominant species in sampling periods (*, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$)

	Depth(m)	Gravel %	Sand %	Silt %	Clay %	Mean grain size(phi)	Temper -ature	Salinity	Dissolved Oxygen
Number of species	-0.06	0.32	0.29	-0.34	-0.22	-0.26	0.11	-0.10	-0.08
diversity(H')	0.09	0.36	0.42*	-0.50**	-0.27	-0.37	0.03	0.09	-0.01
Density	-0.42*	0.20	-0.11	0.05	0.14	0.05	-0.05	-0.22	0.05
Biomass	-0.25	0.47*	0.11	-0.21	-0.02	-0.19	0.21	0.05	0.03
Stegophiura sterea	-0.27	0.04	-0.11	0.12	-0.04	0.01	-0.35	-0.41*	0.19
Mactrinula dolabrata	0.10	-0.34	-0.21	0.24	0.09	0.17	-0.03	0.02	-0.25
Acila divaricata	-0.16	0.03	-0.22	0.17	0.27	0.25	-0.23	0.06	0.26
Hormathia andersoni	-0.25	-0.24	-0.11	0.09	0.01	0.11	-0.20	-0.22	0.15
Zeuxis siquijorensis	-0.37	-0.14	-0.50**	0.47*	0.52**	0.52**	-0.28	-0.08	0.49**
Siphonalia fuscolineata	-0.11	0.06	0.00	-0.04	0.04	0.00	-0.23	0.01	0.14
Pandalus gracilis	-0.19	0.47*	0.19	-0.19	-0.19	-0.30	0.25	-0.25	0.13
Pentacta doliolum	-0.28	0.68***	0.28	-0.28	-0.28	-0.43*	0.00	-0.29	0.33

diversity of megafauna and depth. The number of species and density of macrobenthos decreased with distance from the coast (Yu et al., 2008). The especially decreasing dissolved organic matter released from the sediment to the water layer is considered to have caused these differences (Kojima and Ohta, 1989). The distribution of megabenthos is affected by food availability and organic matter (Hecker, 1990; Smith et al., 2008). In this study, therefore, the decreased density of megabenthos in deep waters may be related with organic conditions in the sediment. However, it is difficult to explain the relationship between the density and TOC, because TOC analysis has not been performed in this study.

The major dominant species in this study such as S. *sterea* (EOp), A. *divaricata* (Mbi), Z. *siquijorensis* (MGs), P. gracilis (CDe), and P. *doliolum* (EHo) were found in high density only in certain areas, and H. *andersoni* (Others), S. *fuscolineata* (MGs) appeared at the most stations except in the southern sea of Jeju Island (Fig. 4). S. *sterea* was distributed in the East Sea and Korea Strait at 150-300 m depth (Shin, 1992; García at al., 2002), and in this study, it appeared at high density in E1, west of Jeju Island. M. *dolabrata* is known to be distributed in the East Sea and East China Sea in silty sand and mud (Barnes, 1997), and dominated at B4 in silty sediment with a mean grain size of 6.4. A. *divaricata* and Z. *siquijorensis* were dominant in muddy sediment B2 with mean grain size of 8.1. H. *andersoni* and S. *fuscolineata* are usually dominant in subtidal sandy sediment in the South Sea of the Korea as a symbiotic relationship (Hong et al., 2006; Park and Huh, 2018). P. *gracilis* appears in the southern coast of Korea and the Korea Strait, and plays an important role as an energy transmitter in the food web of the marine ecosystem (Komai, 1999;). In this study, P. gracilis (CDe), P. *doliolum* were dominant in C3 with high density. As a result, the distribution of the dominant species is related to the composition of sediments. In general, deposit feeding macrobenthos dominate in sediments with high silt contents, while suspension feeding macrobenthos dominate in sediments with high sand contents (Sanders, 1958; Paik et al., 2007). Mollusks and crustacea are dominant in sandy sediments with smooth flow of seawater due to the relatively low organic matter contents (Maurer and Leathem, 1981; Frouin, 2000). Crustacea and mollusks are the most diverse epibenthic animal taxa in the numerous trawl investigations (Park and Huh, 2018). In this study, the ratio of mollusks and crustacea was relatively high because it was investigated on megabenthos such as epibenthic animals.

The community structures of megabenthos in this study were divided into 4 groups (Fig. 5). The community structures were affected by many environmental variables (Table 4). The number of species, diversity and biomass were higher in C3 with poor quality sorting value and coarse sand sediment (Fig 3). H12, located in the southernmost of Jeju Island, showed a low number of species, diversity, density and biomass. Rhoads et al.(1985) reported that the density decreases with increased silt and clay contents from the center of the East China Sea to the southern part of Jeju Island, and it was related to resuspension of Yellow Sea sediment. The species diversity of macrobenthos generally increases with fine grain size (McLachlan, 1990), but sometimes the number of species relatively increases with the coarser grain size of the sediment (Lim and Choi, 2001; Yu et al., 2013; Jung et al., 2014). The community structures of megabenthos are affected by substratum, sediment types (Jones et al., 2007; Yu et al., 2014; Briggs et al, 2017). In the present study, it was noted that the sediment size can affect the species compositions and density south of Jeju Island. In addition, the megabenthos diversity showed a positive correlation with sand content and a significant negative correlation with silt content (Table 5). Therefore, community structures and species composition of megabenthos in this study may be affected by the different sediment composition.

This study was conducted only in Spring and Fall, and we could not identify the changes in seasonal species composition. Megabenthos, which has relatively higher mobility compared to macrobenthos, can actively react with the environmental conditions they inhabit (Seo and Hong, 2007). Therefore, the seasonal investigation of megabenthos needs to be carried out in future studies.

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Appendix 1. The list of the megabenthos collected in this study

Taxon			
Polychaete	Crustacea Decapoda	*Ceratopagurus pilosimanus*	*Entricoplax vestita*
Aphrodita sp.	*Aegaeon lacazei*	*Dardanus arrosor*	*Eplumula phalangium*
Aphrodita talpa	*Aegaeon rathbuni*	*Diogenes edwardsii*	*Ethusa quadrata*
Arabella iricolor	*Alpheus brevicristatus*	*Diogenes* sp.	*Euclosiana obtusifrons*
Eunice indica	*Alpheus japonicus*	*Paguristes digitalis*	*Eumedonus zebra*
Eunice sp.1	*Alpheus* sp.1	*Paguristes japonicus*	*Hemigrapsus penicillatus*
Eunoe shirikishinensis	*Axiopsis consobrina*	*Paguristes ortmanni*	*Latreillopsis bispinosa*
Glycera nicobarica	*Betaeus granulimanus*	*Paguristes* sp.	*Leptomithrax bifidus*
Iphione ovata	*Birulia kishinouyei*	*Pagurus brachiomastus*	*Leptomithrax edwardsii*
Lagis bocki	*Crangon affinis*	*Pagurus debius*	*Liocarcinus corrugatus*
Lepidonotus spiculus	*Crangon hakodatei*	*Pagurus gracilipes*	*Maja japonica*
Marphysa bellii	*crangon* sp.	*Pagurus minutus*	*Mursia trispinosa*
Neoleanira areolata	*hadropenaeus lucasii*	*Pagurus pectinatus*	*Ovalipes punctatus*
Nereis longior	*Heptacarpus acuticarinatus*	*Pagurus pilosipes*	*Petalomera yamashitai*
Onuphis sp.	*Hippolyte* sp.	*Pagurus proximus*	*Pilumnus minutus*
Phylo sp.	*Latretus anoplonyx*	*Pagurus similis*	*Pilumnus* sp1.
Sabellarte sp.	*Latreutes* sp.	*pagurus* sp.	*Pinnotheres pholadis*
Sternaspis chinensis	*Leptochela gracilis*	*Pagurus triserratus*	*Platymaia alcocki*
Terebellides horikoshii	*Leptochela* sp.	*Galathea orientalis*	*Platymaia wyvillethomsoni*
Pycnogonida	*Leptochela sydniensis*	*Munida japonica*	*Pleistacantha sanctijohannis*
Ascorhynchus glaberrimum	*Metacrangon sinensis*	*Paramunida scabra*	*Portunus (monomia) gladiator*
Nymphon kodanii	*Metapenaeopsis dalei*	*Achaeus japonicus*	*Portunus (portunus) trituberculatus*
Crustacea Isopoda	*Palaemon gravieri*	*Achaeus tuberculatus*	*Portunus pelagicus*
Cymodoce acuta	*Palaemon ortmanni*	*Anatolikos* sp.	*Pugettia incisa*
Cymodoce japonica	*Pandalus gracilis*	*Cancer gibbulosus*	*Pugettia vulgaris*
Janira sp.	*Paracrangon abei*	*Cancer* sp.	*Puggetia* sp.
Pleuroprion sp1	*Parapenaeopsis hardwickii*	*Carcinoplax longimana*	*Randallia eburnea*
Crustacea Amphipoda	*Petrarctus brevicornis*	*Carcinoplax purpurea*	*Romaleon gibbosulum*
Ampelisca miharaensis	*Plesionika ortmanni*	*Carcinoplax* sp.	*Scyra* sp.
Aorcho nanus	*solenocera comata*	*Carcinoplax surugensis*	*Trachycarnicus balssi*
Gammaropsis japonicus	*Solenocera melantho*	*Carcinoplax vestita*	*Tymolus japonicus*
Liljeborgia japonica	*Trachysalambria curvirostris*	*Charybdis bimaculata*	*Singhaplax danielae*
Melita denticulata	*Callianassa japonica*	*Charybdis riversandersoni*	*Scalopidia spinosipes*
Pareuystheus latipes	*Boninpagurus pilosipes*	*Choniognathus reini*	
Protomedeia crudoliops	*Catapagurus* sp.	*Entomonyx spinosus*	

Appendix 1. (continued)

Taxon			
Crustacea Stomatopoda	*Stegophiura sterea*	*Inquisitor nudivaricosus*	*Porifera* unid.
Oratosquilla oratoria	*Ophiothrix (Ophiothrix) koreana*	*Mactrinula dolabrata*	Cnidaria
Squilla sp.	Echinoidea	*Microfusus magnifica magnifica*	*Adeona sp.*
Crinoidea	*Clypeasteroida* sp.	*Nassarius variciferus*	*Bellonella rigida*
Crinoidea sp.	*Coelopleurus undulatus*	*Neptunea* sp.	*Bellonella rubra*
Asteroidea	*Phalacrocidaris japonica*	*Nudibranchia*	*Echinoptillum macintoshi*
Aphelasterias sp.	*Schizaster lacunosus*	*Primovula frumentum*	*Flabellum distinctum*
Asterina sp.	*Stereocidaria japonica*	*Siphonalia fuscolineata*	*Flabellum (Ulocyathus) deludens*
Asteropecten kagoshimensis	*Strongylocentrotus nudus*	*Siphonalia fusoides*	*Hormathia andersoni*
Astroboa arctos	*Temnotrema rubrum*	*Tristichotrochus aculeatus*	*Maldreporaria* sp.
astrocladus coniferus	Holothuroidea	*Tristichotrochus haliarchus*	*paraspongodes hirotai*
Astropecten polyacanthus	*Molpadia oolitica*	*unedogemmula deshayesi*	*Paraspongodes spiculosa*
Ctenopleura fisheri	*Pentacta doliolum*	*Vokesimurex rectirostris*	*Pennatulacea*
Ctenopleura sp.	*Pseudocnus* sp.	*Zeuxis siquijorensis*	*Scleractinia* sp.
Dipsacater pretiosus	Polyplacophora	Bivalvia	*Aglaophenia* sp.
Echiniasteridae	*Leoidozona andrigiaschevi*	*Acila divaricata*	Sipunculida
Henricia ohshimai	Gastropoda	*Acila mirabilis*	*Phascolosoma agassizii*
Leptychaster anomalus	*Adamnetia japonica*	*Angulus vestalioides*	Brachiopoda
Luidia quinaria	*Boreotrophon candelabrum*	*Chlamys irregularis*	*Ctenoides annulata*
Ophiuroidea	*Brachytoma tuberosa*	*Chlamys nobilis*	*Laqueus* sp.
Amphioplus sp.	*Bullacta exarata*	*Chlamys squamata*	*Terebratuling japonuca*
Amphiura koreae	*Calliostoma consors*	*Clycymeris imperialis*	*Bryozoa*
astrocladus coniferus	*Calliostoma koma*	*Cryptopecten vesiculosus*	*Bryozoa* sp.
Crossaster sp.	*Calyptraea* sp.	*Enucula tenuis*	Chordata
Ophiocentrus sp.	*Chicoreus aculeatus*	*Hawaiarca uwaensis*	*Ciona* sp.
Ophiocreas caudatus	*Crepidula* sp.	*Lima fujitai*	
Ophiocreas sp.	*Cymatium parthehopeum*	*Mactrinula dolabrata*	
Ophiogymma sp.	*Cyprass vitellus*	*Meiocardia tetragona*	
Ophionereis eurybrachiplax	*Dhiline argentata*	*Modiolus elongatus*	
Ophionereis variegata	*Emarginula crassicostata*	*Nitidotellina nitidula*	
Ophiopholis mirabilis	*Emarginula* sp.	*Portlandia lischkei*	
Ophiopsammus anchista	*Fascioariidae*	*Striarca symmetrica*	
Ophiotrix sp.	*Fusinus ferrugineus*	Porifera	
Ophiura sp.	*Gemmula kieneri*	*Axinella* sp.	
Pectinura sp.	*Guildfordia triumphans*	*Oscarella lobularis*	
Stegophiura sp.	*Inquisitor jeffreysii*	*Polyclinidae*	