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Study of the Distribution and Species Composition of the Megabenthos in the South Sea of Korea

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본 논문을 강수민의 이학석사 학위논문으로 인준함

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우리나라 남해 초대형저서동물의 종 조성 및 분포에 관한 연구

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Abstract

우리나라 남해, 제주도 및 이어도 해역은 고온, 고염분의 제주난류, 중국의 양쯔강으로부터 흘러나오는 저염수와 황해 저층냉수대의 영향을 받는다. 또한 계절에 따른 다양한 수괴 형성으로 인해 다양한 환경변화가 나타나는 것으로 알려져 있다. 이러한 다양한 환경 변화가 나타나는 제주도 주변 해역은 높은 생물다양성을 나타내며, 따라서 본 연구 지역의 생물다양성도 높을것으로 생각되어진다. 그러나, 본 연구지역의 저서동물에 관한 연구는 대형저서동물의 종 조성과 군집에 한정되었으며, 초대형저서동물에 관한 연구는 매우 제한적이다. 따라서 본 연구에서는 우리나라 남해 및 인근 해역의 초대형저서동물의 종 조성 및 분포를 분석하였다. 초대형저서동물은 2015년 6월, 11월 2016년 4월 17개 정점에서 Beam trawl (width:1.0m)을 10분 동안 예인하여 채집되었다. 초대형저서동물은 총 301종이 출현하였으며, 평균서식밀도는 28.7 ind/100 m^2, 평균 생체량은 81.1 g/100 m^2으로 나타났다.

주요 우점종은(> 1 % of the total density) 지붕거미불가사리(*Stegophiura sterea*), 버선조개(*Mactrinula dolabrata*), 호두조개(*Acila divaricata*), 고둥끈말미잘(*Hormathia andersoni*)순으로 나타났다. 초대형저서동물의 군집구조는 깊이에 따라 2015년 6월 3개의 그룹, 2015년 11월 두 개의 그룹으로 나뉘었으며, 2016년 4월 초대형저서동물의 군집구조는 퇴적물 조성에 따라 두 개의 그룹으로 나뉘었다. 총 종수, 종다양도, 평균 생체량은 남해에 위치한 정점 C3에서 각각 116종, 3.7, 1173 g/100 m^2으로 높게 나타났으며, 총 종수, 종다양도, 평균서식밀도는 제주도 남쪽에 위치한 정점 H12에서 각각 5종, 1.3, 1.4 g/100 m^2으로 낮게 나타났다. 생물다양성의 차이는 환경요인 중 수심, 자갈 함유량, 분급도에 영향을 받는것으로 나타났다. 이러한 결과는 남해 해역의 해양환경의 변동이 초대형저서동물의 종 조성과 분포 및 다양도에 영향을 주는 것으로 보인다.

KEY WORDS: 남해전선역; 동중국해; 저서군집; 조하대; 환경요인;

Study of the Distribution and Species Composition of the Megabenthos in the South Sea of Korea

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Abstract

The South Sea of Korea is affected by three systems of 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. In addition, seasonal flow differences from various water flows drive environmental variability in these regions. As a result, biodiversity in this study area is assumed to be very high. However, there is no information on the diversity and distribution of the megabenthos. Therefore, in this study, we analyzed the diversity and distribution of the megabenthos in the South Sea based on environmental factors.

Sampling of megabenthos were collected using a Beam trawl for 10 minutes towed at 17 stations in June 2015, November 2015, April 2016. The total number of species, density (ind/100 m^2), and biomass (g/100 m^2) of megabenthos were 301 species/9900 m^2, 28.7 ind/100 m^2, and 81.1 g/100 m^2, respectively. 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%) (bivalve mollusks). Megabenthic community structures in June and November 2015 were divided into three groups and two groups, respectively, which were affected by water depth. However, in April 2016, megabenthic community was divided into two groups according to sediment grain sizw and sorting value (σ). The total numbers of species, diversity and biomass were highest in st. C3 (116 species, 3.7 and 1173 g/100 m^2 respectively) and lowest in st. H12 (5 species, 1.3 and 1.4 g/100 m^2 respectively). According to the environmental factor analysis, the differences in megabenthos community were found to be related to depth, gravel contents, and sorting value (σ). This study suggests that variations in sediment conditions and depth in the South Sea of Korea are important factors controlling at the megabenthos species composition and diversity.

KEY WORDS: Benthic community, East China Sea, Environmental variable, Frontal zone of South Sea, Subtidal

1. Introduction

1.1 Megabenthos

Benthic animals live on the bottom of the ocean, including soft bottom such as muddy and sandy sediments and hard bottom such as rocks. Depending on their size, benthic animals are divided into megabenthos (> 1cm in size), macrobenthos (> 1 mm in size), and meiobenthos (0.063 – 1mm in size). 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; Rhoads 1974; Bilyard 1987; Snelgrove 1998). 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). Species composition varies depending on the grain size and sorting values of sedimentary facies, among other environmental factors (Weston, 1988). Macrobenthic 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).

Megabenthos are larger than 1 cm in size and include as starfish, sea cucumbers, crabs, and shrimp, and have value as a resource for fisheries. Megabenthos have greater mobility than macrobenthos, and they can respond to the habitats environment. Therefore, the megabenthos community structure and distribution pattern may vary greatly. In addition, megabenthos are important for the transfer of organic matter, which adjust the habitats so that macrofauna can detect ecological niches. Until now, research on megabenthos is mainly carried out using visible in bottom photographs, scuba diving, trawls, and fishing nets. Especially as their greate mobility, the quantitative investigations on megabenthos were difficult. Previous studies on Megabenthos have been conducted mostly in the deep sea using a deep sea camera and ROV. (Hecker, 1990; Yu et al., 2014). Rodrigues et al. (2001) found that megabenthos plays a role in abyssal ecosystems as they comprise a major fraction of the deep-sea benthic biomass. Amon et al, (2016) reported that megafauna showed a positive correlation to nodule abundance in the abyssal seafloor of the Clarion-Clipperton Zone. Several studies reported that density and distribution of megabenthos is related with depth (Hecker, 1990; Jones, 2007; Linse, 2013). Distribution of megabenthic fauna community is related with topography, substratum, sediment conditions and food resources (Hecker, 1990; Jones, 2007; Ramirez-Llodra et al., 2010; Yu et al., 2014). Diversity of megabenthos is affacted by benthic disturbance (Rodgrigues et al., 2001). Consequently, study of the megabenthos community structure according to the environmental variables of a surveyed area can facilitate understanding of their biodiversity and distribution.

1.2 Information of study area

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 bottom cold-water of the Yellow Sea. Changes in the environment such as particle organic matter and low salinity from the Yangtze River have a great impact on the pelagic ecosystem in the East China Sea and the South Sea of Korea (Chen et al., 1999; MOF, 2006; Kim et al., 2006). Seasonal flow differences from various water flows drive environmental variability in these regions. As a result, the study area has been reported high biodiversity (Hur et al. 1999; Jang et al. 2011). The East China Sea, Jeju Island, Ieodo coast and South Sea of Korea are known as a fisheries for variety fishery resources (MLTL, 2011; MLTL, 2012; Yoon, 2013). In addition, 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, studies of the distribution and diversity on benthic ecosystem in that area have been very limited (Aller and Aller, 1986; Yu et al., 2008). Previous studies have been conducted only on the species composition and community structure of macrobenthos in the East China Sea and the Korea Strait affected by pelagic organisms (Rhoads et al., 1985; Yu et al., 2008). However, there is no study on the megabenthos in the South Sea of Korea.

1.3 Aim of this study

Under the influence of the subtropical current, the South Sea of Korea is expected to appear tropical or subtropical megafaunal species. However, study of the benthic animals inhabiting this study area, where various environmental changes occur, is very limited. Therefore, this study aim to analyze the species diversity and distribution of megabenthos in the South Sea and Jeju Island region which have various water masses and dynamic changes in the environment. Our specific objectives are to (1) identify species of the megabenthos, (2) analyse the distribution and community structure of the megabenthos and (3) find out the significant environmental variables on the distribution and species composition of the megabenthos.

2. Materials and Methods

2.1 Collecting samples

sampling was conducted at 17 stations in the South Sea, Jeju Island and Ieodo coast in June and November 2015 and April 2016 and around the frontal zone of the South Sea of Korea in April 2016, to identify the impact of environmental variables on the diversity and distribution of the megabenthos in this study area (Fig. 1, Table1). Megabenthos (> 1 cm in size) samples were collected using a beam trawl (width: 1.0 m) for 10 minutes at each site. The samples were immediately refrigerated on the research vessel, and transferred them to the laboratory. The megabenthos samples were sorted under a stereomicroscope (Leica MZ16A), counted and, 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.

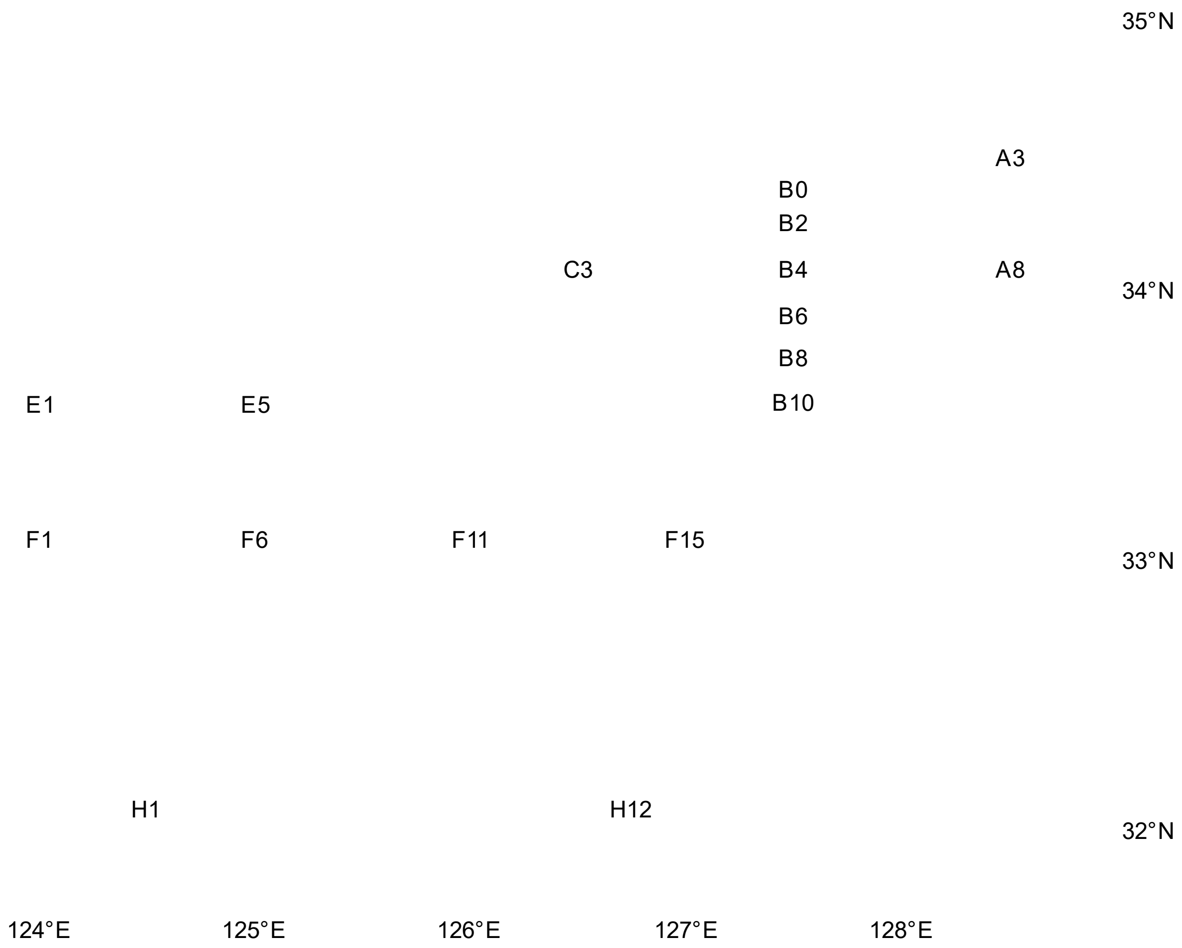

Fig. 1 Sampling sites in southern sea and Jeju island · Ieodo coast of Korea

Table 1 Sampling sites and information of the study area

Station No.	Longitude	Latitude	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	

2.2 Environment analysis

The environmental factors such as, temperature, salinity, and dissolved oxygen (DO) were measured with a CTD instrument at each sampling site, and surface sediment samples were collected in a 50mL conical tube for analysis of sediment grain size. The sediment samples were classified into coarse-grained sediment and fine-grained sediment after removal of organic matter and $CaCO_3$. 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 more than 100℃ to evaporate the hydrogen peroxide, and then washed 3 times with distilled water to remove organic matter and salts. 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, and mean grain size was calculated according to Folk and Ward (1957).

2.3 Making images

The megabenthic fauna 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 existing two-dimensional images (Fig. 2).

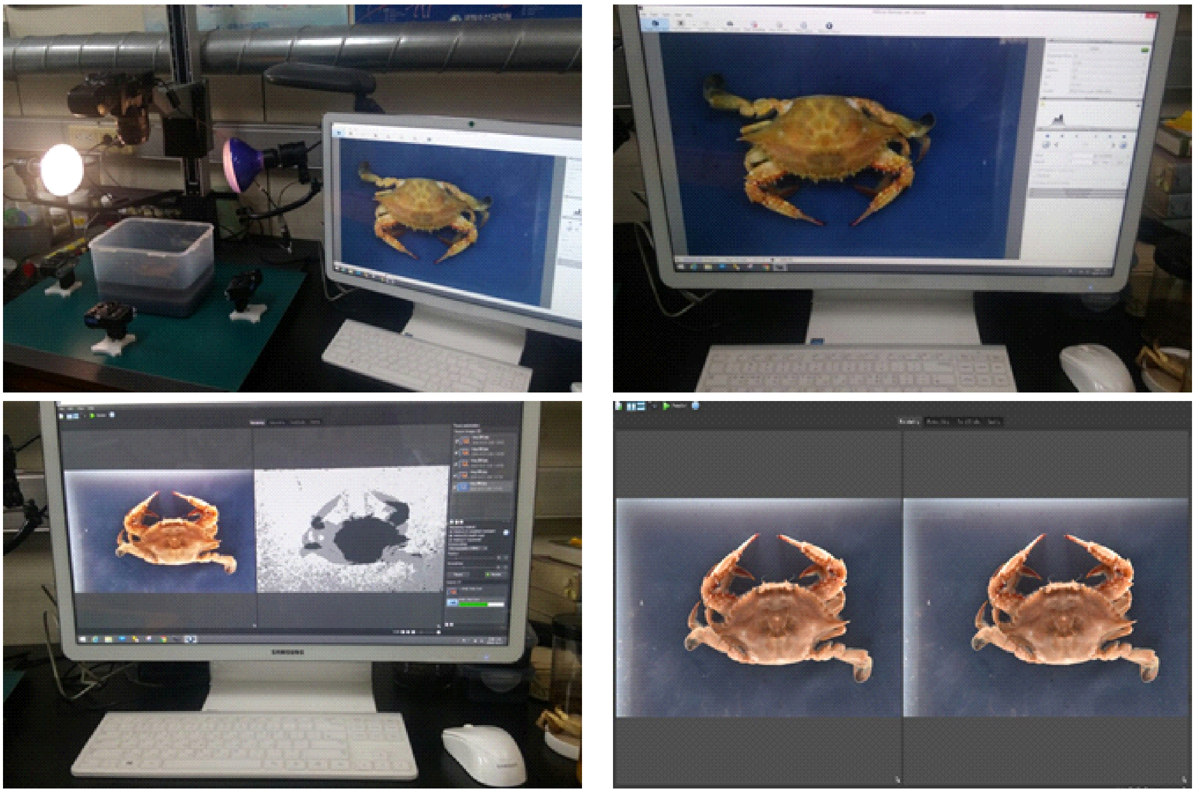

Fig. 2 Multifocal images using Helicon remote and Helicon Focus6 program

2.4 Data analysis

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 fourth root-transformed density data and group average linkage. Multidimensional scaling analysis was also performed. Similarity percentage (SIMPER) analysis was 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. Result

3.1 Environmental conditions

The study area had an average depth of 74 m, depth range of 24 to 109 m, and the maximal depths deeper than 100 m in the southern of Jeju Island (Table 1). In June 2015, the average bottom temperature was 13.8℃ (range: 10.5–14.8℃). In November 2015 and April 2016, the mean bottom temperatures were 16.9℃ (range: 12.0–22.1℃) and 14.5℃ (range: 13.8–15.4℃), respectively (Fig. 3). The bottom temperatures of E1 and E5 in the northwest of Jeju Island were 10.4℃ and 11.4℃, respectively, which were lower than the average temperature in June 2015. The temperatures of F1 and H1 southwest of Jeju Island were 20.8℃ and 22.1℃, respectively, which were about 4℃ higher than the average and 10℃ higher than E1 in November 2015. 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 other stations. Bottom dissolved oxygen (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 ⌀ and varied within 2.3-8.1 ⌀ among the stations. B0, B2, and B4 in the South Sea had very fine-grained sediment that was mainly muddy. The sorting value (⌀) of sediment ranged from 1.8 ⌀ to 3.7 ⌀, poorly sorted and very poorly sorted. The average total organic carbon (TOC) in sediment was 0.9% (range: 0.54-1.40%) in April 2016.

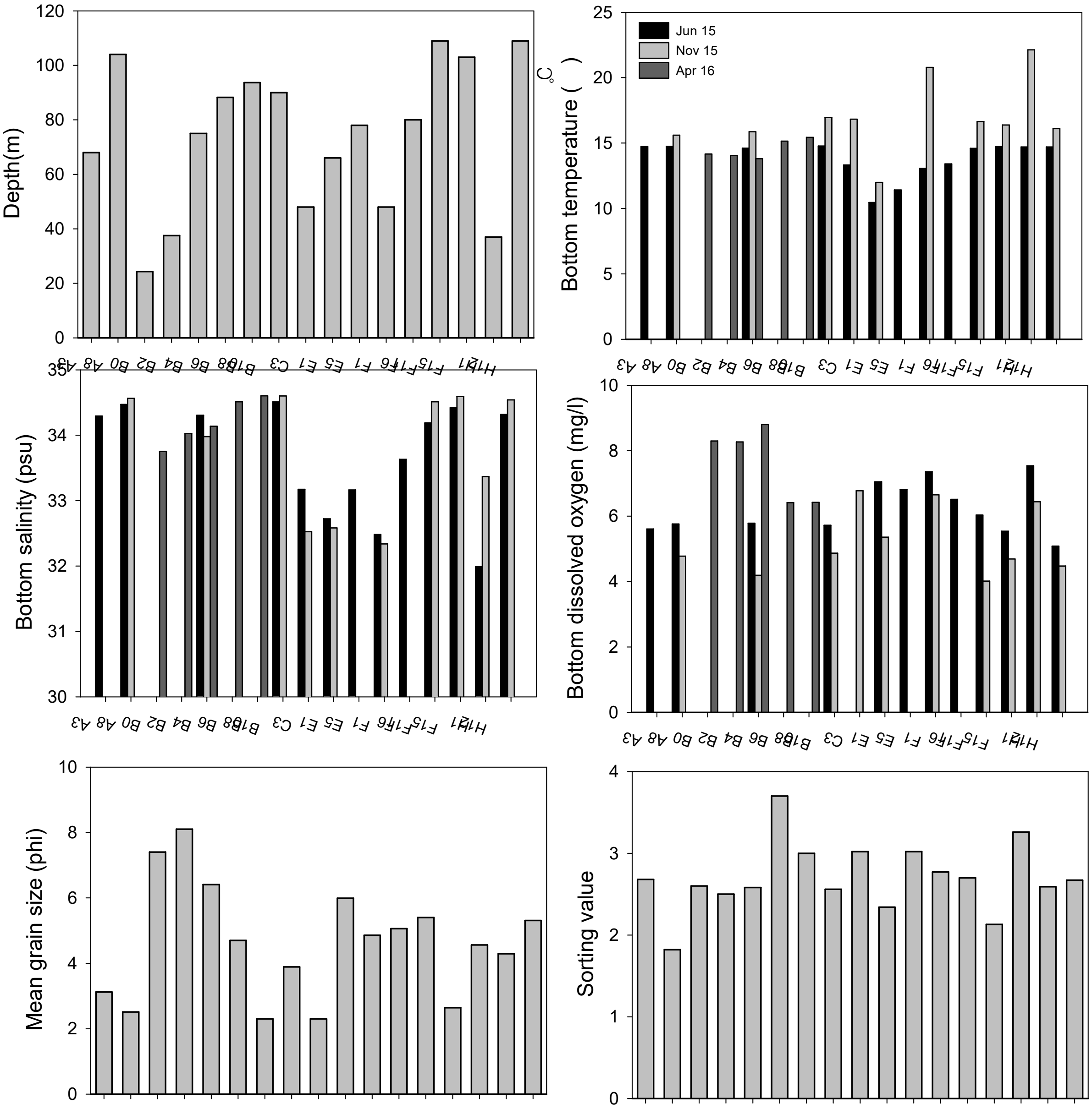

Fig. 3 Environmental variables at each station

3.2 Diversity of megabenthos

In this study, 301 species of megabenthos were sorted, of which 187 species belonging to 187 genera of 116 families in 8 phyla were identified. Some of species were provided distributions, habitats, and particular remarks.

List of Megafauna in this study

*** First reported from Korea in this study**

Phylum Porifera
Class Demospongiae
Order Poecilosclerida
Family Microcionidae
***Echinoclathria arborea* (Tanita, 1968)**

Class Homoscleromorpha
Order Homosclerophorida
Family Oscarellidae
***Oscarella lobularis* (Schmidt, 1862)**

Phylum Cnidaria
Class Anthozoa
Order Actiniaria
Family Hormathiidae
***Hormathia andersoni* Haddon, 1888** 고동끈말미잘

Order Alcyonacea
Family Alcyoniidae
***Bellonella rigida* Pütter, 1900** 곤봉바다딸기
***Bellonella rubra* Brundin, 1896** 바다딸기

Family Nephtheidae
***Umbellulifera hirotai* (Utinomi, 1951)** 빨강해면맨드라미
***Umbellulifera spiculosa* (Küenhal, 1906)** 침해면맨드라미
Order Pennatulacea
Family Echinoptilidae
***Echinoptilum macintoshi* Hubrecht, 1885** 가시선인장

Order Scleractinia

Family Flabellidae

***Flabellum* (*Flabellum*) *pavoninum* Lesson, 1831 부채돌산호**

***Flabellum* (*Ulocyathus*) *deludens* Marenzeller, 1904**

Distribution: Philippines, Vietnam, China, Japan, South Korea

Habitat: Depth range 106-1035 m; 5.3-18.4℃; mostly sand and mud shell fragments.

Fig. 4 *Flabellum* (*Ulocyathus*) *deludens*

Phylum Annelida

Class Polychaeta

Order Eunicida

Family Eunicidae

***Eunice indica* Kinberg, 1865 자주색털갯지렁이**

Marphysa bellii (Audouin & Milne Edwards, 1833)

Family Oenonidae

***Arabella iricolor* (Montagu, 1804) 홍점갯지렁이**

Order Phyllodocida

Family Aphroditidae

***Aphrodita talpa* Quatrefages, 1866**

Family Glyceridae

***Glycera nicobarica* Grube, 1868**

Family Iphionidae

Iphione ovata **Kinberg, 1855**

Family Nephtyidae
Nereis longior **Chlebovitsch & Wu, 1962 길쭉참갯지렁이**

Family Polynoidae
Eunoe shirikishinai **Imajima & Hartman, 1964**
Lepidonotus spiculus **(Treadwell, 1906)**

Family Sigalionidae
Neoleanira areolata **(McIntosh, 1885)**

Order Terebellida
Family Acrocirridae
Amphicteis gunneri **(M. Sars, 1835) 큰사슴갯지렁이**

Family Pectinariidae
Lagis bocki **(Hessle, 1917) 잎빗갯지렁이**

Family Sternaspidae
Sternaspis chinensis **Wu, Salazar-Vallejo & Xu, 2015**

Family Trichobranchidae
Terebellides horikoshii **Imajima & Williams, 1985**

Phylum Sipuncula
Class Phascolosomatidea
Order Phascolosomatida
Family Phascolosomatidae
Phascolosoma **(Phascolosoma)** *agassizii* **kurilense Keferstein, 1866 쿠릴별벌레**

Phylum Arthropoda
Class Malacostraca
Order Amphipoda
Family Ampeliscidae
Ampelisca miharaensis **Nagata, 1959 미하라안경옆새우**

Family Corophiidae
Pareurystheus latipes **Tzvetkova, 1977 큰손북방육질꼬리옆새우**
Protomedeia crudoliops **Hirayama, 1984**

Family Kamakidae

***Aorcho nanus* Hirayama, 1984**

Family Liljeborgiidae

***Liljeborgia japonica* Nagata, 1965**

Family Melitidae

Melita denticulata

Family Photidae

***Gammaropsis japonica* (Nagata, 1961)** 극동육질꼬리옆새우

Order Decapoda

Family Alpheidae

***Alpheus brevicristatus* De Haan, 1844** 딱총새우

***Alpheus japonicus* Miers, 1879** 긴발딱총새우

***Betaeus granulimanus* Yokoya, 1927** 옴발딱총새우

Family Calappidae

***Mursia trispinosa* Parisi, 1914** 세가시금게붙이

Family Callianassidae

***Nihonotrypaea japonica* (Ortmann, 1891)** 쏙붙이

Family Cancridae

***Romaleon gibbosulum* (De Haan, 1833)** 두드러기은행게

Family Crangonidae

***Aegaeon lacazei* (Bate, 1888)** 톱등자주새우

***Aegaeon rathbuni* de Man, 1918**

Distribution: Southwestern Australia, New caledonia, Madagascar, Hawaii, Taiwan, Indonesia, Japan.

Habitat: Depth range 11-809 m; Deep water, Tropical and subtropical.

Fig. 5 *Aegaeon rathbuni*

Crangon affinis **De Haan, 1849** 자주새우
Crangon hakodatei **Rathbun, 1902** 마른자주새우
Metacrangon sinensis **Fujino & Miyake, 1970** 가시자주새우
Paracrangon abei **Kubo, 1937** 꼬마가시투성어리새우

Family Cyclodorippidae
Tymolus japonicus **Stimpson, 1858** 꼬마조개치레

Family Diogenidae
Areopaguristes japonicus **(Miyake, 1961)** 작은꼬마긴눈집게
Dardanus arrosor **(Herbst, 1796)** 털줄왼손집게
Diogenes edwardsii **(De Haan, 1849)** 넓적왼손집게
Paguristes digitalis **Stimpson, 1858** 갈색털보긴눈집게
Paguristes ortmanni **Miyake, 1961** 털보긴눈집게

Family Dromiidae
Tunedromia yamashitai **(Takeda & Miyake, 1970)**

Family Epialtidae
Pugettia incisa **(De Haan, 1837)** 오늬이마물맞이게
Pugettia vulgaris **Ohtsuchi, Kawamura & Takeda, 2014** 잔털뿔물맞이게

Family Ethusidae
****Ethusa quadrata*** **Sakai, 1937**
Distribution: New Caledonia, Philippines, China, Japan, South Korea
Habitat: Depth range 35-393 m; fine sand, muddy or shelly bottoms.

Fig. 6 *Ethusa quadrata*

Family Galatheidae

Galathea orientalis **Stimpson, 1858** 새우붙이

Family Goneplacidae

Carcinoplax longimana **(De Haan, 1833)** 원숭이게

Carcinoplax purpurea **Rathbun, 1914**

Entricoplax vestita **(De Haan, 1835)** 털보원숭이게

Pycnoplax suruguensis **(Rathbun, 1932)**

******Singhaplax danielae*** **Takeda & Komatsu, 2010**

Family Heptacarpus

Heptacarpus acuticarinatus **Komai & Ivanov, 2008** 북방좁은뿔꼬마새우

Family Hippolytidae

Latreutes anoplonyx **Kemp, 1914** 매끈등꼬마새우

Family Homolidae

Latreillopsis bispinosa **Henderson, 1888**

Family Inachidae

Achaeus japonicus **(De Haan, 1839)** 아케우스게

Achaeus tuberculatus **Miers, 1879** 가는다리아케우스게

Platymaia alcocki **Rathbun, 1918**

Platymaia wyvillethomsoni **Miers, 1885** 거미다리게

Family Latreilliidae

***Eplumula phalangium* (De Haan, 1839) 사슴게**

Family Leucosiidae

***Euclosiana obtusifrons* (De Haan, 1841) 둥근무늬밤게**

****Tokoyo eburnea* (Alcock, 1896)**

Randallia eburnea Alcock, 1896: 197; Serène & Vadon, 1981: 124; Chen, 1989: 212, Figs. 12, 13. (cited from Galil & Ng 2007);

Tokoyo eburnea, Galil, 2003: 408, Figs. 1f, 4d-f

Tokoyo trilobata Komatsu, Manuel & Takeda, 2005: 116, Figs. 5, 6, 7a-c, g, 8C, D.

Distribution: Australia, Vietnam, Taiwan, Indonesia, Philippines, Thailand, China, Japan, South Korea

Habitat: Depth range 35-366 m

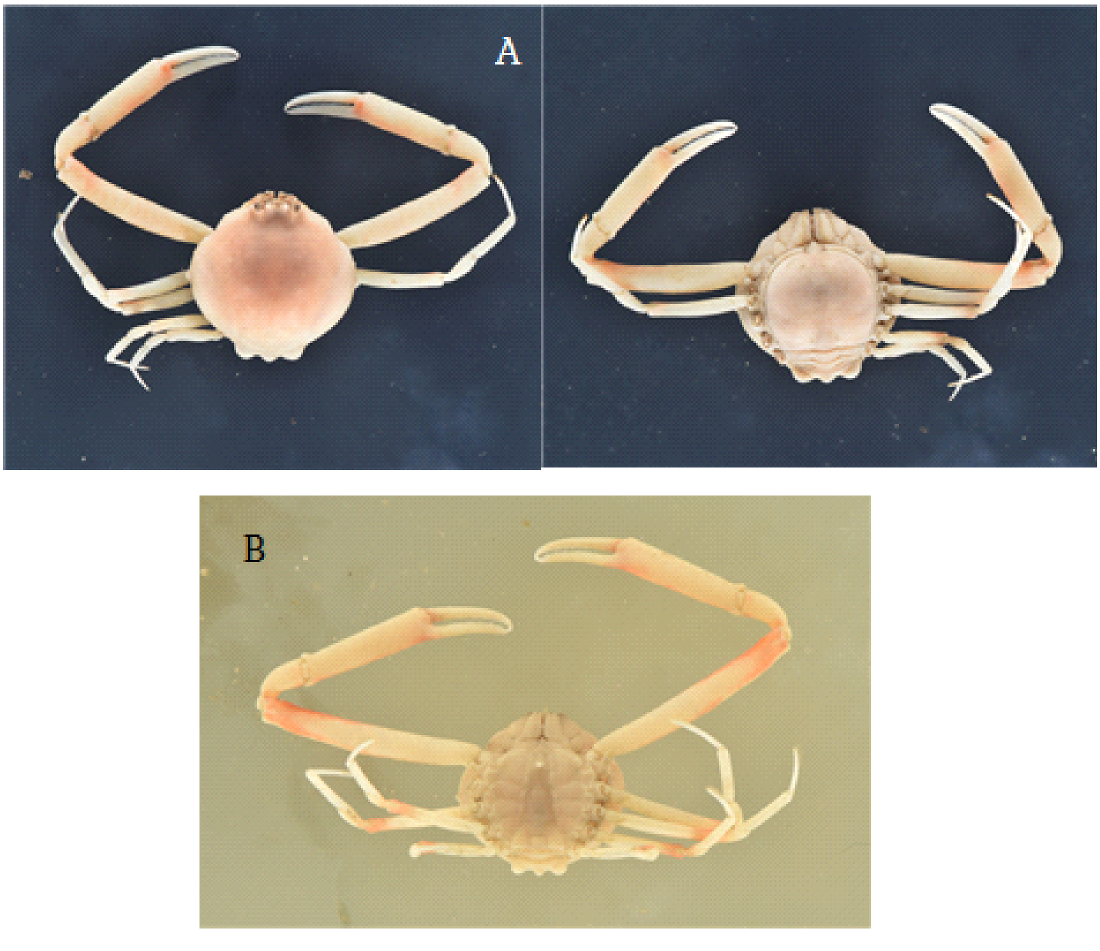

Fig. 7 *Tokoyo eburnea* (A: female, B: male)

Family Majidae

***Choniognathus reini* (Balss, 1924)**

Choniognathus koreensis Rathbun, 1932: 33

Eurynome reini Balss, 1924: 31, pl. 1, fig. 3; Yokoya, 1933: 158, fig. 57; Sakai, 1936: 92, pl. 22, fig. 1. (cited from Takeda & Miyake 19697);

Distribution: Japan, South Korea

Habitat: Depth range 80-120 m.

Fig. 8 *Choniognathus reini*

***Entomonyx spinosus* Miers, 1884 가시뿔게**

***Leptomithrax bifidus* (Ortmann, 1893) 가시두드럭게**

***Leptomithrax edwardsii* (De Haan, 1835) 두드럭게**

***Sakaija japonica* (Rathbun, 1932)**

Maja japonica Rathbun, 1932: 33; Takeda & Miyake, 1969: 512, pl. 17, fig. A, B, pl. 18, fig. B.

Distribution: Singapore, Taiwan, Hong Kong, China, Japan, South Korea (In this study)

Habitat: Depth range 85-120 m

Fig. 9 *Sakaija japonica*

Family Munididae

Munida japonica **Stimpson, 1858** 바늘이마새우붙이

Paramunida scabra **(Henderson, 1885)**

Family Oregoniidae

Pleistacantha sanctijohannis **Miers, 1879** 삼천가시게

Family Ovalipidae

Ovalipes punctatus **(De Haan, 1833)** 깨다시꽃게

Family Paguridae

Boninpagurus pilosipes **(Stimpson, 1858)** 줄무늬참집게

Ceratopagurus pilosimanus **Yokoya, 1933**

Lophopagurus **(Australeremus)** ***triserratus*** **(Ortmann, 1892)** 꼬마참집게

Pagurus brachiomastus **(Thallwiz, 1891)** 털손참집게

Pagurus minutus **Hess, 1865** 긴발가락참집게

Pagurus gracilipes **(Stimpson, 1858)** 납작손참집게

Pagurus pectinatus **(Stimpson, 1858)** 빗참집게

Pagurus proximus **Komai, 2000** 검은손참집게

Pagurus similis **(Ortmann, 1892)** 주황얼룩참집게

Family Palaemonidae

Palaemon gravieri **(Yu, 1930)** 그라비새우

Palaemon ortmanni **Rathbun, 1902** 긴발줄새우

Family Palinuridae

***Plesionika ortmanni* Doflien, 1902** 긴줄꼬마도화새우

Family Pandalidae

***Pandalus gracilis* Stimpson, 1860** 남방도화새우

Family Pasiphaeidae

***Leptochela* (Leptochela) *gracilis* Stimpson, 1860** 돗대기새우

***Leptochela* (Leptochela) *sydniensis* Dakin & Colefax, 1940** 둥근돗대기새우

Family Penaeidae

***Metapenaeopsis dalei* (Rathbun, 1902)** 산모양깔깔새우

***Parapenaeopsis hardwickii* (Miers, 1878)** 긴뿔민새우

***Trachysalambria curvirostris* (Stimpson, 1860)** 꽃새우

Family Pilumnidae

***Eumedonus zebra* Alcock, 1895**

Distribution: Sri Lanka, Philippine, Japan, South Korea

Fig. 10 *Eumedonus zebra*

***Pilumnus minutus* De Haan, 1833** 애기털보부채게

Family Pinnotheridae

***Pinnotheres pholadis* De Haan, 1835** 섭속살이게

Family Polybiidae

***Liocarcinus corrugatus* (Pennant, 1777)** 주름꽃게

Family Portunidae

***Charybdis* (Gonioneptunus) *bimaculata* Miers, 1886** 두점박이민꽃게

Charybdis riversandersoni

***Portunus* (Monomia) *gladiator* Fabricius, 1798** 두드러기꽃게

***Portunus* (Portunus) *trituberculatus* (Miers, 1876)** 꽃게

***Portunus* (Portunus) *pelagicus* (Linnaeus, 1758)** 청색꽃게

Family Scalopidiidae

***Scalopidia spinosipes* Stimpson, 1858**

Family Scyllaridae

Petrarctus brevicornis 혹등매미새우

Family Solenoceridae

***Hadropenaeus lucasii* (Bate, 1888)** 매끈대롱수염새우

Charybdis riversandersoni 꼬마대롱수염새우

***Portunus* (Monomia) *gladiator* Fabricius, 1798** 대롱수염새우

Family Thoridae

Birulia kishinouyei (Yokoya, 1930) 어리꼬마새우

Family Pinnotheridae

***Pinnotheres pholadis* De Haan, 1835** 뿔밤송이게

Family Hemigrapsus

***Liocarcinus corrugatus* (Pennant, 1777)** 풀게

Order Isopoda

Family Sphaeromatidae

***Cymodoce acuta* Richardson, 1904** 두드러기잔벌레

***Cymodoce japonica* Richardson, 1904** 두혹잔벌레

Order Stomatopoda

Family Squillidae

***Oratosquilla oratoria* (De Haan, 1844)** 갯가재

Class Pycnogonida

Order Pantopoda

Family Ascorhynchidae

Ascorhynchus glaberrimus **Schimkewitsch, 1913** 매끈코바다거미
Family Nymphonidae
Nymphon kodanii **(Hedgpeth, 1949)** 고다니기생바다거미

Phylum Mollusca
Class Bivalvia
Order Arcida
Family Glycymerididae
Glycymeris imperialis **Kuroda, 1934** 이랑줄조개

Family Noetiidae
Striarca symmetrica **(Reeve, 1844)** 흑인대복털조개

Order Arcoida
Family Arcidae
Hawaiarca uwaensis **(Yokoyama, 1928)** 외줄돌조개

Order Cardiida
Family Tellinidae
Hanleyanus vestalioides **(Yokoyama, 1920)** 은백색접시조개

Order Limida
Family Limidae
Ctenoides annulatus **(Lamarck, 1819)** 좁은개가리비
Lima fujitai **Oyama, 1943** 삼태기개가리비

Order Nuculida
Family Nuculidae
Acila divaricata **(Hinds, 1843)** 호두조개
Acila mirabilis **(A. Adams & Reeve, 1850)**
Ennucula tenuis **(Montagu, 1808)** 북방호두조개

Order Pectinida
Family Pectinidae
Cryptopecten vesiculosus **(Dunker, 1877)** 예쁜가리비
Laevichlamys cuneata **(Reeve, 1853)** 짝귀비단가리비
Scaeochlamys squamata **(Gmelin, 1791)** 비늘가리비

Order Venerida
Family Mactridae

Genus *Mactrinula* Gray, 1853

Mactrinula dolabrata **(Reeve, 1854) 버선조개**

Distribution: Australia, Indonesia, Taiwan, Thailand, China, Japan, South Korea

Habitat: Depth range 25-250 m; Silty sand and mud.

Fig. 11 *Mactrinula dolabrata*

Family Glauconomidae

Meiocardia samarangiae **Bernard, Cai & Morton, 1993** 능선조개

Class Gastropoda

Order Cephalaspidea

Family Haminoeidae

Bullacta exarata **(Philippi, 1849)** 민챙이

Family Mnestiidae

Adamnestia japonica **(A. Adams, 1862)** 흰민챙이

Family Philinidae

Philine orientalis **A. Adams, 1855** 큰관고둥

Order Lepetellida

Family Fissurellidae

Emarginula crassicostata **Sowerby in Adams & Sowerby, 1863** 넓은이랑삿갓조개

Order Littorinimorpha

Family Cymatiidae

Monoplex parthenopeus **(Salis Marschlins, 1793)** 각시수염고둥

Family Cypraeidae

Lyncina vitellus **(Linnaeus, 1758)** 제주개오지

Family Ovulidae

Primovula frumentum **(Sowerby, 1828)** 어깨토끼고둥

Order Neogastropoda

Family Buccinidae

***Siphonalia fuscolineata* (Pease, 1860)** 갈색고리돼지고둥

***Siphonalia fusoides* (Reeve, 1846)** 민허리돼지고둥

Family Fasciolariidae

***Fusinus ferrugineus* (Kuroda & Habe in Habe, 1961)** 매끈이긴뿔고둥

Family Muricidae

***Boreotrophon candelabrum* (Reeve, (1848 in 1843-65)** 지느러미뿔고둥

***Chicoreus aculeatus* (Lamarck, 1822)** 세줄분홍꽃뿔소라

***Vokesimurex rectirostris* (G. B. Sowerby II, 1841)**

Family Nassariidae

***Nassarius variciferus* (A. Adams, (1852 in 1852-53))** 언덕좁쌀무늬고둥

***Zeuxis siquijorensis* (A. Adams, 1852 in 1852-53)** 고랑좁쌀무늬고둥

Family Pseudomelatomidae

***Brachytoma tuberosa* (E. A. Smith, 1875)** 띠줄언청이고둥

***Funa jeffreysii* (E. A. Smith, 1875)** 담풍고둥

***Inquisitor nudivaricosus* Kuroda & Oyama in Kuroda et al., 1971** 잔줄무늬단풍고둥

Family Turridae

***Gemmula kieneri* (Doumet, 1840)** 염주고둥

***Unedogemmula deshayesii* (Doumet, 1840)**

Order Trochida

Family Calliostomatidae

***Tristichotrochus aculeatus* Sowerby III, 1912** 가시방석고둥

***Tristichotrochus haliarchus* (Melvill, 1889)** 매끈이방석고둥

***Tristichotrochus consors* (Lischke, 1872)** 주홍방석고둥

***Calliostoma koma* (Shikama & Habe, 1965)** 팽이방석고둥

Family Turbinidae

***Guildfordia triumphans* (Philippi, 1841)** 월계관납작소라

Phylum Echinodermata

Class Asteroidea

Order Paxillosida

Family Astropectinidae

***Astropecten kagoshimensis* de Loriol, 1899** 가고시마불가사리

***Astropecten polyacanthus* Müller & Troschel, 1842** 가시불가사리

***Ctenopleura fisheri* Hayashi, 1957** 피셀측불가사리

***Dipsacaster pretiosus* (Döderlein, 1902)** 마른불가사리

Leptychaster anomalus **Fisher, 1906 울투작은불가사리**

Family Luidiidae

Luidia quinaria **von Martens, 1865 검은띠 불가사리**

Class Asteroidea

Order Arbacioida

Family Arbaciidae

Coelopleurus undulatus **Mortensen, 1934 파동측강성게**

Order Camarodonta

Family Strongylocentrotidae

Mesocentrotus nudus **(A. Agassiz, 1864) 둥근성게**

Family Temnopleuridae

Temnotrema rubrum (Döderlein, 1885) 빨강작은성게

Order Cidaroida

Family Cidaridae

Phalacrocidaris japonica **(Döderlein, 1885) 가는관극성게**

Order Spatangoida

Family Schizasteridae

Schizaster lacunosus **(Linnaeus, 1758) 염통성게**

Class Holothuroidea

Order Dendrochirotida

Family Cucumariidae

Pentacta doliolum **(Pallas, 1766) 오각해삼**

Order Molpadida

Family Molpadiidae

Molpadia oolitica **(Pourtalès, 1851)**

Class Ophiuroidea

Order Euryalida

Family Euryalidae

Ophiocreas caudatus **Lyman, 1879**

Family Gorgonocephalidae

Astrocladus coniferus **(Döderlein, 1902) 혹가지거미불가사리**

Astroboa arctos **Matsumoto, 1915 곰거미불가사리**

Order Ophiurida

Family Amphiuridae

Amphiura koreae **Duncan, 1879 턱뱀거미불가사리**

Family Ophiactidae

Ophiopholis mirabilis **(Duncan, 1879) 뿔거미불가사리**

Family Ophiodermatidae

Ophiopsammus anchista **H.L. Clark, 1911 빗거미불가사리**

Family Ophionereididae

Ophionereis eurybrachiplax **H.L. Clark, 1911 둥근따기거미불가사리**

Ophionereis variegata **Duncan, 1879**

Family Ophiotrichidae

Ophiothrix **(Ophiothrix) *koreana*** **Duncan, 1879 고려가시거미불가사리**

Family Ophiuridae

Stegophiura sterea **(H.L. Clark, 1908) 지붕거미불가사리**

Ophioglypha sterea H.L. Clark, 1908: 293

Distribution: Japan, Korea

Habitat: Depth range 150-300m; Warm-temperate species.

Three species (*S. sladeni, S. sterea, S. vivipara*) in the genus *Stegophiura* were reported from Korea.

Fig. 12 *Stegophiura sterea*

Table 2 The Ecological information of the megabenthos in this study with ecological data for dominant species and several described species (*: first recorded in this study area)

Taxon	Ecological data		
	Depth range (m)	Substratum	Temperature (℃)
Polychaeta			
Neoleanira areolata	66-104	sM, mS, S	10.5-15.6
Mollusca			
Acila divaricata	38-90	sM, mS, (g)mS	10.5-15.2
Mactrinula dolabrata	38-109	M, sM, mS, (g)mS, S, sZ	10.5-20.8
Siphonalia fuscolineata	38-104	sM, mS, (g)mS, S	10.5-20.8
Zeuxis siquijorensis	24-75	M, sM, (g)mS	13.8-14.2
Crustacea			
**Aegaeon rathbuni*	88	(g)mS	15.2
Charybdis bimaculata	37-109	M, sM, mS, (g)mS, zS	11.4-22.1
**Choniognathus reini*	104	S	15.6
**Ethusa quadrata*	109	mS	14.6
**Eumedonus zebra*	75	M	14.6
Paguristes digitalis	48-94	mS, (g)mS	15.4-16.8
Paguristes ortmanni	75-109	M, mS, (g)mS, S	14.6-15.6
Palaemon gravieri	37-109	sM, mS, zS	11.4-22.1
Pandalus gracilis	48	(g)mS	16.8
Parapenaeopsis hardwickii	37-48	sM, zS	20.8-22.1
**Sakaija japonica*	104	S	15.6
**Tokoyo eburnea*	75-109	sM	14.6-16.6
Echinodermata			
Coelopleurus undulatus	75	M	14.6-15.9
Pentacta doliolum	48	(g)mS	13.3-16.8
Pseudocnus sp.	66-109	sM, mS	10.5-14.7
Stegophiura sterea	48-104	sM, (g)mS, S,	10.5-20.8
Others			
Flabellum distinctum	48-109	M, sM, mS, (g)mS, S	13.3-16.8
Hormathia andersoni	38-104	M, sM, mS, (g)mS, S	10.5-20.8

Table 3 Distribution of the megabenthos collected in this study

Taxon	Station																
	A3	A8	B0	B2	B4	B6	B8	B10	C3	E1	E5	F1	F6	F11	F15	H1	H12
Polychaete																	
Aphrodita sp.	○									○	○						
Aphrodita talpa									○			○					
Arabella iricolor		○							○								
Eunice indica										○							
Eunice sp.1									○					○			
Eunoe shirikishinensis									○								
Glycera nicobarica									○								
Iphione ovata	○					○			○	○		○					
Lagis bocki									○								
Lepidonotus spiculus												○					
Marphysa bellii									○								
Neoleanira areolata									○								
Nereis longior		○								○					○		
Onuphis sp.														○			
Phylo sp.										○			○				
Sabellarte sp.						○											
Sternaspis chinensis																	
Terebellides horikoshii														○			
Pycnogonida																	
Ascorhynchus glaberrimum				○													
Nymphon kodanii									○								
Crustacea Isopoda																	
Cymodoce acuta									○								
Cymodoce japonica									○								
Janira sp.		○															
Pleuroprion sp1									○								
Crustacea Amphipoda																	
Ampelisca miharaensis									○								
Aorcho nanus		○															
Gammaropsis japonicus		○															
Liljeborgia japonica		○															
Melita denticulata									○								
Pareuystheus latipes												○					
Protomedeia crudoliops														○			
Crustacea Decapoda																	
Aegaeon lacazei				○										○			
Aegaeon rathbuni							○										
Alpheus brevicristatus			○														
Alpheus japonicus			○		○	○						○					
Alpheus sp.1					○										○		
Axiopsis consobrina				○													

Taxon	Station																
	A3	A8	B0	B2	B4	B6	B8	B10	C3	E1	E5	F1	F6	F11	F15	H1	H12
Axiopsis consobrina				○													
Betaeus granulimanus												○					
Birulia kishinouyei							○										
Crangon affinis					○	○											
Crangon hakodatei			○		○	○			○	○		○				○	
crangon sp.												○					
hadropenaeus lucasii														○			
Heptacarpus acuticarinatus									○			○					
Hippolyte sp.									○								
Latretus anoplonyx									○								
Latreutes sp.									○								
Leptochela gracilis									○							○	
Leptochela sp.												○					
Leptochela sydniensis						○										○	○
Metacrangon sinensis									○								
Metapenaeopsis dalei						○											
Palaemon gravieri										○	○	○	○		○	○	
Palaemon ortmanni				○		○			○					○			
Pandalus gracilis									○								
Paracrangon abei									○								
Parapenaeopsis hardwickii												○				○	
Petrarctus brevicornis														○			
Plesionika ortmanni	○					○			○				○				
solenocera comata														○			
Solenocera melantho						○							○				○
Trachysalambria curvirostris				○	○	○			○			○				○	
Callianassa japonica				○													
Boninpagurus pilosipes								○									
Catapagurus sp.		○															
Ceratopagurus pilosimanus							○						○				
Dardanus arrosor		○		○													
Diogenes edwardsii												○					
Diogenes sp.																○	
Paguristes digitalis								○	○								
Paguristes japonicus		○							○								
Paguristes ortmanni		○		○			○							○			
Paguristes sp.				○									○				

Taxon	Station																
	A3	A8	B0	B2	B4	B6	B8	B10	C3	E1	E5	F1	F6	F11	F15	H1	H12
Pagurus brachiomastus				○			○		○								
Pagurus debius		○															
Pagurus gracilipes		○		○													
Pagurus minutus								○	○								
Pagurus pectinatus		○					○										
Pagurus pilosipes		○															
Pagurus proximus		○															
Pagurus similis				○													
pagurus sp.		○		○										○			
Pagurus triserratus		○		○													
Galathea orientalis		○							○								
Munida japonica				○				○						○			
Paramunida scabra		○		○													
Achaeus japonicus									○								
Achaeus tuberculatus		○															
Anatolikos sp.									○								
Cancer gibbulosus											○	○					
Cancer sp.								○	○								
Carcinoplax longimana	○					○											○
Carcinoplax purpurea											○						
Carcinoplax sp.			○														
Carcinoplax surugensis					○	○									○		○
Carcinoplax vestita										○					○		
Charybdis bimaculata	○		○		○	○			○	○	○	○	○			○	
Charybdis riversandersoni														○			
Choniognathus reini		○															
Entomonyx spinosus							○										
Entricoplax vestita			○		○	○											
Eplumula phalangium		○		○										○			
Ethusa quadrata														○			
Euclosiana obtusifrons		○		○													
Eumedonus zebra				○													
Hemigrapsus penicillatus				○													
Latreillopsis bispinosa		○															
Leptomithrax bifidus							○							○			
Leptomithrax edwardsii				○					○					○			
Liocarcinus corrugatus				○					○								
Maja japonica		○															
Mursia trispinosa		○												○			

Taxon	Station																
	A3	A8	B0	B2	B4	B6	B8	B10	C3	E1	E5	F1	F6	F11	F15	H1	H12
Ovalipes punctatus												○					
Petalomera yamashitai				○													
Pilumnus minutus									○								
Pilumnus sp1.														○			
Pinnotheres pholadis									○								
Platymaia alcocki		○															
Platymaia wyvillethomsoni		○															
Pleistacantha sanctijohannis														○			
Portunus (monomia) gladiator		○															
Portunus (portunus) trituberculatus												○				○	
Portunus pelagicus														○			
Pugettia incisa									○		○						
Pugettia vulgaris									○					○			
Puggetia sp.				○													
Randallia eburnea				○									○	○			
Romaleon gibbosulum										○							
Scyra sp.									○								
Trachycarnicus balssi													○				
Tymolus japonicus		○											○				
Singhaplax danielae														○			
Scalopidia spinosipes													○				
Crustacea Stomatopoda																	
Oratosquilla oratoria					○							○	○			○	
Squilla sp.														○			
Crinoidea																	
Crinoidea sp.				○													
Asteroidea																	
Aphelasterias sp.		○							○								
Asterina sp.				○													
Asteropecten kagoshimensis		○															
Astroboa arctos									○								
astrocladus coniferus									○								
Astropecten polyacanthus									○				○				
Ctenopleura fisheri														○			
Ctenopleura sp.		○								○							
Dipsacater pretiosus								○									
Echiniasteridae				○									○				
Henricia ohshimai														○			

Taxon	Station																
	A3	A8	B0	B2	B4	B6	B8	B10	C3	E1	E5	F1	F6	F11	F15	H1	H12
Leptychaster anomalus				○									○	○			
Luidia quinaria		○															
Ophiuroidea																	
Amphioplus sp.														○			
Amphiura koreae									○								
astrocladus coniferus									○								
Crossaster sp.									○								
Ophiocentrus sp.														○			
Ophiocreas caudatus						○				○				○		○	
Ophiocreas sp.						○											
Ophiogymma sp.			○		○		○										
Ophionereis eurybrachiplax									○								
Ophionereis variegata									○								
Ophiopholis mirabilis				○					○								
Ophiopsammus anchista				○													
Ophiotrix sp.									○								
Ophiura sp.		○								○							
Pectinura sp.				○													
Stegophiura sp.							○		○				○				
Stegophiura sterea		○							○	○		○					
Ophiothrix (Ophiothrix) koreana				○													
Echinoidea																	
Clypeasteroida sp.		○		○													
Coelopleurus undulatus				○													
Phalacrocidaris japonica							○										
Schizaster lacunosus										○							
Stereocidaria japonica		○							○								
Strongylocentrotus nudus									○								
Temnotrema rubrum								○									
Holothuroidea																	
Molpadia oolitica											○					○	
Pentacta doliolum									○								
Pseudocnus sp.										○	○			○	○		
Polyplacophora																	
Leoidozona andrigiaschevi									○								
Gastropoda																	
Adamnetia japonica														○			
Boreotrophon candelabrum		○															
Brachytoma tuberosa																○	
Bullacta exarata										○							
Calliostoma consors							○	○									
Calliostoma koma									○								

Taxon	Station																
	A3	A8	B0	B2	B4	B6	B8	B10	C3	E1	E5	F1	F6	F11	F15	H1	H12
Calyptraea sp.									○								
Chicoreus aculeatus				○													
Crepidula sp.		○															
Cymatium parthehopeum				○													
Cyprass vitellus				○													
Dhiline argentata									○								
Emarginula crassicostata									○								
Emarginula sp.									○								
Fascioariidae									○								
Fusinus ferrugineus				○					○								
Gemmula kieneri														○			
Guildfordia triumphans		○															
Inquisitor jeffreysii			○														
Inquisitor nudivaricosus			○														
Mactrinula dolabrata													○				
Microfusus magnifica magnifica	○	○															
Nassarius variciferus																○	
Neptunea sp.										○							
Nudibranchia									○								
Primovula frumentum									○								
Siphonalia fuscolineata	○	○			○	○	○		○	○	○	○			○		
Siphonalia fusoides		○			○												
Tristichotrochus aculeatus		○															
Tristichotrochus haliarchus														○			
unedogemmula deshayesi																○	
Vokesimurex rectirostris														○			
Zeuxis siquijorensis			○		○	○				○							
Bivalvia																	
Acila divaricata	○				○	○	○			○							
Acila mirabilis						○				○							
Angulus vestalioides											○						
Chlamys irregularis				○													
Chlamys nobilis				○													
Chlamys squamata									○								
Clycymeris imperialis									○								
Cryptopecten vesiculosus														○			
Enucula tenuis										○							
Hawaiarca uwaensis														○			

Taxon	Station																
	A3	A8	B0	B2	B4	B6	B8	B10	C3	E1	E5	F1	F6	F11	F15	H1	H12
Lima fujitai									○								
Mactrinula dolabrata		○		○	○	○				○		○	○		○		○
Meiocardia tetragona													○				
Modiolus elongatus										○							
Nitidotellina nitidula										○							
Portlandia lischkei										○							
Striarca symmetrica												○					
Others																	
Hormathia andersoni	○	○		○	○	○			○	○	○	○			○		
Adeona sp.									○								
Bellonella rigida									○								
Bellonella rubra	○																
Echinoptillum macintoshi	○																
Flabellum distinctum		○		○					○				○	○			
Leioptilus fimbriatus		○											○				
Litaspongia arborea									○								
Maldreporaria sp.							○										
paraspongodes hirotai									○								
Paraspongodes spiculosa									○								
Pennatulacea													○				
Scleractinia sp.		○															
Flabellum (Ulocyathus) deludens		○															
Flabellum pavonium		○															
Phascolosoma agassizii														○			
Ctenoides annulata									○								
Laqueus sp.		○		○					○								
Terebratuling japonuca									○								
Ciona sp.															○		
Bryozoa				○					○								
Axinella sp.									○								
Oscarella lobularis				○													
Polyclinidae																	
Aplidium sp.									○								
Polyclinidae									○								
Aglaophenia sp.									○								

3.3 Distribution and species composition of megabenthos

3.3.1 Species composition

In total, 301 species have occurred during the survey period, and 187 species were identified. Arthropod crustaceans represented the most abundant taxon with 118 species (39 %), followed by mollusks with 55 species (18 %), echinoderms with 44 species (14 %), annelid polychaetes with 19 species (6 %), and others phyla with 71 species (23 %) (Fig. 13). An average of 29 species were recorded at site. The highest number of species (116) was found at C3, and the lowest number of species (5) was identified at H12, south of Jeju Island (Fig. 14).

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, density was highest at C3 (89 ind/100 m^2), in the South Sea, and values were less than 5 ind/100 m^2 at F11, H1, and H12, southwest of Jeju Island. In November 2015, 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, 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 %).

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, 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, biomass was also 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, 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 diversity (H′) value in the study area was 2.0, and higher than 3.0 at C3 and F15 in June 2015, and A8 and C3 in November 2015. The lowest diversity was 0.6 at H12 in June 2015.

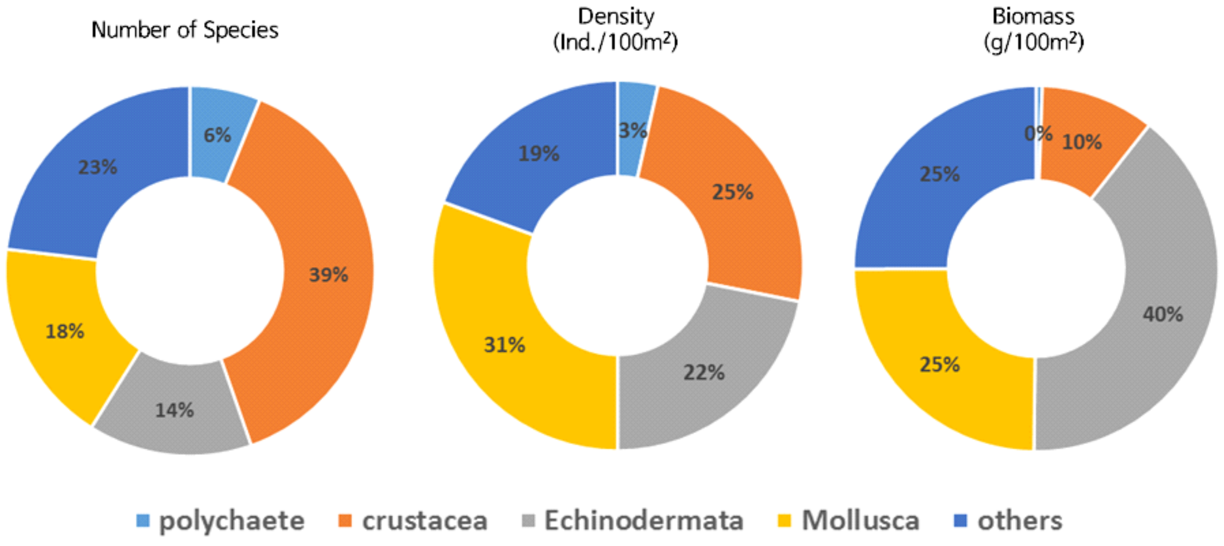

Fig. 13 Composition of species number, density (ind./100 m^2) and biomass (g/100 m^2) of the megabenthos in the study area

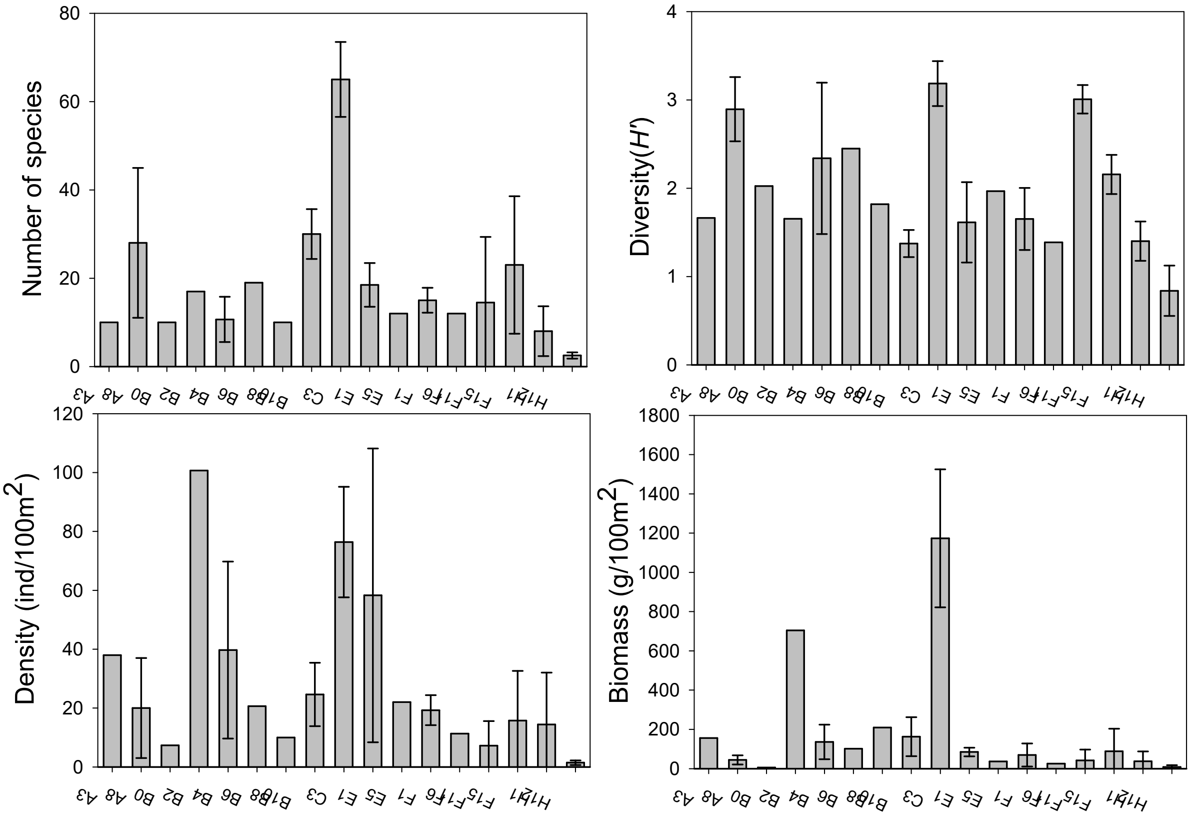

Fig. 14 Number of species, diversity(H′), density (ind./100 m^2) and biomass (g/100 m^2) of the megabenthos in the study area

3.3.2 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 4, Fig. 15). *Stegophiura sterea*, the most 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.

Table 4 Dominant species of megabenthos ranking based on the density

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

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

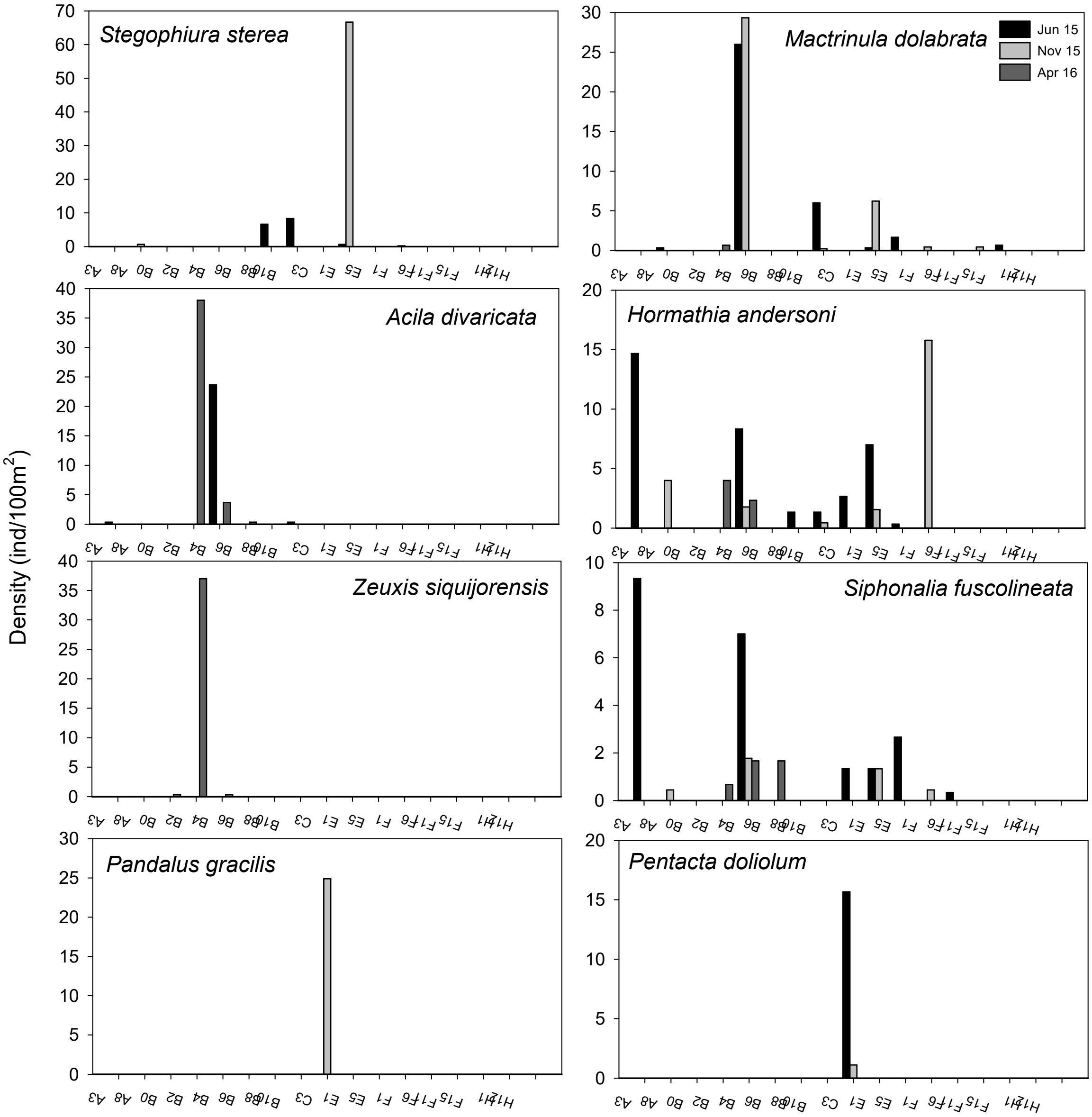

Fig. 15 Dominant species of the megabenthos at each station

3.3.3 Community structure

A cluster analysis and MDS analysis of the Bray-Curtis similarity matrix based on the density of the megabenthos in June 2015 were divided the study area into three groups by species contributions: Group a were placed east of Jeju Island, Group b consisting of the South Sea station and south of Jeju Island, Group c located diagonally from the South coast to the region southwest of Jeju Island (SIMPROF test, P < 0.05) (Fig. 16). Group b was deeper than 100 m. The average similarity of Group a was 22.71 %, and *Leptomithrax edwardsii,* , *Munida japonica*, *Eplumula phalagium* contributed 16.8 %, 16.8 %, and 15.2 %, respectively (SIMPER test, $P < 0.05$) (Table 5). The average similarity of Group b was 16.9 %, and *Solenocera melantho*, *Mactrinula dolabrata*, and *Leioptilus fimbriatus* contributed 60.9 %, 20.2 % and 18.9 %, respectively. The average similarity of Group c was 21.7 %, and *Hormathia andersoni, Siphonalia fuscolineata and Mactrinula dolabrata* contributed 29.2 %, 17.9 % and 10.4 % respectively.

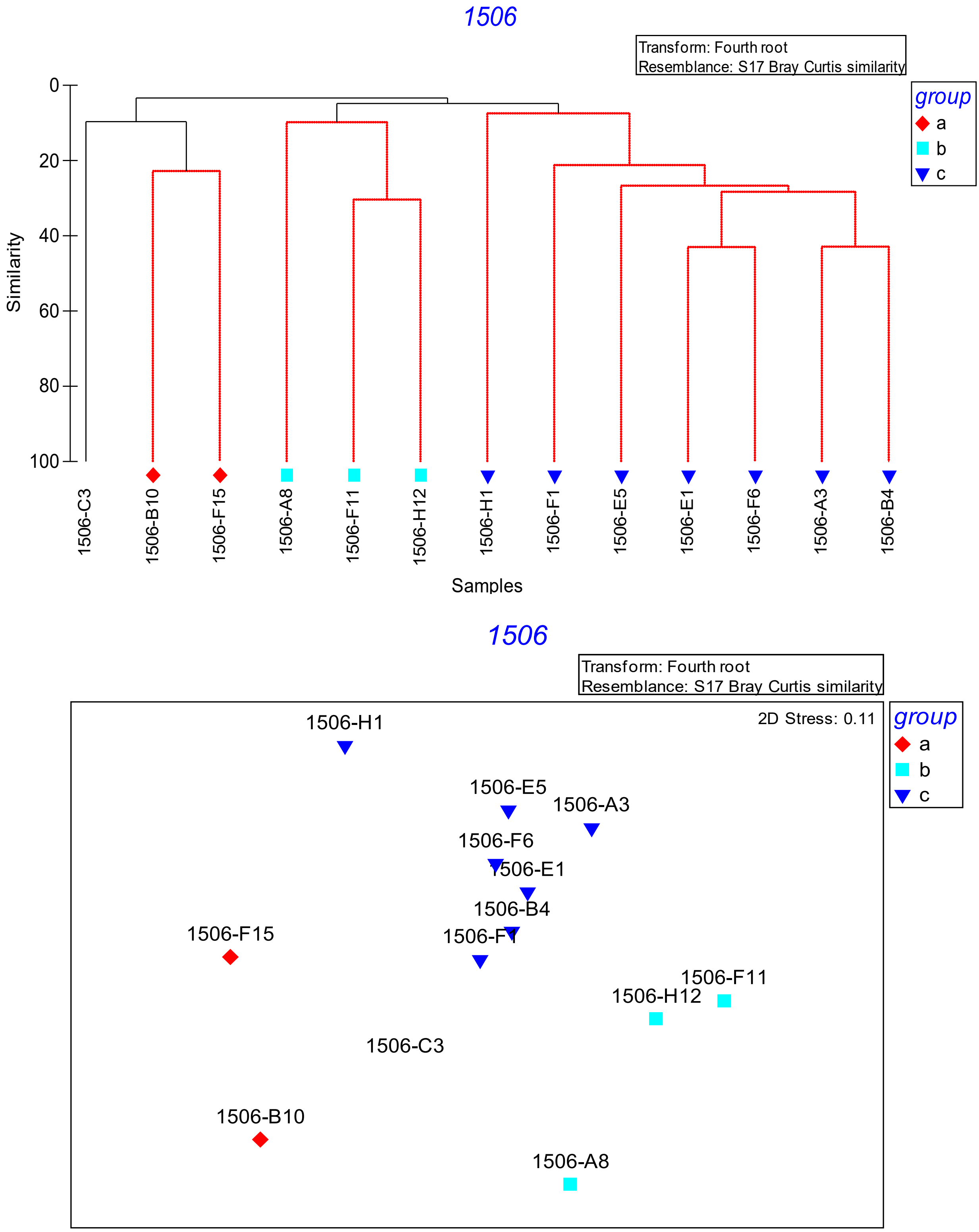

Fig. 16 Dendogram and 2-dimensional plot using megabenthic faunal abundance data by Bray-Curtis similarities calculated on the fourth-root transformed abundance data in the South Sea of Korea in June 2015

Table 5 SIMPER analysis of the megabenthic fauna, listing the main characterizing species at each group in June 2015

	Species	Average Abundance (log)	Contribution %	Cumulative %
Group a Average similarity: 22.71%	*Leptomithrax edwardsii*	1.00	16.83	16.83
	Munida japonica	1.07	16.83	33.65
	Eplumula phalangium	0.99	15.20	48.86
Group b Average similarity: 16.58%	*Solenocera melantho*	0.61	60.91	60.91
	Mactrinula dolabrata	0.55	20.21	81.12
	Leioptilus fimbriatus	0.51	18.88	100
Group c Average similarity: 21.66%	*Hormathia andersoni*	1.20	29.20	29.20
	Siphonalia fuscolineata	0.93	17.88	47.09
	Mactrinula dolabrata	0.82	10.37	57.46

A cluster analysis and MDS analysis of the Bray-Curtis similarity matrix based on the density of the megabenthos in November 2015 were divided the study area into two groups by species contributions. Group a were placed east of Jeju Island and group b consisted of the west of the Jeju Island stations with B4 in the frontal zone of the South Sea (Fig. 17). The average similarity of Group a was 17.83 %, and *Hormathia andersoni, Eplumula phalangium* and *Euclosiana obtusifrons* contributed 14.52 %, 12.21 %, and 12.21 %, respectively (SIMPER test, $P < 0.05$) (Table 6). The average similarity of Group b was 24.44 %, and *Charybdis bimaculata, Hormathia andersoni* and *Mactrinula dolabrata* contributed 18.00 %, 13.57 % and 12.57 %, respectively.

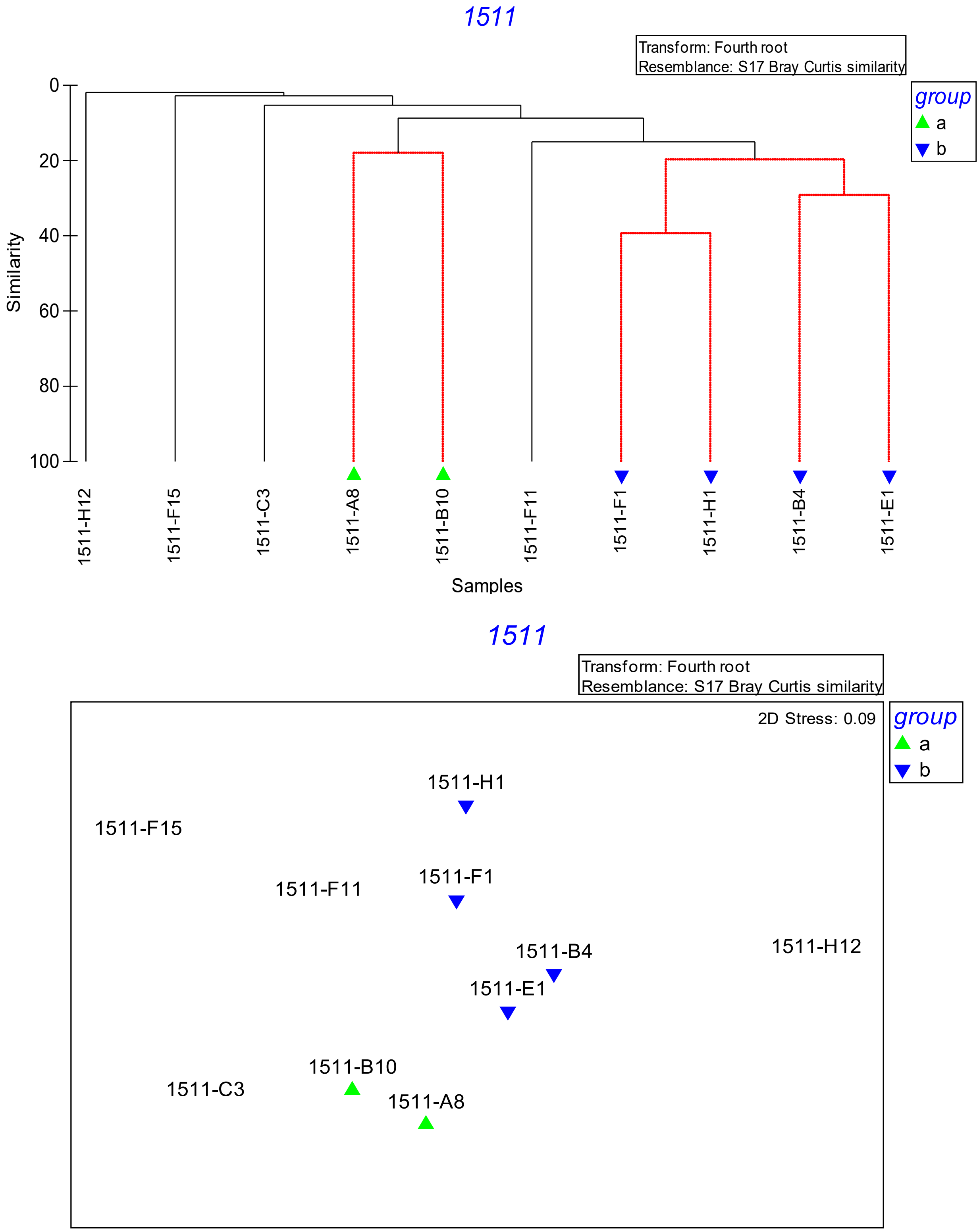

Fig. 17 Dendogram and 2-dimensional plot using megabenthic faunal abundance data by Bray-Curtis similarities calculated on the fourth-root transformed abundance data in the South Sea of Korea in November 2015

Table 6 SIMPER analysis of the megabenthic fauna, listing the main characterizing species at each group in November 2015

	Species	Group a Average Abundance (log)	Group b Average Abundance (log)	Contribution %	Cumulative %
Group a & b Average dissimilarity: 91.52%	*Mactrinula dolabrata*	0.34	1.18	2.28	2.28
	Coelopleurus undulatus	0.86	0.00	2.10	4.38
	Palaemon gravieri	0.00	0.89	2.07	6.45
	Eplumula phalangium	0.90	0.00	2.07	8.52

A cluster analysis and MDS analysis of the Bray-Curtis similarity matrix based on the density of the megabenthos in November 2015 were divided the study area into two groups by species contributions (Fig. 18). Group a and b were located in the frontal zone of the South Sea. Group a was mainly muddy sediment and Group b was sandy sediment with vary poorly sorted. The average dissimilarity of Group a and b was 93.88 %, and *Zeuxis siquijorensis, Charybdis bimaculata, Ascidiacea* sp. and *Acila divaricata* contributed 5.39 %, 5.38 % 5.17 % and 4.96 respectively (SIMPER test, $P < 0.05$) (Table 7).

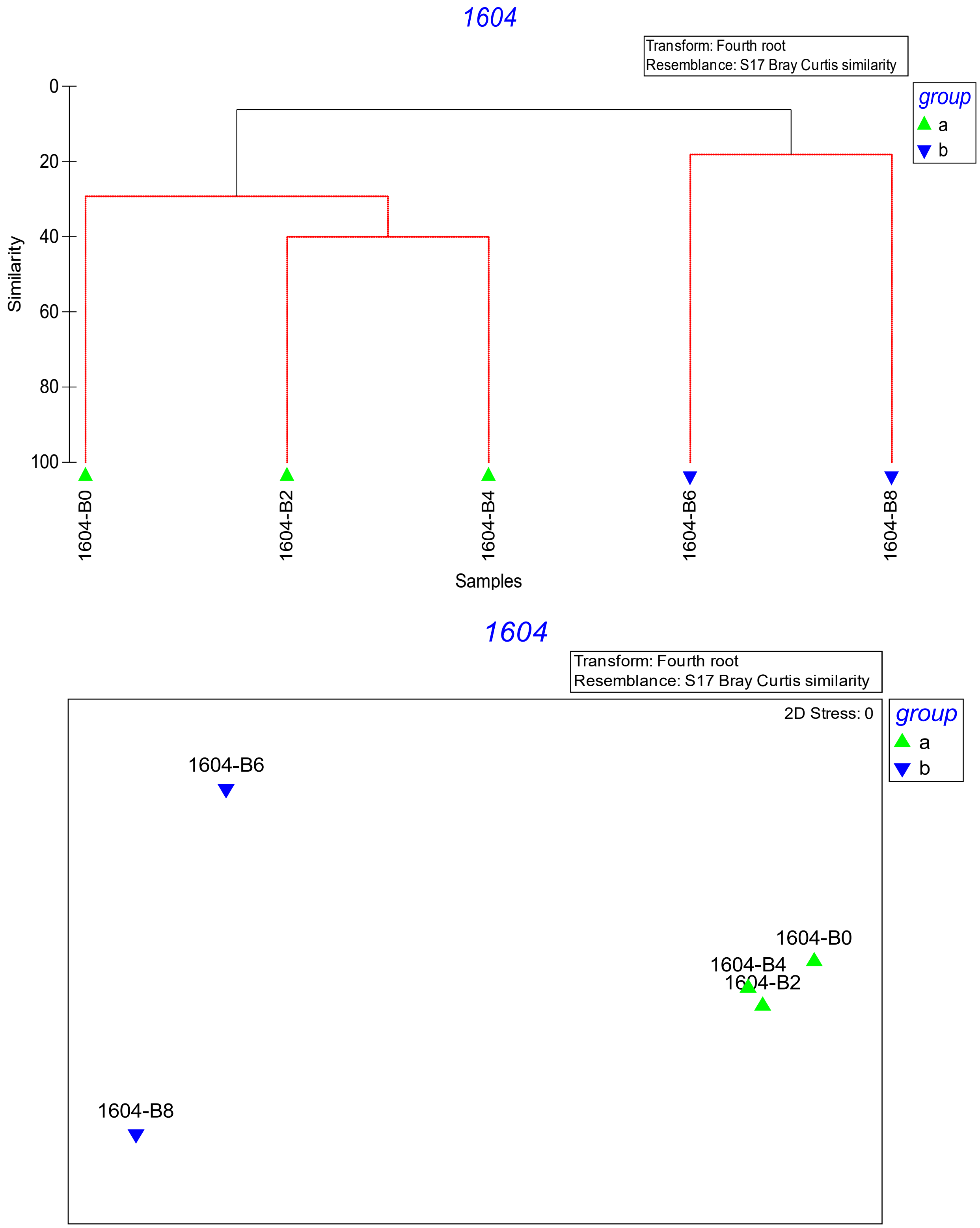

Fig. 18 Dendogram and 2-dimensional plot using megabenthic faunal abundance data by Bray-Curtis similarities calculated on the fourth-root transformed abundance data in the South Sea of Korea in April 2016

Table 7 SIMPER analysis of the megabenthic fauna, listing the main characterizing species at each group in April 2016

	Species	Group a Average Abundance (log)	Group b Average Abundance (log)	Contribution %	Cumulative %
Group a & b Average dissimilarity: 93.88%	*Zeuxis siquijorensis*	1.33	0.00	5.39	5.39
	Charybdis bimaculata	1.20	0.00	5.38	10.77
	Ascidiacea sp.	0.00	1.14	5.17	15.9
	Acila divaricata	1.29	0.38	4.96	20.89

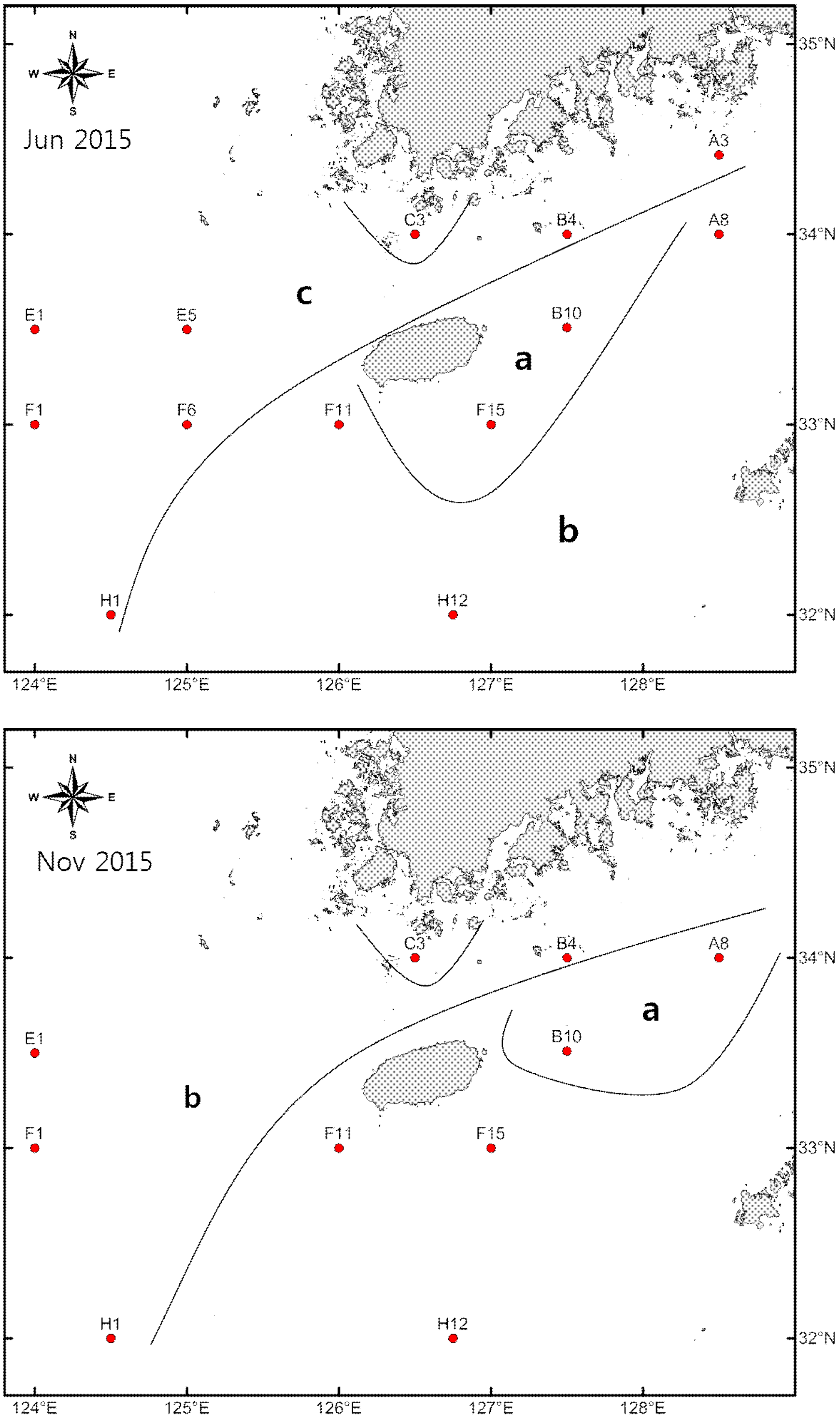

Fig. 19 Distribution of station groups, based on the species composition in 2015

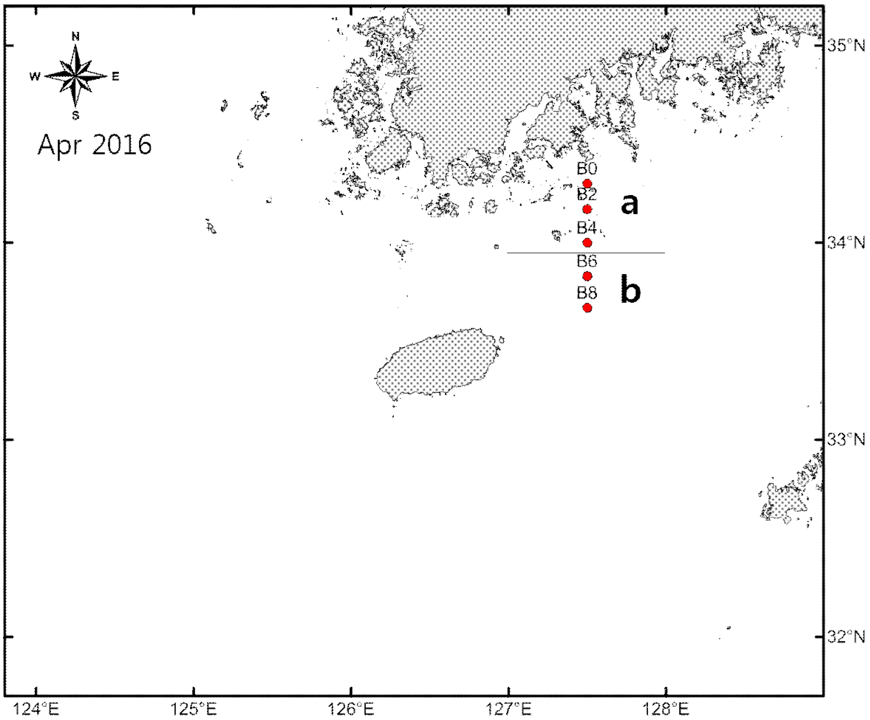

Fig. 20 Distribution of station groups, based on the species composition in 2016

A cluster analysis and MDS analysis of the Bray-Curtis similarity matrix based on the density of the megabenthos in study period divided the study area into seven groups by species contributions (Fig. 21). The average similarity of Group a was 16.58 %, and *Solenocera melantho*, *Mactrinula dolabrata* and *Leioptilus fimbriatus* were contributed 60.91 %, 20.21 % and 18.88 % respectively (SIMPER test, $P < 0.05$) (Table 8). The average similarity of Group b was 25.11 %, and *Leptochela sydniensis* was contributed 100 %. The average similarity of Group c was 25.87 %, and *Hormathia andersoni, Siphonalia fuscolineata* and *Charybdis bimaculata* were contributed 27.95 %, 19.05 %, and 11.55 %, respectively. The average similarity of Group d was 11.47 %, and *Flabellum distinctum* and Porifera were contributed 58.58 % and 41.42 %, respectively. The average similarity of Group e was 17.33 %, and *Eplumula phalangium, Munida japonica* and *Paguristes ortmanni* were contributed 16.61 %, 11.09 %, and 9.12 %, respectively. The average similarity of Group f was 21.34 %, and *Paguristes digitalis, Pentacta doliolum* and *Pilumnus minutus* were contributed 8.69 %, 8.31 %, and 7.85 %, respectively. The average similarity of Group g was 25.43 %, and *Ascidiacea* sp. and *Calliostoma consors* were contributed 37.29 % and 31.36 % respectively.

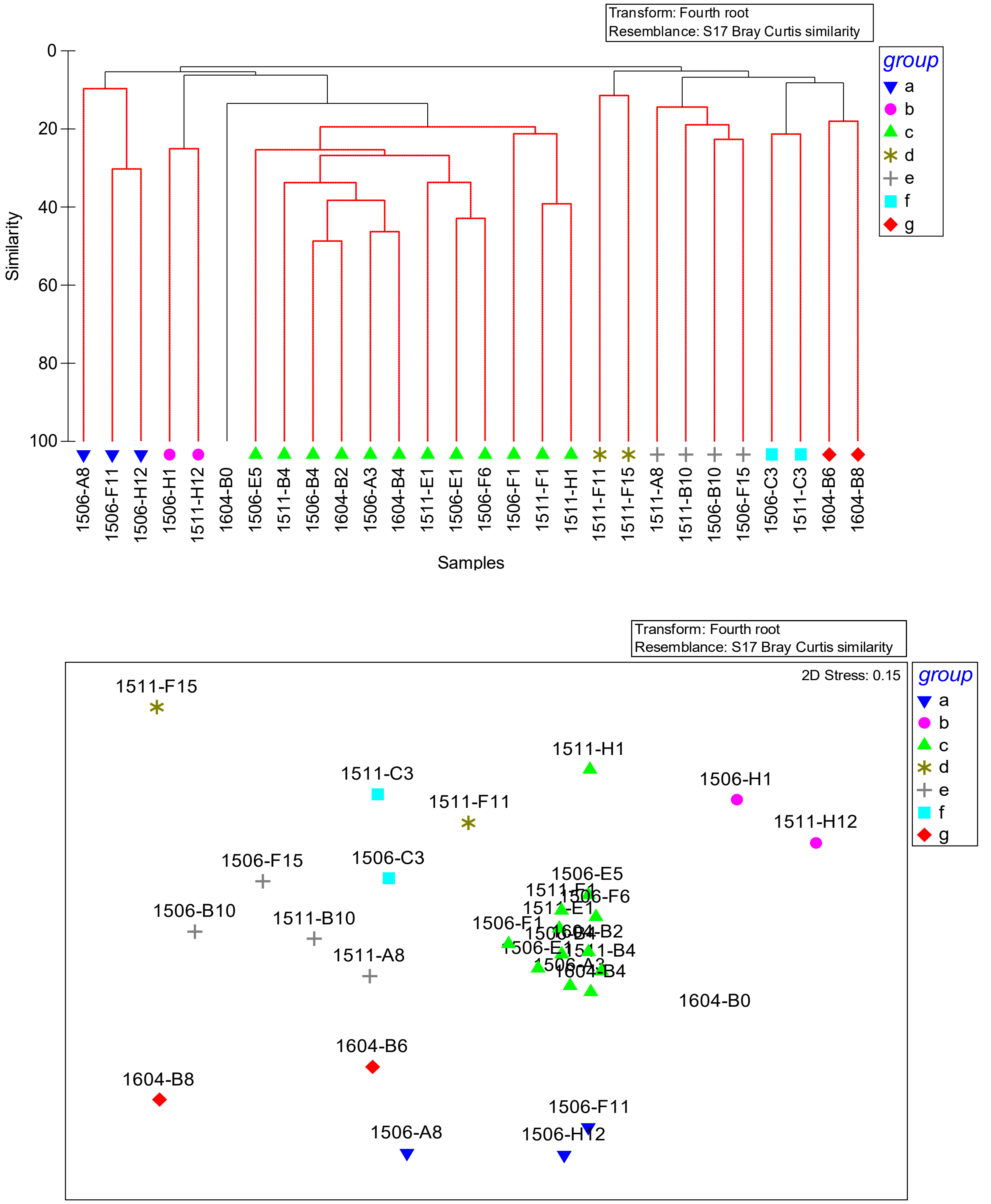

Fig. 21 Dendogram and 2-dimensional plot using megabenthic faunal abundance data by Bray-Curtis similarities calculated on the fourth-root transformed abundance data in the South Sea of Korea

Table 8 SIMPER analysis of the megabenthic fauna, listing the main characterizing species at each group in study periods

	Species	Average Abundance (log)	Contribution %	Cumulative %
Group a Average similarity: 16.58%	*Solenocera melantho*	0.61	60.91	60.91
	Mactrinula dolabrata	0.55	20.21	81.12
	Leioptilus fimbriatus	0.51	18.88	100
Group b Average similarity: 25.11%	*Leptochela sydniensis*	0.72	100	100
Group c Average similarity: 25.87%	*Hormathia andersoni*	1.28	27.95	27.95
	Siphonalia fuscolineata	0.96	19.05	47.01
	Charybdis bimaculata	0.66	11.55	58.56
	Mactrinula dolabrata	0.95	11.30	69.86
Group d Average similarity: 11.47%	*Flabellum distinctum*	1.00	58.58	58.58
	Porifera	0.75	41.42	100
Group e Average similarity: 17.33%	*Eplumula phalangium*	0.95	16.61	16.61
	Munida japonica	0.85	11.09	27.71
	Paguristes ortmanni	0.86	9.12	36.83
	Flabellum distinctum	0.71	7.24	44.06
Group f Average similarity: 21.34%	*Paguristes digitalis*	1.24	8.69	8.69
	Pentacta doliolum	1.51	8.31	17.00
	Pilumnus minutus	1.05	7.85	24.85
	Paraspongodes spiculosa	1.02	7.31	32.16
Group g Average similarity: 25.43%	*Ascidiacea* sp.	1.14	37.29	37.29
	Calliostoma consors	0.83	31.36	68.64
	Porifera	0.88	31.36	100.0

The BIO-ENV analyses of the megabenthos and environmental variables revealed that depth, gravel content and sorting value (ø) showed the highest correlations with megabenthic community (Rho = 0.353, $P < 0.01$)(Table 9).

The correlations between the total number of species, diversity, density, biomass, and dominant species with environmental factors were determined (Table 10). 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 (mean diameter), 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 (⌀).

Table 9 BIO-ENV test to analyze the effect of environmental variables on the megabenthic community

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)

Table 10 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 %	MZ(phi)	Temp.	Salinity	DO
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

4. Discussion

4.1 Environmental conditions

In June and November 2015 and April 2016, sampling was conducted at 17 stations in the South Sea, Jeju Island region and Ieodo coast of Korea, to identify the impact of environmental variables on the diversity and distribution of megabenthos in the South Sea of Korea. Bottom temperature in June 2015 was relatively lower than November 2015 (Fig. 3). Especially, E1 and E5 in the northwest of Jeju were lower than the average temperature. These patterns may caused by the summer cold-weather bottom currents of the Yellow Sea (KIOST, 2018). On the other hand, bottom temperature at HI in November 2015 considered to be relatively high, which may be the influence of the high-temperature Kuroshio Current driving northward.

4.2 Ecological characteristics and biogeography on the megabenthos species in this study area

A total 8 phyla, 45 classes, 116 family, 187 genus and 187 species of megabenthos were identified. In this study, environmental characteristics such as depth range, substratum, temperature of several species including dominant species were considered. *Stegophiura sterea*, it appeared in the depth range of 48-104 m which is shallower than previous reported depth range of 150-300 m. Many species were determined with sp., and it was regarded that several species were first recorded species in Korea. In this study on the megabenthos of the South Sea have first recorded 6 crustacean crabs. This can be an important information for understanding the species distribution around South Korea.

In addtion, subtropical species are increased in this study area. Therefore, species composition and distribution in this study area will be important data for monitoring the sea of Korea in the future. Also, it is considered that future study on the biogeography of distribution of species and northern limit line of species are needed.

4.3 Impact of environmental conditions on the distribution and species composition of the megabenthos

During the study period, the total number of megabenthos species, density (ind/100 m^2), and biomass (g/100 m^2) were 301 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 biomass increased with increasing gravel content (Table 10). Rex et al.(2000) reported that benthic animals decrease with increasing water depth. Jones et al.(2007) found that the megafaunal assemblages show a significant correlation with depth, but no correlation between diversity of megafauna and depth. The number of species and density of macrobenthos decrease with distance from the coast (Yu et al., 2008). Especially, the 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 sediments. However, it is difficult to explain the relationship between density and TOC, because TOC analysis has not been performed in this study.

The major dominant species in this study such as the ophiuroid *Stegophiura sterea* , two molluscks *Acila divaricata* and *Zeuxis siquijorensis* , the decapod *Pandalus gracilis* (CDe), and the holoturoid *Pentacta doliolum* (EHo) were found in high density only in certain areas, but the anthozoan *Hormathia andersoni*

(Others) and the gastropod *Siphonalia fuscolineata* (MGs) were appeared at the most stations except in the southern sea of Jeju Island (Fig. 15). *Stegophiura 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. *Mactrinula 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 sediments with a mean grain size of 6.4. *Acila divaricata* and *Z. siquijorensis* were dominant in muddy sediment B2 with mean grain size of 8.1. *Hormathia andersoni* and *S. fuscolineata* are usually dominant in subtidal sandy sediments in the South Sea of the Korea as a symbiotic relationship (Hong et al., 2006; Park and Huh, 2018). *Pandalus 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 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 which are mostly epibenthic 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 sediment with high sand contents (Sanders, 1968; Paik et al., 2007). Suspension feeding species generally increase in coasrse sediments (Jones et al., 2007). These tendency would reflected a general increase in food availability for suspension feeders compared to deposit feeders. 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). The distribution of benthic animals in deep-sea was greatly affected by the total organic matter supplied from the surface layer and varied in distribution depending on the feeding type of megabenthos (Smith et al. 2008). Among deep sea megafauna, Echinodermata such as Ophiuroidea usually dominate abyssal benthic communities (Piepenburg et al., 1997, 2001), Crustacea and mollusks are the most diverse epibenthic animal taxa in numerous trawl investigations (Park and Huh, 2018). The habitats of megabenthos is greatly affected by the feeding method of each taxon (Jones et al. 2013). Therefore, the difference in species composition and distribution of megabenthos in this study area maybe related to sediment composition and feeding type.

The community structures of megabenthos in June 2015 were divided into 3 groups, but divided into 2 groups in November 2015 and April 2016 (Figs. 19 & 20). The community structures were affected by several environmental variables such as depth, Gravel % and sorting value (ø) (Table 9). The number of species, diversity and biomass were higher in station C3 with poor quality sorting value and coarse sand sediment (Fig 3). However, the low density and biomass were at station H12 in the southernmost of Jeju Island. Rhoads et al.(1985) reported that the density decrease with increased silt and clay contents from the center of the East China sea to the southern of Jeju Island, and it was related to resuspension of Yellow Sea sediments. The species diversity of macrobenthos generally increase with fine grain size (McLachlan, 1990), but sometimes the number of species relatively increased with coarse 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 type (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 in the 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 10). Therefore, community structures and species composition of megabenthos in this study may be affected by the different sediment composition.

This study were 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 with future studies.

감사의 글

학부과정을 해양생명공학과에 진학하였고, 전공을 살리겠다는 의지로 이 자리까지 오게 되었습니다. 이 자리까지 올 수 있도록 인도하여 주신 하나님께 가장 먼저 감사드립니다. 처음 실습생으로 저서연구실에 들어오게 되었고, 저서생물에 대한 호기심과 연구의 즐거움으로 학위 공부를 시작하게 되었습니다. 짧지 않은 석사 과정동안 부족한 점이 많았지만 많은 분들의 가르침과 격려로 무사히 마칠 수 있었습니다. 긴 시간동안 저를 믿고 기다려주고 지원해주신 부모님 감사합니다. 그리고 항상 바쁜 언니 기다려주는 혜영이 고맙고 사랑해. 부족한 저를 이끌어주시고 지도해주신 유옥환 박사님 감사합니다. 진심어린 조언과 많은 가르침을 주신 이지민 박사님 감사합니다. 저를 위해 귀중한 시간을 내어 학위논문을 심사해주시고 앞으로의 방향성을 제시해 주신 박진순 교수님 감사합니다. 학문적 가르침을 주시고 관심을 주신 김동성 박사님 감사합니다. 현실적인 조언과 충고를 아끼지 않고 현재까지도 저에게 도움을 주는 순현오빠 고마워요. 연구실에서 동고동락하며 여러 방면에서 도움 주는 상렬오빠 고마워요. 연구소에서 생활하며 항상 응원해주고 버팀목이 되어준 아영언니 고마워요. 석사생활 서로 고민 상담해가며 졸업할 때까지 함께한 대학원 동기 은진언니 고마워요. 일본 교환학생 시간을 함께 지내며 추억 쌓은 승호야 고마워, 마지막까지 힘내자. 타지인 영도에서 맛있는 것 먹으며 즐거움을 준 지현씨 고마워요. 마지막 논문 수정할 때까지 도움주고 조언해주신 강태욱 박사님, 김종국 박사님, 최정민 선생님 고맙습니다. 연구소 생활에 도움을 주신 조혜경 선생님, 오제혁 선생님 고맙습니다. 멀리서 진심어린 응원해주며 기도해준 명진이, 인애, 하윤이, 효선이, 윤성이, 은평이, 현철이 고마워. 전공은 다르지만 각자 학교에서 석사생활하며 마음이 통하는 미리, 은진이, 지영이 고마워. 큰 응원과 부산까지 날 보러오는 민주 고마워. 다 전하지 못하였지만, 많은 도움을 주신 분들 모두 감사합니다. 주신 가르침으로 한걸음 더 나아가겠습니다.

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