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Quantitative distribution and functional groups of intertidal macrofaunal assemblages in Fildes Peninsula, King George Island, South Shetland Islands, Southern Ocean

Xiaoshou Liu [a,*], Lu Wang [a], Shuai Li [a], Yuanzi Huo [b], Peimin He [b], Zhinan Zhang [a]

[a] College of Marine Life Sciences, Ocean University of China, Qingdao 266003, PR China
[b] College of Fisheries and Life Sciences, Shanghai Ocean University, Shanghai 201306, PR China

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ABSTRACT

To evaluate spatial distribution pattern of intertidal macrofauna, quantitative investigation was performed in January to February, 2013 around Fildes Peninsula, King George Island, South Shetland Islands. A total of 34 species were identified, which were dominated by Mollusca, Annelida and Arthropoda. CLUSTER analysis showed that macrofaunal assemblages at sand-bottom sites belonged to one group, which was dominated by *Lumbricillus* sp. and *Kidderia subquadrata*. Macrofaunal assemblages at gravel-bottom sites were divided into three groups while *Nacella concinna* was the dominant species at most sites. The highest values of biomass and Shannon–Wiener diversity index were found in gravel sediment and the highest value of abundance was in sand sediment of eastern coast. In terms of functional group, detritivorous and planktophagous groups had the highest values of abundance and biomass, respectively. Correlation analysis showed that macrofaunal abundance and biomass had significant positive correlations with contents of sediment chlorophyll a, phaeophorbide and organic matter.

With unstable environment due to ice melting, studies of Antarctic shallow benthic fauna especially in intertidal areas received a lot of attention (Knox, 1960; Arntz et al., 1994; Peck et al., 2006; Barnes and Conlan, 2007). Arnaud (1992) summarized that scarce fauna in Antarctic intertidal and upper subtidal zones. Most studies about intertidal macrofauna in the Southern Ocean were carried out in Adelaide Islands (Antarctic Peninsula), South George Island, Signy Island (Scotia Arc) and South Shetlands Islands. Several investigations focused on the correlation between macrofaunal distribution and depth, latitude, season, food web in intertidal and subtidal areas (Arntz et al., 1994; Corbisier et al., 2004; Filgueiras et al., 2007; Aldea et al., 2008; Choy et al., 2011; Siciński et al., 2011; Gillies et al., 2012).

The highest species richness and diversity of Scotia Arc were found at high latitude areas, which were under the highest physical disturbance due to ice scour (Waller, 2008). The investigation about subtidal benthic communities showed that the community simplicity and dominance of unitary (compared to colonial) fauna increased with latitude (Barnes and Arnold, 1999). Jazdzewski et al. (2001) found that the order of macrofaunal biomass of the stony beach in King George Island was as follows: autumn > summer > spring > winter.

Until now, studies of intertidal benthos were much less than those from the deep sea. While many marine organisms are reported from the Southern Ocean, most of these species were found from trawls and grab samples from early expeditions and fishery bycatch (Strebel, 1908; Thiele, 1912; Roux et al., 2002). Coastal and subtidal biota are still relatively obscure (Barnes et al., 2006).

King George Island is the largest island in the South Shetland Islands in Antarctica. The island is about 80 km in length while it has different sizes in width from south to north with 30 km width at its broadest point. The whole island is covered with ice and snow all year round except some places along the coast in austral summer. The island is about 960 km away from Cape Horn which is at the southern tip of South America and 129.5 km away from Antarctic Peninsula. There are several scientific research stations on this island: Great Wall (China), Bellingshausen (Russia), Frei (Chile), Arctowski (Poland), Jubany (Argentina), Ferraz (Brazil), Artigas (Uruguay), King Sejong (R.O. Korea), Machu Picchu (Peru), and the summer stations of Chile and Argentina on Ardley Island. Situated on the southwest part of the King George Island, Fildes Peninsula is the largest ice-free zone in King George Island. This Peninsula, which is about 10 km in width, has an area of about

* Corresponding author.
E-mail address: liuxs@ouc.edu.cn (X. Liu).

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30 square kilometers. There is a multi-level marine deposit bench mostly consisting of gravel and sandiness beach in Fildes Peninsula (Fig. 1, E, 2010).

Most of the investigations of intertidal macrofauna in Fildes Peninsula focused on the qualitative analysis and food chain of macrofauna (Yang et al., 1992a,b; Shen et al., 1999), while quantitative investigations are restricted to areas in Maxwell Bay and Admiralty Bay (Filcek, 1993; Siciński et al., 2011; Bick and Arlt, 2013). In order to reveal the quantitative distribution of intertidal macrofaunal assemblages in Fildes Peninsula and to provide a baseline for evaluation of the effect of climate changes and human activities on intertidal ecosystems in the Southern Ocean, we report here about comprehensive survey results of intertidal macrofaunal assemblages.

In the austral summer (January to February 2013), macrofauna and environmental variables at 20 intertidal sites in Fildes Peninsula (Fig. 1; Table 1) were sampled during the Chinese 29th exploration on the Antarctic Ocean. Samples were collected at low tide during flood tide of every month, without dividing them into different tidal zones because of the narrow intertidal zones. Two samples were collected by a metal square-shaped frame (0.5 m × 0.5 m) at each sites of the gravel beach and four samples were collected by a square-shaped frame (0.25 m × 0.25 m) at each sandy site for macrofaunal analysis. The samples were sieved with a 0.5 mm mesh sieve. All animals were fixed by 5% buffered formalin solution and identified in the laboratory. Samples for sediment characteristics were collected from surface sediments and stored at −20 °C until analysis. Sediment organic matter content was measured by the ($K_2Cr_2O_7$–H_2SO_4) oxidization method. Sediment chlorophyll a (Chl-a) and phaeophorbide (Pha) contents were measured by spectrophotometer (Liu et al., 2007). Sediment grain size was measured by sieving method. Seawater characteristics (temperature, salinity, pH) were measured by YSI 600XLM sonde *in situ*.

Shannon–Wiener diversity index (H'), species richness index (d), species evenness index (J') were used to evaluate the macrofaunal biodiversity, which were calculated according to the following formulas:

$$H' = -\sum_{i=1}^{s} P_i \ln P_i;\ d = (S-1)/\log_2 N;\ J' = H'/\log_2 N;$$

where P_i is the percentage of the abundance of species i; N is the abundance of all species; S is the number of macrofaunal species of each sample.

Principal component analysis (PCA) was performed to identify the dominant environmental factors. Hierarchical clustering (CLUSTER) analysis was used to delineate macrofaunal assemblages of the sampling stations. BIOENV analysis was used to reveal the most important environmental factors to determine the macrofaunal distribution patterns. All of the abovementioned data analyses were performed using the PRIMER 6.0 software package. In order to assess relationships among the dominant species abundance and environmental variables, Spearman Correlation analysis was performed by SPSS software package.

Index of relative importance (IRI) was calculated to find the dominant species according to the following formula:

$$\mathrm{IRI} = (N + W) * F$$

where N and W are the percentages of abundance and biomass of each species; F is the frequency of each species in all the sampling sites (Pinkas et al., 1971).

The classification of functional groups of macrofauna is based on Li et al. (2013), including: (1) Planktophagous group (Pl): animals feeding on small microzooplankton by filter organs; (2) Phytophagous group (Ph): animals feeding on vascular plants and seaweeds; (3) Carnivorous group (C): animals feeding on meiofauna and larva; (4) Omnivorous group (O): animals feeding on other organisms, rotted leaf, small bivalves and crustaceans; (5) Detritivorous group (D): animals feeding on organic detritus and sediment.

Seawater temperature of the intertidal zones ranged from 0.69 °C to 4.22 °C with a mean of 2.09 °C. The highest and lowest temperature values of the eastern coast occurred at E4 (4.22 °C), E5 (0.69 °C) while the highest and lowest temperature values of the western coast occurred at W5 (3.12 °C), W6 (1.33 °C). Seawater salinity ranged from 28.95 to 36.26 with a mean of 34.63. The highest and lowest salinity values of eastern coast occurred at E11 (36.26), E2 (28.95) while the highest and lowest salinity values of the western coast occurred at W4 (36.24), W1 (33.82). Seawater pH ranged from 7.33 to 8.61 with a mean of 8.13. The highest and lowest pH of the eastern coast occurred at E2 (8.53), E5 (7.33) while the highest and lowest pH values of the western coast occurred at W1 (8.61), W6 (8.05).

Sediment median grain size (Md) in the intertidal zone ranged from 0.45 to 1.60 mm with a mean of 1.04 mm. The highest and lowest overall Md occurred at W4 (1.60 mm), E6 (0.45 mm). At the sandy sites, Md ranged from 0.59 to 1.60 mm with a mean of 1.09 mm. The highest and lowest of sandy sediment Md occurred

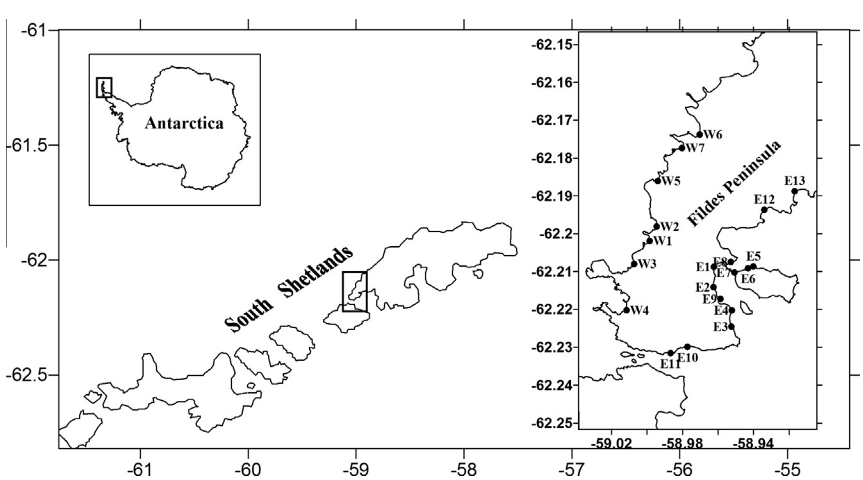

Fig. 1. Map of the sampling sites of intertidal zones in Fildes Peninsula, King George Island.

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Table 1
Environmental variables and information of the sampling sites of intertidal zones in Fildes Peninsula, King George Island.

Site	Latitude (S)	Longitude (W)	Sediment type	SWT (°C)	SWS	pH	Md (mm)	Chl-a (μg/g)	Pha (μg/g)	OM (%)
E1	62°12.527′	58°57.740′	Sand	0.97	34.74	7.73	1.56	0.578	0.019	0.79
E2	62°12.850′	58°57.750′	Sand	1.53	28.95	8.53	1.18	0.221	0.117	0.64
E3	62°13.476′	58°57.146′	Gravel	3.66	34.54	7.82	0.79	0.578	0.687	0.74
E4	62°13.217′	58°57.129′	Gravel	4.22	34.00	8.44	1.07	3.425	0	0.9
E5	62°12.522′	58°56.404′	Sand	0.69	33.96	7.33	1.07	0.171	0	0.71
E6	62°12.550′	58°56.586′	Gravel	1.62	34.78	8.23	0.45	2.439	0.638	1.11
E7	62°12.617′	58°57.042′	Gravel	2.40	34.89	8.25	0.79	1.217	1.198	1.09
E8	62°12.449′	58°57.164′	Gravel	1.47	32.74	7.96	1.07	0.328	0.931	0.79
E9	62°13.037′	58°57.513′	Gravel	3.15	35.33	8.15	1.59	3.251	2.497	1.37
E10	62°13.796′	58°58.632′	Gravel	1.87	35.33	8.07	1.02	3.028	0.142	0.91
E11	62°13.894′	58°59.200′	Gravel	1.48	36.26	8.05	0.87	0.812	0.296	0.84
E12	62°11.623′	58°56.032′	Gravel	1.87	35.64	8.1	1.13	0.698	0.157	0.97
E13	62°11.328′	58°55.005′	Gravel	2.62	35.77	8.15	1.08	0.209	0.086	0.63
W1	62°12.117′	58°59.908′	Sand	1.76	33.82	8.61	1.16	1.333	0	0.59
W2	62°11.889′	58°59.673′	Sand	1.83	34.75	8.07	0.59	8.658	2.251	1.28
W3	62°12.481′	59°00.432′	Sand	2.51	34.25	8.36	0.91	2.843	0.278	0.74
W4	62°13.216′	59°00.691′	Sand	1.75	36.24	8.16	1.60	8.732	1.284	1.46
W5	62°11.166′	58°59.634′	Sand	3.12	35.26	8.30	1.31	0.727	0	0.41
W6	62°10.430′	58°58.217′	Sand	1.33	35.59	8.05	0.68	0.395	0	0.75
W7	62°10.644′	58°58.816′	Sand	1.98	35.84	8.26	0.86	0.360	0.012	0.56

SWT: seawater temperature; SWS: seawater salinity; Md: median grain size; pH: pondus hydrogenii; Chl-a: chlorophyll a content; Pha: phaeophorbide content; OM: organic matter content.

at W4 (1.60 mm) and W2 (0.59 mm). At the gravel sites, Md ranged from 0.45 to 1.59 mm with mean of 0.98 mm. The highest and lowest Md of gravel sediment occurred at E9 (1.59 mm) and E6 (0.45 mm).

Chl-a contents of sediment in intertidal zones ranged from 0.17 to 8.73 μg/g with mean of 1.30 μg/g. The highest and lowest Chl-a contents occurred at W4 (8.73 μg/g) and E5 (0.17 μg/g). Pha contents of sediment ranged from 0 to 2.50 μg/g with mean of 0.53 μg/g. The highest Pha content occurred at E9 (2.50 μg/g) while at E4, E5, W1, W5, W6, the contents of Pha were zero.

Organic matter contents of sediment in the intertidal zones ranged from 0.41% to 1.46% with a mean of 0.86%. The highest and lowest organic matter contents occurred at W4 (1.46%) and W5 (0.41%).

The principal components analysis (PCA) based on environmental factors (including seawater temperature, salinity, pH, Mdø, Chl-a, Pha, organic matter) at the sampling sites of intertidal zones in Fildes Peninsula (Fig. 2), showed the first two principal components (PC1 and PC2) explaining 58.0% of the total variability. On PC1 axis, organic matter (−0.572), Chl-a (−0.548) and Pha (−0.532) were important factors to differentiate the sampling stations. On the PC2 axis, the important factors included pH (−0.723), temperature (−0.605), salinity (0.231).

A total of 34 species of macrofauna were found which contained 8 phyla: Mollusca (9 species), Arthropoda (9 species), Annelida (9 species), Platyhelminthes (3 species), Cnidaria (1 species), Nemertinea (1 species), Sipuncula (1 species), Echinodermata (1 species). Annelida was the most abundant taxa with 975.7 (max. 9060) ind./m^2 (46%) on average, followed by Platyhelminthes with 519.3 (max. 2104) ind./m^2 (25%), Mollusca with 355.5 (max. 2258) ind./m^2 (15%) and Arthropoda with 259.3 (max. 1434) ind./m^2 (12%).

Species numbers ranged from 2 to 17. The highest species number occurred at Site E7 (17 species), followed by E9 (16 species). The lowest species number occurred at W1 (2 species), W7 (2 species), followed by W2 (3 species), W3 (3 species). The highest Shannon–Wiener diversity index (H'), species richness index (d), species evenness index (J') occurred at E9 (1.55), E7 (1.89), W4 (0.88), respectively. The lowest species richness index (d), species evenness index (J'), Shannon–Wiener diversity index (H') occurred at W7 with 0.14, 0.06, 0.04, respectively. The average value of species richness index (d) and Shannon–Wiener diversity index (H') at the eastern coast was higher than those in the western coast. The average value of species evenness index (J') at the western coast was higher than that at the eastern coast (Table 2).

Table 2
Abundance, biomass and biodiversity indices of intertidal macrofauna assemblages in Fildes Peninsula, King George Island.

Site	S	d	J'	H' (loge)	Abundance (ind./m^2)	Biomass (gwwt./m^2)
E1	7	0.66	0.07	0.13	9264	3.509
E2	5	0.48	0.07	0.11	4112	1.866
E3	8	0.88	0.61	1.26	2892	35.615
E4	13	1.48	0.43	1.10	3278	145.261
E5	7	0.87	0.54	1.05	960	0.245
E6	7	0.91	0.67	1.31	724	78.488
E7	17	1.89	0.51	1.43	4784	43.641
E8	7	0.71	0.56	1.09	4574	79.021
E9	16	1.78	0.56	1.55	4490	67.241
E10	4	0.57	0.87	1.20	202	0.679
E11	12	1.47	0.35	0.87	1814	7.897
E12	5	0.55	0.17	0.28	1462	42.714
E13	6	0.67	0.08	0.15	1832	23.923
W1	2	0.31	0.65	0.45	24	0.003
W2	3	0.63	0.79	0.87	24	0.007
W3	3	0.67	0.87	0.95	20	8.508
W4	4	0.84	0.88	1.22	36	0.042
W5	5	0.64	0.18	0.29	536	0.069
W6	4	0.64	0.56	0.78	108	0.029
W7	2	0.14	0.06	0.04	1104	0.176

Note: S: species number; d: species richness index; J': species evenness index; H': Shannon–Wiener diversity index.

Macrofaunal abundance ranged from 20 to 9264 ind./m^2, and biomass ranged from 0.003 to 145.261 gwwt./m^2. The average abundance and biomass were 2112 ind./m^2 and 26.95 gwwt./m^2. The highest abundance occurred at the sand-bottom sites of the eastern coast, while the highest biomass occurred at the gravel-bottom sites of the eastern coast. The average abundance and biomass at the gravel-bottom sites of the eastern coast were 2455.64 ind./m^2 and 52.45 gwwt./m^2. The average abundance and biomass at the sand-bottom sites of the eastern coast were 4778.67 ind./m^2 and 1.873 gwwt./m^2. The average abundance and biomass at the sand-bottom sites of the western coast were 264.57 ind./m^2 and 1.26 gwwt./m^2.

Lumbricillus sp. was the most dominant species at all sites which contributed significantly to the total number of individuals

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at most sites, attaining a maximum of 99.3% at Site W7, and appeared at all sand-bottom sites of the eastern coast. The biomass of *Nacella concinna* was the most dominant species in terms of biomass with 23.27 gwwt./m^2 on average. *N. concinna* appeared at most gravel-bottom sites of the eastern coast. Nevertheless, no *N. concinna* and less *Lumbricillus* sp. appeared on the western coast.

The CLUSTER analysis showed that macrofaunal assemblages at the 10 sand-bottom sites belonged to one group. The most dominant species of this group were *Lumbricillus* sp., *Kidderia subquadrata*, *Plagiostomum* sp. 3, *Margarella antarctica*. Results of CLUSTER analysis divided macrofaunal assemblages at the 10 gravel-bottom sites into three groups (Fig. 3). Six sites near Great Wall cove were included into Group 1. The most dominant species of Group 1 were *Plagiostomum* sp. 1, *Laevilacunaria antarctica*, *Lumbricillus* sp., *N. concinna*. Two sites in the southeastern coast were included into Group 2. The most dominant species of Group 2 were *Melita* sp., *Lumbricillus* sp., *Plagiostomum* sp. 2, *L. antarctica*. Two sites at the northeastern coast were included into Group 3. The most dominant species of Group 3 were *Plagiostomum* sp. 3, *N. concinna*, *Melita* sp. and *Lumbricillus* sp.

According to the value of IRI, 15 dominant species were identified, including Gastropoda: *N. concinna*, *Laevilittorina antarctica*, *Neobuccinum eatoni*, *M. antarctica*; *Bivalvia*: *K. subquadrata*; *Polychaeta*: *Polycirrus kerguelensis*, *Exogone heterosetosa*, *Oligochaeta*: *Lumbricillus* sp.; *Holothuroidea*: *Cucumariidae* sp., *Malacostraca*: *Paramoera edouardi*, *Melita* sp., *Hippomedon kergueleni* and *Platyhelminthes*: *Plagiostomum* sp. 1, *Plagiostomum* sp. 2, *Plagiostomum* sp. 3. The 15 species belong to 5 types of functional groups, including 2 species in the planktophagous group (Pl), 1 species in the phytophagous group (Ph), 3 species in the detritivorous group (D), 7 species in the omnivorous group (O) and 2 species in the carnivorous group (C). The percentage of abundance of 5 types of functional groups (Pl, Ph, D, O, C) were 5.3%, 11.3%, 45.7%, 37.6% and 0.1%, respectively. The percentage of biomass of 5 types of functional groups (Pl, Ph, D, O, C) were 87.1%, 3.0%, 3.0%, 6.1% and 0.8%, respectively (Table 3).

Correlation analysis between abundance of dominant species and environmental variables (Table 4) showed that *K. subquadrata* had significant positive correlations with Pha; *L. antarctica* had significant positive correlations with sediment Pha content and seawater temperature; *E. heterosetosa* had significant positive correlations with sediment Pha content and seawater temperature; *N. eatoni* had significant positive correlations with sediment Pha

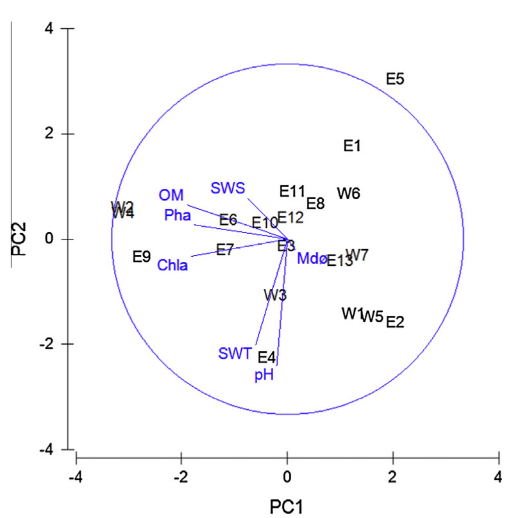

Fig. 2. PCA plot of environmental factors for sampling sites in Fildes Peninsula, King George Island.

content. Correlation analysis between biomass of dominant species and environmental variables showed that (Table 4) *N. concinna* had significant positive correlations with seawater temperature; *K. subquadrata* had significant positive correlations with Pha; *E. heterosetosa* had significant positive correlations with sediment Pha content and seawater temperature; *H. kergueleni* had significant positive correlations with sediment Pha and OM contents; *Plagiostomum* sp. 1 had significant positive correlations with seawater temperature.

Results of BIOENV showed that multiple variables combination influenced upon the macrofaunal assemblages. Two variables combination (Chl-a, OM) were the most important environmental factors influencing the macrofaunal assemblages and the correlations coefficients were 0.216, 0.172 respectively (Table 5). Nevertheless, salinity was not the influencing factor upon the macrofauna assemblages of the intertidal in Fildes Peninsula.

Correlations analysis between abundance of functional groups and environmental variables (Table 6) showed that planktophagous group (Pl) had significant positive correlations with sediment Pha content; phytophagous group (Ph) had significant positive correlations with sediment phaeophorbide content and seawater temperature; omnivorous group (O) had significant positive correlations with seawater temperature. Correlations analysis between biomass of functional groups and environmental variables (Table 6) showed that planktophagous group (Pl) and phytophagous group (Ph) had significant positive correlations with seawater temperature; carnivorous group (C) had significant positive correlations with sediment Pha content.

Correlations analysis between diversity indices and environmental variables (Table 7) showed that the species richness index (*d*) had significant positive correlations with sediment Pha and OM contents; species evenness index (J') had significant positive correlations with sediment Chl-a and OM contents; Shannon–Wiener diversity index (H') had significant positive correlations with sediment Pha and OM contents.

Compared with other polar intertidal areas (Table 8), the abundance of intertidal macrofaunal assemblages in Fildes Peninsula (King George Island) were higher than those observed in other investigations of polar intertidal areas except for Adelaide Island (ca. 7500 ind./m^2). The sediment and climate environment of the eastern coast are significantly more suitable for macrofauna than those of the western coast (Pang and Li, 2012). With the lowest disturbance due to being an inner bay, the abundance (130,000 ind./m^2) and H' values of Maxwell Bay, in the eastern coast of Fildes Peninsula, were significantly higher than those in other intertidal zone, including those at 20 sites of the present study. Notably, two taxa (Nematoda and Bryozoa) which were in the list of macrofauna in the investigation of Maxwell Bay (Bick and Arlt, 2013) were not listed into macrofaunal catalogue in the present study.

Abundant taxa in intertidal zone of Fildes Peninsula were Annelida, Platyhelminthes, Mollusca, Arthropoda. Annelids comprised 46% of the total abundance of macrofauna, followed by Platyhelminthes with 25%, Mollusca with 17% and Arthropoda with 12%. The most abundant groups of this zone were oligochaetes (1906 ind./m^2), turbellarians (929 ind./m^2), molluscs (685 ind./m^2), and crustaceans (502 ind./m^2). Nevertheless, a high proportion of polychaetes at Maxwell Bay (soft-bottom, ca. 25%), Adelaide Island (33%), Signy Island (47%) and South Georgia, and oligochaetes were much less important at these study sites (Bick and Arlt, 2013; Waller, 2008).

Oligochaetes, *Lumbricillus* sp. and the gastropoda *N. concinna* were the most dominant species in the gravel-bottom samples. As the most abundant species, *Lumbricillus* sp. was the only oligochaete found in this investigation, similar to that in hard-bottom samples of Maxwell Bay (Bick and Arlt, 2013). In addition, the

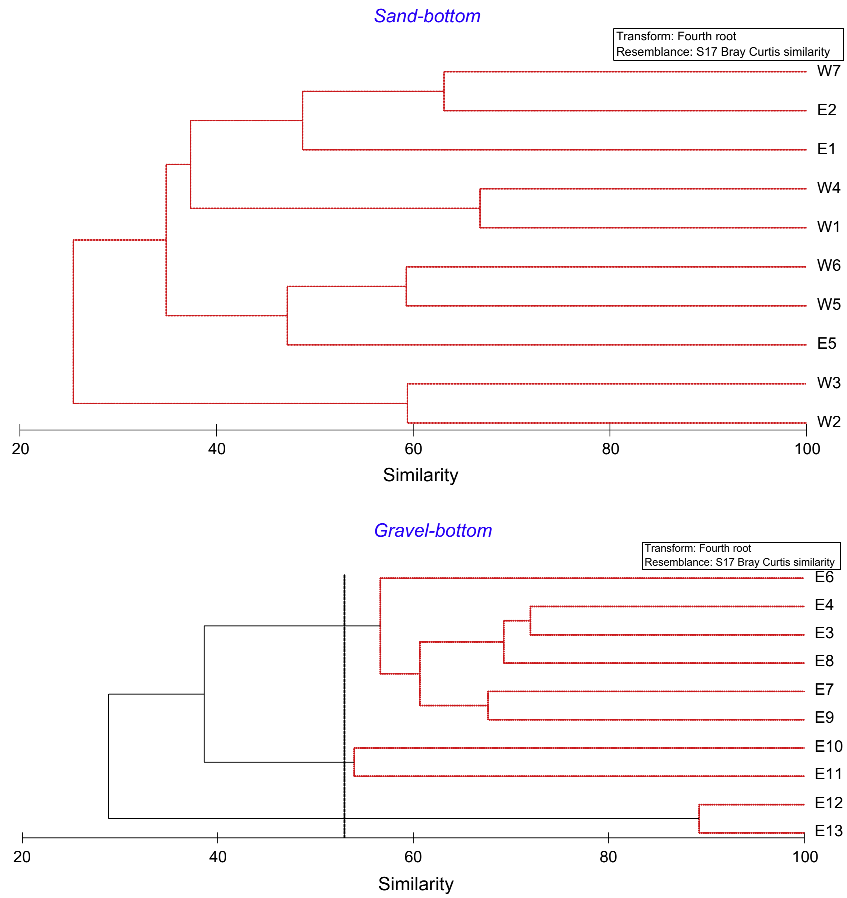

Fig. 3. CLUSTER analysis of intertidal macrofaunal assemblages in Fildes Peninsula, King George Island.

Table 3
Functional groups of dominant species in Fildes Peninsula, King George Island.

Taxon	Species	IRI	Abundance (ind./m^2)/biomass (gwwt./m^2)	Functional groups	References
Gastropoda	*Nacella concinna*	3845.5	328/23.267	Pl	Choy et al. (2011), Corbisier et al. (2004)
Bivalvia	*Kidderia subquadrata*	263.5	1928/0.191	Pl	Picken (1980)
Gastropoda	*Laevilittorina antarctica*	922.5	4742/0.799	Ph	Iken (1999)
Polychaeta	*Polycirrus kerguelensis*	10	144/0.046	D	Schüller and Ebbe (2007)
Oligochaeta	*Lumbricillus* sp.	4637.5	19,060/0.338	D	Coleman and Crossley (2004)
Holothuroidea	*Cucumariidae* sp.	8	4/0.424	D	Sicinski et al. (2011); Mincks et al. (2008)
Polychaeta	*Exogone heterosetosa*	26	274/0.002	O	Schüller and Ebbe (2007)
Malacostraca	*Paramoera edouardi*	9	84/0.017	O	Jazdzewski et al. (2001)
Malacostraca	*Melita* sp.	735	4994/0.415	O	
Malacostraca	*Hippomedon kergueleni*	4.5	66/0.017	O	
Platyhelminthes	*Plagiostomum* sp. 1	622.5	5850/1.060	O	
	Plagiostomum sp.2	21.5	304/0.098	O	
	Plagiostomum sp. 3	304.5	4232/0.036	O	
Gastropoda	*Neobuccinum eatoni*	3.5	8/0.188	C	Yang et al. (1992a)
Gastropoda	*Margarella antarctica*	6	32/0.025	C	Yang et al. (1992a)

abundance of *Lumbricillus* sp. was high in the mid- and lower littoral areas on the northeast coast of South Georgia Island (Pugh and Davenport, 1997). *N. concinna* was one of the species with the longest research history, wide distribution zone and high abundance species in the Antarctic Ocean (Clarke, 1979; Brêthes et al., 1994; Barnes et al., 2006; Powell, 1973). Similar to that of the south coast of Admiralty Bay (10–200 ind./m^2), the abundance of *N. concinna* was 34.3 ind./m^2 (Filcek, 1993). The IRI value of *N. concinna* was 3845.5, a lower value than that of *Lumbricillus* sp., but the biomass was highest. As an important linkage species of the food chain in the intertidal zone of Fildes Peninsula, *N. concinna* was a key species in the intertidal zone of Fildes Peninsula, which seems to play a decisive role for the intertidal macrofauna assemblages, species diversity and ecosystem stability (Tang, 2006).

Environmental variables, Chl-a, Pha, OM, were closely correlated with macrofaunal assemblages, which are similar to those of macrofauna of Signy Island, South Georgia and meiofauna of Maxwell Bay. Nevertheless, two variable combinations (Chl-a, OM) were the most important environmental factors influencing

Table 4
Correlation coefficients among dominant macrofaunal and environmental variables in Fildes Peninsula, King George Island.

	Abundance							Biomass						
	T	S	pH	Md	Chla	Pha	OM	SWT	SWS	pH	Md	Chla	Pha	OM
S1	0.120	−0.110	0.062	−0.261	−0.082	0.296	0.293	0.520*	−0.082	0.164	−0.092	0.005	0.149	0.261
S2	0.185	0.031	0.109	0.011	−0.029	0.454*	0.352	0.189	0.070	0.099	−0.001	−0.022	0.449*	0.355
S3	0.587**	−0.025	0.097	0.159	0.050	0.490*	0.408	0.642**	−0.097	0.108	0.024	0.034	0.321	0.293
S4	0.152	0.048	0.106	−0.161	−0.062	0.251	0.227	0.207	0.092	0.123	−0.163	−0.062	0.232	0.239
S5	−0.358	−0.355	−0.189	0.354	−0.261	−0.157	−0.141	−0.370	−0.422	−0.158	0.363	−0.259	−0.186	−0.156
S6	0.110	−0.056	0.188	−0.095	0.078	−0.079	−0.105	0.110	−0.056	0.188	−0.095	0.078	−0.079	−0.105
S7	0.502*	0.066	0.009	0.073	0.008	0.587**	0.428	0.451*	0.050	0.038	−0.122	−0.012	0.494*	0.415
S8	−0.220	0.254	−0.135	0.005	−0.105	−0.150	−0.021	−0.154	0.242	−0.054	−0.124	−0.109	−0.09	−0.027
S9	0.382	0.193	−0.175	0.107	−0.052	0.389	0.227	0.084	0.258	−0.124	−0.043	−0.095	0.114	0.090
S10	−0.115	0.029	−0.217	−0.153	0.006	0.292	0.349	0.184	0.103	0.049	0.129	0.116	0.577**	0.499*
S11	0.407	−0.252	0.001	0.002	−0.044	0.150	0.070	0.507*	−0.231	0.013	−0.023	−0.031	0.122	0.065
S12	−0.201	0.259	−0.115	−0.072	−0.106	−0.103	−0.013	−0.201	0.252	−0.113	−0.072	−0.116	−0.098	−0.020
S13	0.046	0.221	−0.129	0.113	−0.276	−0.262	−0.222	0.063	0.224	−0.077	0.088	−0.249	−0.228	−0.179
S14	0.278	0.102	0.016	0.411	0.116	0.616**	0.428	0.278	0.102	0.016	0.411	0.116	0.616**	0.428
S15	0.168	−0.06	0.354	−0.192	−0.277	−0.243	−0.317	−0.161	0.244	−0.062	−0.13	−0.117	−0.081	−0.031

S1: *Nacella concinna*, S2: *Kidderia subquadrata*, S3: *Laevilittorina antarctica*, S4: *Polycirrus kerguelensis*, S5: *Lumbricillus* sp., S6: *Cucumariidae* sp., S7: *Exogone heterosetosa*, S8: *Paramoera edouardi*, S9: *Melita* sp., S10: *Hippomedon kergueleni*, S11: *Plagiostomum* sp. 1, S12: *Plagiostomum* sp. 2, S13: *Plagiostomum* sp. 3, S14: *Neobuccinum eatoni*, S15: *Margarella antarctica*.

SWT: seawater temperature; SWS: seawater salinity; Md: median grain size; pH: *Pondus hydrogenii*; Chl-a: sediment chlorophyll a content; Pha: SEDIMENT phaeophorbide content; OM: sediment organic matter content.

Table 5
BIOENV correlations between macrofaunal assemblages and environmental variables in Fildes Peninsula, King George Island.

Number of environmental variables	Correlation coefficient	Environmental variables selection
2	0.216	Chla, OM
3	0.209	Chla, Pha, OM
2	0.197	Chla, Pha
4	0.183	Md, Chla, Pha, OM
3	0.177	Md, Chla, Pha
2	0.170	Pha, OM
3	0.168	Md, Chla, OM
1	0.165	Pha
3	0.158	Md, Pha, OM
4	0.156	T, Chla, Pha, OM

Table 7
Correlation coefficients between index of macrofaunal biodiversity and environmental variables in Fildes Peninsula, King George Island.

Environmental variables	*S*	*d*	*J′*	*H′*
Seawater temperature	0.382	0.378	0.012	0.231
Seawater salinity	0.07	0.17	0.15	0.164
Seawater pH	−0.083	−0.061	−0.035	−0.189
Sediment median diameter	0.098	0.049	−0.229	−0.18
Sediment Chl-a content	−0.103	0.11	0.621**	0.394
Sediment Pha content	0.369	0.465*	0.435	0.572**
Sediment organic matter content	0.359	0.504*	0.526*	0.644**

* $p < 0.05$.
** $p < 0.01$.

the dominant species, with a correlation coefficient of less than 0.22. The abundance and distribution of macrofauna were influenced by a variety of factors which include large-scale disturbances (ice, asteroid impacts, sediment instability, wind/wave action, pollution, UV irradiation, volcanism, etc.), playing more important role, and small-scale environmental variables (e.g. 7 environmental variables are shown) (Barnes and Conlan, 2007). Gage (2004) summarized that large-scale process strongly influences local diversity at small-scales evidenced by abundance. In addition, the food resources of macrofauna of the intertidal is not from terrestrial sources, the seasonal input of food from sea ice and the water column is increasingly important, and King George Island was influenced frequently by iceberg scouring (Arntz et al., 1994; Yang et al., 1997; Clarke et al., 1988).

There were two kinds of sediments in the intertidal zone of Fildes Peninsula: gravel-bottom and sand-bottom. The species richness and amount of macrofauna was closely correlated with the sediment types. With gravel bottom, the eco-environment was much complex, which was conductive to increasing diversity of macrofauna (Krebs, 1994). Results of CLUSTER analysis showed that the macrofaunal assemblages at the ten sand-bottom sites belonged to one group, while the macrofaunal assemblages at the ten gravel-bottom sites belonged to three groups located in southeastern coast, the middle of the eastern coast, and northeastern coast, respectively. With the effect of lithology and the abrasion of ice floes, there were less macrofauna assemblages at the southeastern coast than at the northeastern coast of Fildes Peninsula due to lower vegetation coverage (Pang and Li, 2012).

Table 6
Correlation coefficients among abundance and biomass of functional groups and environmental variables in Fildes Peninsula, King George Island.

	Abundance					Biomass				
	Pl	Ph	D	O	C	Pl	Ph	D	O	C
T	0.189	0.587**	−0.356	0.521*	0.323	0.521*	0.642**	−0.028	0.435	0.258
S	0.02	−0.025	−0.354	0.084	0.012	−0.08	−0.097	−0.216	−0.037	0.133
pH	0.11	0.097	−0.187	−0.18	0.32	0.165	0.108	0.126	−0.059	0.008
Md	−0.013	0.159	0.352	0.122	0.091	−0.091	0.024	0.043	−0.044	0.394
Chl-a	−0.035	0.05	−0.261	−0.215	−0.169	0.004	0.034	−0.032	−0.09	0.101
Pha	0.464*	0.490*	−0.154	0.201	0.176	0.157	0.321	−0.135	0.138	0.605**
OM	0.365	0.408	−0.138	0.075	−0.007	0.267	0.293	−0.147	0.092	0.424

Table 8
Comparison of macrofaunal assemblages in the intertidal zone between Fildes Peninsula and other polar intertidal areas.

Island	Abundance (ind./m^2)	Biomass (gwwt./m^2)	Dominant taxa	H' (loge)	Sediment type	Reference
Maxwell Bay	130,000		Polychaetes, Oligochates, Mollusks, Crustaceans	2.6–3.1	Boulders, cobbles	Bick and Arlt (2013)
Admiralty Bay			Gastropoda, Amphipods, Turbellarians		Rocky and stony	Sicinski et al. (2011)
Fildes eastern coast	2467	52.45	Polychaetes, Gastropoda, Amphipods, Turbellaria	0.28–1.55	Gravel	Present study
Fildes eastern coast	4779	1.873	Oligochaetes, Gastropoda, Turbellaria,	0.13–1.05	Sand	
Fildes western coast	265	1.26	Oligochaetes, Turbellaria	0.04–1.22	Sand	
Adelaide Island	ca. 7500		Polychaetes, Hydrozoa, Gastropoda	1.05–1.52	Boulders, cobbles	Waller (2008)
Signy Island	ca. 2000		Polychaetes, Bivalvia, Gastropoda	0.64–1.71	Boulders, cobbles	Waller (2008), Peck et al. (2006)
South Georgia	ca. 2000		Malacostraca, Turbellaria	0.97–1.07	Boulders, cobbles	Waller (2008)
Bird Island	ca. 1200		Polychaetes, Oligochaeta, Molluscs, Amphipods	0.74–1.02		Waller (2008)

There are four trophic levels in the intertidal macrofauna assemblages of Fildes Peninsula, including Trophic level I (meioflora, macroalgae, epiphytic algae, and ice algae) and Trophic levels II, III and IV (macrofauna functional groups) (Yang et al., 1992a; Table 3). Functional groups D, Pl, Ph belonged to Trophic level II; functional group O belonged to Trophic level III; functional group C belonged to Trophic level IV. The biomass values of functional groups Pl, Ph, D, O, C were 23.458 g/m^2, 0.799 g/m^2, 0.808 g/m^2, 1.645 g/m^2, 0.213 g/m^2, respectively while the biomass of Trophic levels II, III, and IV were 25.065 g/m^2, 1.645 g/m^2, 0.213 g/m^2, respectively.

The food habits and movement (mainly depositional food habit and burrowing behavior) of macrofauna had an effect on the decomposition of detritus and increasing the oxygen in sediment porewater, which was conducive to accelerate the decomposition of organic matter (Pearson, 2001; Aller, 1983). In addition, as the food of higher trophic levels, Trophic levels II and III were the key factors in maintain ecosystem stability (including trophic relationship stability) (Lu, 2003).

According to the biomass of Trophic levels II, III and IV, the biomass values of Trophic level II were significantly higher than that of the III trophic level. With the growth of large amounts of algae (macroalgae and benthic diatoms, etc.) due to rich nutrient supplies of Fildes Peninsula, the grazers obtained abundant food resource. Meanwhile, larger predation of the predator such as Kelp gull (*Larus dominicanus*), led to a reduction of the abundance of the phytophagous groups (Ph), which was conducive to algal bloom development without a restriction of Ph. With the formation of saprophagous food chains due to excessive algae, the biomass of the detritivorous groups was increased (Yang et al., 1997, 1992a,b).

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Appendix A

Species catalogue of intertidal macrofaunal assemblages in Fildes Peninsula, King George Island.

Phylum	Class	Species
Mollusca	Gastropoda	*Nacella concinna*
		Neobuccinum eatoni
		Laevilacunaria antarctica
		Margarella antarctica
	Bivalvia	*Kidderia subquadrata*
		Nucula sp.
		Musculus sp.
		Limatula sp.
	Polyplacophora	*Lepidozona* sp.
Annelida	Oligochaeta	*Lumbricillus* sp.
	Polychaeta	*Phylo* sp.
		Maldanidae sp.
		Ampharete sp.
		Polycirrus kerguelensis
		Exogone heterosetosa
		Eteone sculpta
		Mysta sp.
		Nereididae sp.
Nemertinea		*Nemertinea* sp.
Sipuncula		*Sipuncula* sp.
Cnidaria	Anthozoa	*Actiniaria* sp.
Arthropoda	Arachnida	*Halacroidea* sp.
	Malacostraca	*Paramoera edouardi*
	Malacostraca	*Paramoera walkeri*
	Malacostraca	*Melita* sp.
	Malacostraca	*Hippomedon kergueleni*
	Malacostraca	*Cheirimedon femoratus*
	Malacostraca	*Ampelisca* sp.
	Malacostraca	*Austrosignum glaciale*
	Maxillopoda	*Harpacticoida* sp.
Platyhelminthes	Rhabditophora	*Plagiostomum* sp. 1
	Rhabditophora	*Plagiostomum* sp. 2
	Rhabditophora	*Plagiostomum* sp. 3
Echinodermata	Holothuroidea	*Cucumariidae* sp.

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