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Understanding the Spatial and Temporal Distribution and Environmental Characteristics of Polychaete Assemblages in the Coastal Waters of Ulleungdo, East Sea of Korea

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Abstract: The coastal area of Ulleungdo in the East Sea has experienced large climate and environmental changes. However, research on marine benthic animals in this area has been very limited. In the present study, we investigated the spatial and temporal distribution of benthic polychaetes to determine their seasonal adaptability to environmental changes in the coastal waters of Ulleungdo in 2019. In total, 116 species (34 families) of polychaetes were identified with an average of 25 species per site. The average density was 772.8 individuals m^{-2}, with the highest density in August and the lowest in February. The dominant species were *Pseudobranchiomma zebuensis* (15.6%), *Scolelepis* sp. (8.6%), *Haplosyllis spongiphila* (7.3%), and *Lumbrineris nipponica* (6.3%). The main factors affecting polychaete community structure were water depth and sediment type (gravel, sand, silt, clay). Based on cluster analysis, the polychaetes tended to group mainly in winter and summer with *P. zebuensis* and *Syllis* sp. contributing to the grouping. The dominant species was the suspension feeder, which correlated highly with habitat sediment type and was substantially consistent with the coast of Dokdo. Some species overlapped in the East Sea coast, but the number and diversity of species were higher in Ulleungdo. Our study results confirm the ecological characteristics of benthic polychaetes of Ulleungdo and provide information for future monitoring of the environmental and biological changes in the East Sea.

Keywords: macrobenthos; polychaetes; assemblage; Ulleungdo; East Sea; spatial distribution; biodiversity

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1. Introduction

The East Sea is the sea between Korea and Japan in the Northwest Pacific Ocean and is a microcosm of a large ocean system model due to its very dynamic marine biogeographic boundaries [1–3]. The Tsushima Warm Current and the Liman Cold Current are important for the subtropical and subarctic circulations in the North Pacific and the East Sea, forming a polar front at approximately 40° N [4]. In particular, the coastal area of the central and northern part of the East Sea shows high productivity due to these currents [5]. Oceanographically, the East Sea was sharply increased in water temperature in 1988 [6]. In the late 1980s, ecosystem components of the ocean changed from fish community structure to zooplankton biomass, associated with changes in the climate system [7–10].

The marine volcanic island Ulleungdo is located in the center of the East Sea and has a steep coastline [11]. The Ulleung basin is a central topography of the southwestern East Sea; the width of the basin is 300 km and the depth is more than 2000 m [12]. The predominant surface current on Ulleungdo is the Tsushima Warm Current [13]. This current in the East China Sea flows into the East Sea through the Korea/Tsushima Strait [14]. Dokdo is close to Ulleungdo (approximately 87 km from Ulleungdo) and the two regions are very similar in habitat types and various benthic organisms [15,16]. In addition, adherent benthic organisms with less seasonality reflect the biological characteristics of the sea area [17].

The macrobenthos communities depend on environmental variables and have been frequently used as a bioindicator to determine the degree of contamination of coastal and estuarine environments [18–21]. Studies on the benthic fauna of the East Sea include sediment resuspension, land freshwater input, wave data, and hot water from nuclear power plants [22–25]. Most studies have focused mainly on coastal areas, while research on offshore areas is very limited [26–28]. Research associated with Ulleungdo has focused on the connectivity of the seabed topography and floating organisms such as fish and plankton [29–32]. In addition, many studies have been conducted based on the increase in water temperature and CO_2 [33–37]. However, studies are lacking in which the effects of these environmental changes on macrobenthic fauna were investigated.

The macrofauna is often used in coastal monitoring research and the polychaetes are an important group [38]. Benthic polychaetes depend almost exclusively on benthic sediment characteristics and the near-bottom water quality [39], represent the macrobenthos assemblages in biomass, and are abundant at almost all depths [40]. In addition, benthic polychaetes contribute to approximately 80% of the infaunal community and their food sources are mainly microbial organisms (bacteria, microalgae, and fungi), meiotic organisms, and organic matter [41]. In the biomonitoring program, polychaetes are used as indicators of organic contamination and are very important among several taxa to evaluate marine health [42,43]. Several polychaetes (e.g., *Capitella capitata*, *Paraprionospio pinnata*, *Scolelepis fuliginosa*, *Nepthys oligobranchia*, and *Neanthes acuminata*) live in conditions of low dissolved oxygen (DO) and high organic matter [44–47]. Polychaetes adapt to various environments and can survive even in extreme conditions and play a major role in interpreting ecosystem functions. Furthermore, polychaetes have been successfully used for estimating the diversity of benthic communities [48–51].

In the present study, we investigated the distribution pattern and diversity of benthic polychaetes on the coast of Ulleungdo. The spatial and temporal distribution of polychaetes was investigated to determine their adaptability to environmental changes. In addition, the relationship between benthic polychaetes and major environmental factors was analyzed to identify differences from other regions.

2. Materials and Methods

2.1. Study Area

The survey area was located at 37.4450°–37.4561° N latitude and 130.8616°–130.8737° E in the coastal waters of Ulleungdo in the East Sea. The survey was conducted quarterly in 2019 (February, June, August, and December) at 12 sites, and a total of 44 samples were conducted (Table 1, Figure 1). The East Sea coast has significant development such as artificial structures, fishing boat activities, and power plants, however, the area around Ulleungdo is relatively unaffected by human influence and is a natural environment [52–54]. The circulation of ocean current is important for studying the benthic environment and ecology of Ulleungdo. In the coastal waters of Ulleungdo, warm-water fish and phytoplankton have been reported due to the increase in water temperature and subtropical currents [55]. In addition, the number of cold-water fish species, such as pollock, inhabiting the East Sea has been continuously decreasing [56].

Table 1. Sampling information.

Site	Depth (m)	Tem (°C)	Salinity (psu)	DO (mg/L)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Mz (ø)	Sorting (ø)	TOC (%)
1902-1	88.14	11.82	34.27	8.72	0.0	83.4	13.9	2.6	2.76	1.55	0.72
1902-2	59.45	11.97	34.29	8.69	2.2	92.1	4.7	1.0	2.26	1.05	0.46
1902-3	18.01	12.08	34.31	8.67	0.2	98.1	1.5	0.3	2.20	0.71	0.17
1902-4	107.83	11.85	34.28	8.72	3.5	70.8	21.8	4.0	3.50	2.05	0.46
1902-5	81.11	11.91	34.28	8.70	12.0	80.3	6.6	1.0	2.14	1.66	0.40
1902-6	33.87	12.14	34.32	8.66	3.0	94.2	2.4	0.4	2.13	0.77	0.25
1902-7	110.85	11.80	34.28	8.72	0.8	22.3	61.7	15.3	5.54	2.57	0.45
1902-8	92.12	11.86	34.28	8.71	0.0	90.7	7.7	1.6	2.75	0.95	0.38
1902-9	37.58	11.89	34.29	8.71	49.3	47.1	3.0	0.5	−0.21	2.26	0.29
1902-10	114.07	11.83	34.28	8.72	0.5	80.4	15.7	3.5	2.94	1.70	0.60
1902-12	96.62	11.83	34.28	8.72	59.9	22.0	15.1	3.0	0.27	3.24	0.84
1906-1	96.28	11.95	34.35	6.63	0.25	96.86	2.40	0.49	2.29	0.73	0.15
1906-2	52.78	13.03	34.39	6.69	2.18	86.52	9.10	2.20	2.59	1.48	0.35
1906-3	19.98	16.10	34.46	6.20	0.36	80.33	16.90	2.42	2.98	1.73	0.37
1906-4	100.97	12.06	34.35	6.68	2.03	75.13	19.59	3.25	3.27	1.84	0.40
1906-5	64.03	16.94	34.35	5.77	2.47	88.83	7.28	1.42	2.55	0.92	0.28
1906-6	36.29	13.41	34.36	6.14	11.23	86.07	2.38	0.32	1.60	1.52	0.18
1906-7	111.63	11.90	34.34	6.66	1.08	83.90	13.05	1.96	2.26	1.54	0.36
1906-8	79.05	12.22	34.36	6.62	9.39	88.03	2.42	0.16	2.31	1.20	0.36
1906-9	55.54	12.02	34.36	6.09	29.53	65.34	4.19	0.95	1.03	2.01	0.17
1906-11	87.34	12.11	34.35	6.64	0.26	85.04	11.91	2.78	2.81	1.35	0.34
1906-12	60.64	12.22	34.35	6.05	77.97	19.51	2.22	0.29	−1.48	1.00	0.09
1908-1	88.94	13.33	34.38	5.53	0.00	81.31	16.22	2.47	2.94	1.61	0.49
1908-2	60.10	14.15	34.45	5.31	0.48	89.09	8.66	1.77	2.59	1.23	0.73
1908-3	21.28	22.88	33.64	5.70	67.48	32.49	0.03	0.00	−1.27	1.28	0.12
1908-4	102.85	12.10	34.34	5.79	0.50	68.56	26.89	4.05	3.72	1.86	1.07
1908-5	69.25	15.10	34.20	6.01	17.14	78.66	3.45	0.75	1.33	2.00	0.33
1908-6	27.55	22.79	33.70	5.77	39.59	58.96	1.24	0.21	0.84	2.25	0.24
1908-7	110.19	11.80	34.34	5.85	0.42	73.20	22.53	3.85	3.53	1.89	0.55
1908-8	72.42	13.48	34.38	5.61	1.72	80.01	15.51	2.77	3.08	1.71	0.57
1908-9	34.31	21.92	33.66	5.81	11.67	82.11	5.15	1.07	1.59	1.86	0.40
1908-11	100.34	12.70	34.39	5.65	65.20	29.97	4.20	0.63	−0.63	2.25	0.27
1908-12	51.62	16.55	34.38	5.67	0.16	84.96	12.67	2.21	2.86	1.32	0.83
1912-01	81.83	14.77	33.69	5.54	52.34	45.64	1.69	0.34	−0.64	1.56	0.80
1912-02	49.48	15.12	33.83	5.46	0.41	76.54	19.72	3.33	3.33	1.71	0.58
1912-03	16.40	15.63	33.88	5.44	0.73	91.86	6.27	1.14	2.60	0.80	0.51
1912-04	94.92	14.55	33.78	5.33	59.46	37.90	2.26	0.39	−0.64	2.05	0.32
1912-05	69.35	14.96	33.71	5.58	21.67	75.28	2.55	0.51	1.30	2.00	0.24
1912-06	26.79	15.40	33.86	5.53	0.00	87.26	10.64	2.10	2.75	1.29	0.42
1912-07	88.31	14.85	33.69	5.61	1.07	89.53	7.94	1.46	2.68	1.12	0.38
1912-08	81.77	14.60	33.74	5.51	39.47	55.29	4.34	0.90	0.66	2.36	0.31
1912-09	34.67	15.25	33.84	5.55	11.67	82.11	5.15	1.07	1.59	1.86	0.40
1912-11	94.06	13.13	34.05	4.83	77.91	16.28	5.04	0.77	−1.38	1.93	0.69
1912-12	38.83	14.66	33.80	5.59	0.16	84.96	12.67	2.21	2.86	1.32	0.83

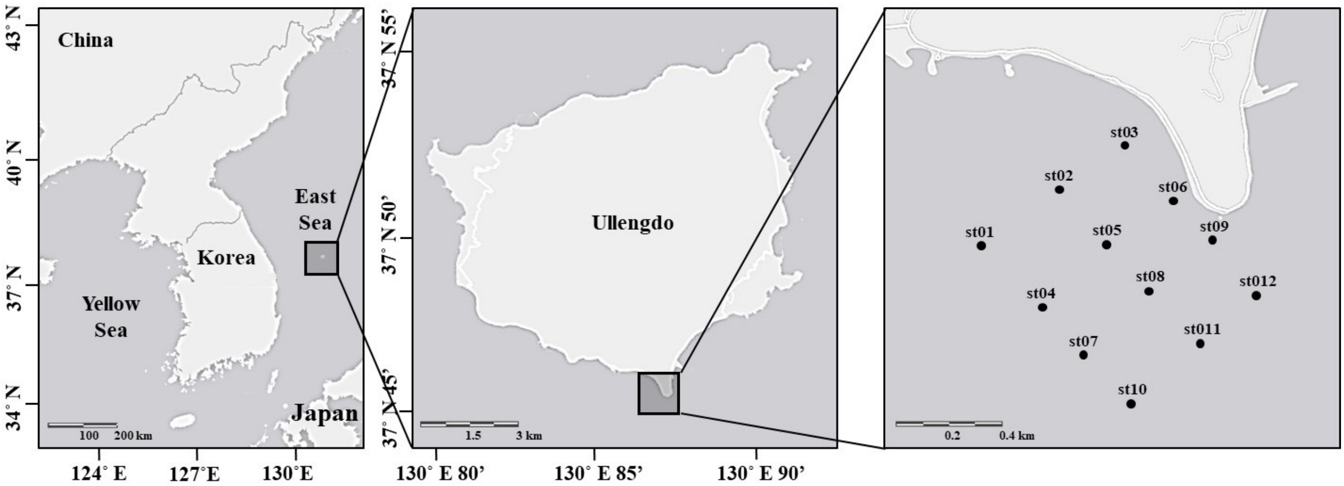

Figure 1. Sampling area at Ulleungdo in the East Sea.

2.2. Sample Processing

Samples were collected two replicated in each station at every sampling time using a Smith-McIntyre grab (0.1 m^2) in the survey area. In the field, samples were filtered with a 1-mm-sized sieve and fixed in a 10% formalin solution. A smaller mesh size (0.5 mm) is preferred for investigating macrobenthos, but a 1 mm mesh size is used to sufficiently cover the distribution of macrobenthic polychaete communities [57–59]. For total organic carbon (TOC) analysis and sediment particle size, surface sediment was sampled and frozen at −20 °C. All polychaetes were sorted in the laboratory and identified at the species level using a stereomicroscope.

Bottom water temperature, salinity, and dissolved oxygen (DO) were determined using a conductivity, temperature, and depth (CTD) instrument (SBE 19plus V2; Sea-Bird Electronics, Bellevue, WA, USA). For sediment grain size analysis, a 10% hydrogen peroxide solution was added and heated to 100 °C or higher to evaporate the hydrogen peroxide. The treated samples were washed with distilled water to remove salts and organisms. The washed samples were passed through a 63 μm sieve, the sediments remaining in the sieve were weighed, and a dispersant (sodium hexametaphosphate) was added to the passed sample; the particle size was measured using a SediGraph 5120 (Micromeritics Instrument, Norcross, GA, USA). For TOC analysis, the sediments were dried at 50 °C (48 h) and then carbonate was removed with 0.1 N hydrochloric acid. Finally, analysis was performed using a TOC analyzer (SSM-5000A; Shimadzu, Kyoto, Japan).

2.3. Data Processing

The abundances of the two replicate species were summed and converted to density (m^2). Ecological indices included the Margalef's index (d), Pielou's evenness index (J'), and Shannon–Wiener diversity index (log_e; H') of the sites surveyed quarterly. Cluster and non-metric multidimensional scaling (nMDS) analyses were performed to classify polychaete communities. The data used a Bray-Curtis similarity with fourth root transformed density. A similarity profile (SIMPROF) permutation test was used to identify differences among the polychaete groups. Similarity percentage (SIMPER) analysis was performed to determine which species were associated with the similarity or dissimilarity in the groups. Multivariate analyses were analyzed using the PRIMER version 6 software with PERMANOVA plus add on (Plymouth Marine Laboratory, Plymouth, UK). A canonical correspondence analysis (CCA) was performed for correlations between dominant species and environment variables using CANOCO version 4.5 software (Microcomputer Power, Ithaca, NY, USA).

3. Results

3.1. Environmental Variability

The water depth in the survey area ranged from 16.4–114.07 m and the average depth was 68.62 ± 6.14 m (Table 1). The water was the deepest at st10 and the shallowest at st06. The bottom water temperature ranged from 11.8–22.9 °C, and was higher in the summer than in winter, especially in August. Regarding salinity, the average value was 34.27 psu in the summer and 34.01 psu in the winter. Similar to the water temperature, salinity was generally higher in summer than in winter. The DO ranged from 4.83–8.72 mg/L, and on average, was higher in winter than in summer (summer: 6.04 mg/L, winter: 7.15 mg/L), with an average of 7.15 in winter and 6.04 in summer (Table 1).

In the total area, sand was the predominant sediment type (71.3%), followed by gravel (16.7%) and clay (1.9%; Figure 2). In st03, sand was the main sediment type accounting for 98.1% of the sediment in February. Gravel was the principal sediment type in st11 with 78% gravel and 16.3% sand in December. Silt was the predominant sediment type in st07 and accounted for 61.7% of the sediment in February. At that time, clay was the second highest sediment type (15.3%) and gravel contributed only 0.8%. In general, gravel and sand decreased further away from the coast. TOC values (calculated based on dry weight) averaged 0.44 and were highest in st08 and lowest in st06. The mean grain size (Mz) ranged from 5.54 to −1.48, with the highest value in st07 and the lowest value in st12. Mz was higher as the content of silt and clay increased and was lower with increasing gravel content (Figure 2).

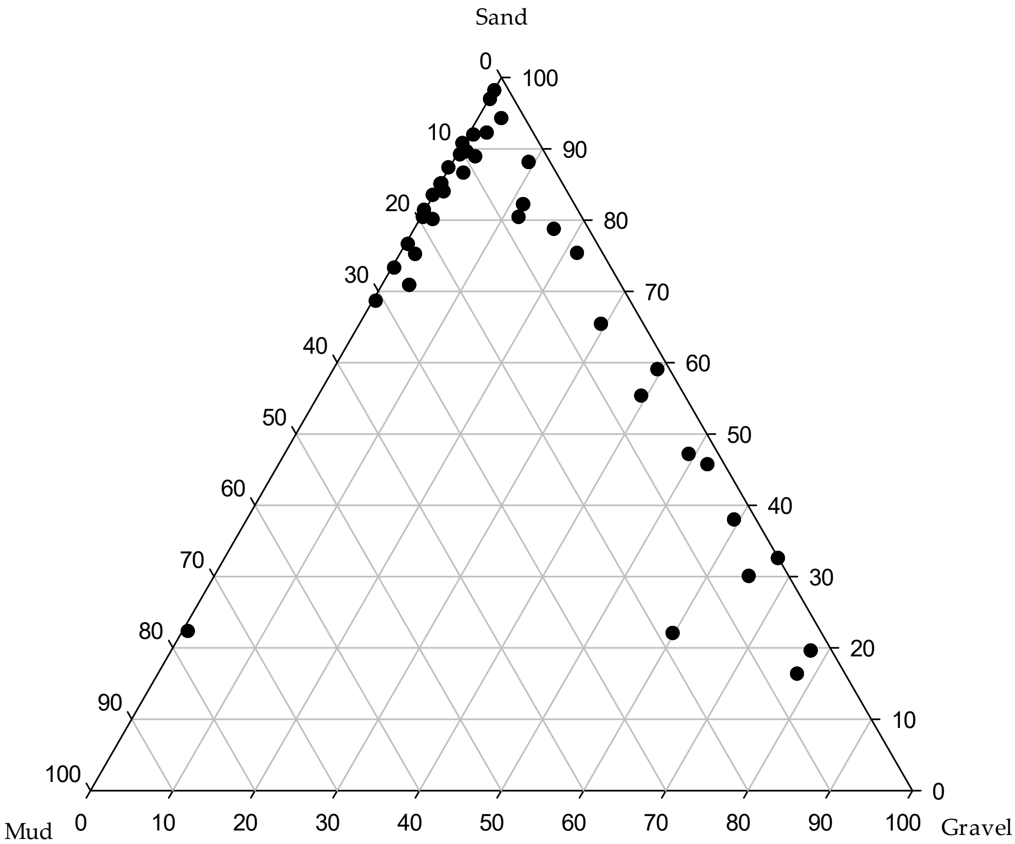

Figure 2. A ternary diagram of sediment percentage (x-Gravel, y-Sand, z-Mud).

3.2. Dominant Species

Polychaetes included 34 families, 76 genera, and 119 species, and average density was 772.8 individuals m^{-2} (Table 2). The most common polychaete families were Spionidae (18.5%), Sabellidae (16.5%), Syllidae (13.9%), and Lumbrineridae (7.8%). Most families appeared both in summer and winter, however, Aphroditidae, Dorvilleidae, Flabelligeridae, and Nereididae appeared only in winter, and Scalibregmidae only in summer. The dominant polychaete species (>3%) were *Pseudobranchiomma zebuensis*, *Scolelepis* sp., *Haplosyllis spongiphila*, *Lumbrineris nipponica*, *Chaetozone spinosa*, *Syllis* sp., *Notomastus latericeus*, *Micropodarke dubia*, *Spiophanes bombyx*, and *Glycera unicornis* (Table 3). The dominant species, *P. zebuensis*, showed the highest density in st06 in June (2195 ind. m^{-2}). At that time, the second most abundant species was *Scolelepis* sp. (995 ind. m^{-2}).

Table 2. List of polychaete species and family information at Ulleungdo in spring and winter. SN, species number; Adv, Average density; FT, feeding type; SR-De, surface deposit feeder; SS-De, subsurface deposit feeder; Dt, detritus feeder; Su, suspension/filter feeder; Pr, predator; *, present; -, absent.

No	Family	SN	Adv (ind. m^{-2})	Summer	Winter	FT
1	Ampharetidae	4	18.3	*	*	SR-De
2	Aphroditidae	1	0.5	-	*	SS/Pr
3	Capitellidae	2	42.0	*	*	SS-De
4	Chrysopetalidae	1	2.4	*	*	Pr
5	Cirratulidae	5	50.0	*	*	SR-De
6	Dorvilleidae	2	10.0	-	*	Pr
7	Eunicidae	3	10.1	*	*	Pr
8	Euphrosinidae	1	7.5	*	*	Pr
9	Flabelligeridae	1	0.1	-	*	Su
10	Glyceridae	9	39.4	*	*	Pr
11	Hesionidae	7	34.9	*	*	Pr
12	Lacydoniidae	1	2.3	*	*	SS-De
13	Lumbrineridae	5	60.3	*	*	De/Dt/Pr
14	Magelonidae	2	1.6	*	*	SR-De
15	Maldanidae	10	21.3	*	*	SS-De
16	Nephtyidae	2	5.5	*	*	Pr
17	Nereididae	1	0.1	-	*	Dt/Pr
18	Onuphidae	2	4.2	*	*	SS-De
19	Opheliidae	4	1.1	*	*	SS-De
20	Orbiniidae	1	16.6	*	*	SS-De
21	Oweniidae	3	1.4	*	*	Su
22	Paraonidae	3	17.7	*	*	SR-De
23	Pectinariidae	1	0.6	*	*	Su
24	Phyllodocidae	3	1.4	*	*	Pr
25	Pilargidae	1	7.4	*	*	Pr
26	Pisionidae	1	2.8	*	*	SS-De
27	Polynoidae	5	5.8	*	*	Pr
28	Sabellidae	7	127.8	*	*	Su
29	Scalibregmidae	1	0.1	*	-	SS-De
30	Sigalionidae	2	1.1	*	*	Pr
31	Spionidae	16	142.8	*	*	De/Su
32	Syllidae	4	107.7	*	*	Pr
33	Terebellidae	5	25.5	*	*	SR-De
34	Trichobranchidae	2	2.5	*	*	De

Table 3. Dominant polychaete species (>3%). Adv, average density; Per (%), percentage (%); SR-De, surface deposit feeder; SS-De, subsurface deposit feeder; Dt, detritus feeder; Su, suspension/filter feeder; Pr, predator.

Species	Adv (ind. m^{-2})	Per (%)	Feeding Type
Pseudobranchiomma zebuensis	120.45	15.59	Su
Scolelepis sp.	66.70	8.63	De/Su
Haplosyllis spongiphila	56.59	7.32	Pr
Lumbrineris nipponica	48.86	6.32	De/Dt/Pr
Chaetozone spinosa	44.55	5.76	SR-De
Syllis sp.	42.16	5.46	Pr
Notomastus latericeus	40.34	5.22	SS-De
Micropodarke dubia	27.95	3.62	Pr
Spiophanes bombyx	25.57	3.31	De/Su
Glycera unicornis	23.52	3.04	Pr

3.3. Ecological Indices

The number of species was highest in st07 and lowest in st10 (30.7 ± 2.9 and 17.0 ind. m^{-2}, respectively; Table 4). Habitat density was highest in st12 (1495.0 ± 862.5 ind. m^{-2}) and lowest in st10 (355 ind. m^{-2}). The average Shannon–Wiener diversity index (H′) value was 2.4, with the highest value in st07 (2.86 ± 0.12) and lowest value in st03 (1.86 ± 0.30). The Margalef's index (d) values ranged from 1.15–5.33 and similar to the diversity index, the highest value was in st07 (4.65 ± 0.38) and the lowest value was in st03 (2.42 ± 0.85). The average Pielou's index (J′) was 0.8, with the highest value (0.84) in st02 and st08 and the lowest value in st06 (0.67; Table 4).

Table 4. Ecological indices of polycheate densities (ind. m^{-2}) (S, number of species; N, total density; d, Margalef's index; J′, Pielou's evenness index; H′, Shannon–Wiener diversity index).

Site	S	N	d	J′	H′ (Loge)
01	24.0 ± 4.1	761.2 ± 273.8	3.50 ± 0.55	0.78 ± 0.04	2.46 ± 0.08
02	24.2 ± 5.3	507.5 ± 110.7	3.75 ± 0.90	0.84 ± 0.03	2.69 ± 0.25
03	17.5 ± 6.3	848.7 ± 247.4	2.42 ± 0.85	0.67 ± 0.10	1.86 ± 0.30
04	23.7 ± 1.1	473.7 ± 85.2	3.70 ± 0.10	0.83 ± 0.05	2.64 ± 0.15
05	27.0 ± 1.6	565.0 ± 175.4	4.15 ± 0.42	0.77 ± 0.15	2.54 ± 0.53
06	24.7 ± 2.3	1280.0 ± 1275.0	3.57 ± 0.49	0.67 ± 0.21	2.15 ± 0.67
07	30.7 ± 2.9	601.2 ± 126.2	4.65 ± 0.38	0.83 ± 0.03	2.86 ± 0.12
08	24.2 ± 7.9	556.2 ± 278.2	3.72 ± 1.06	0.84 ± 0.04	2.62 ± 0.31
09	22.0 ± 2.7	727.5 ± 375.9	3.41 ± 0.51	0.69 ± 0.22	2.11 ± 0.68
10	17.0 ± 0.0	355.0 ± 0.0	2.72 ± 0.00	0.82 ± 0.00	2.33 ± 0.00
11	30.3 ± 5.2	795.0 ± 145.7	4.39 ± 0.75	0.78 ± 0.00	2.66 ± 0.15
12	30.7 ± 6.5	1495.0 ± 862.5	4.20 ± 1.08	0.70 ± 0.12	2.38 ± 0.48

3.4. Polychaete Assemblages

Cluster and nMDS analyses of polychaetes density were performed (Figure 3). Based on the SIMPROF test, the clusters were divided into 10 groups and the clusters were divided mainly into summer and winter. Based on SIMPER analysis, the average similarity value in summer was 43.37 and the most related species were *N. latericeus*, *Syllis* sp., and *L. nipponica* (Table 5). In winter, the average similarity value was 38.32 and *C. spinosa*, *N. latericeus*, and *Thelepus* sp. had the greatest influence. The average dissimilarity between summer and winter was 61.95%. The polychaetes *P. zebuensis* and *Syllis* sp. contributed significantly to group division (Table 5).

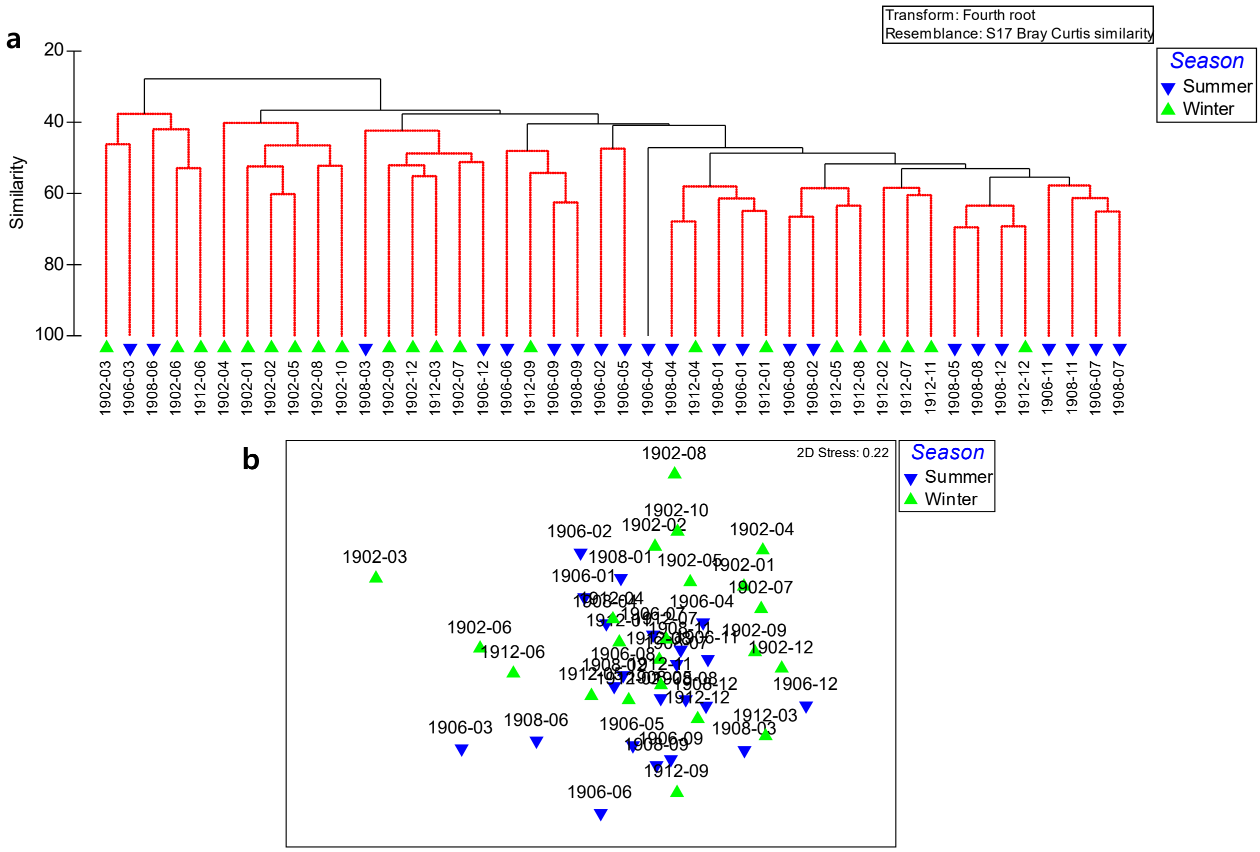

Figure 3. (**a**) Cluster analysis and (**b**) non-metric multidimensional scaling (nMDS) analysis of fourth root transformed polychaete species abundance at Ulleungdo island.

Table 5. SIMPER analysis of polychaete species clusters (Av.Abund, average abundance; Av.Sim, average similarity; Av.Diss, average dissimilarity; Contrib %, contribution %; Cum %, cumulative %).

Group Summer		**Average Similarity: 43.37**		
Species	**Av.Abund**	**Av.Sim**	**Contrib %**	**Cum %**
Notomastus latericeus	2.37	3.92	9.04	9.04
Syllis sp.	2.33	3.65	8.41	17.45
Lumbrineris nipponica	2.26	3.31	7.62	25.07
Glycera unicornis	1.95	2.85	6.57	31.64
Thelepus sp.	1.76	2.74	6.32	37.96
Chaetozone spinosa	2.08	2.72	6.28	44.24
Prionospio sp.	1.43	2.11	4.86	49.1
Glycera sp.	1.35	2.04	4.7	53.8
Group Winter		**Average similarity: 38.32**		
Species	**Av.Abund**	**Av.Sim**	**Contrib %**	**Cum %**
Chaetozone spinosa	2.29	4.22	11	11
Notomastus latericeus	2.03	3.05	7.97	18.97
Thelepus sp.	1.82	2.66	6.93	25.9
Lumbrineris nipponica	1.79	2.22	5.81	31.71
Glycera unicornis	1.6	2.16	5.62	37.33
Pseudobranchiomma zebuensis	1.62	1.75	4.58	41.91
Clymenella koellikeri	1.33	1.58	4.12	46.03
Ampharete arctica	1.27	1.49	3.88	49.91

Table 5. *Cont.*

Groups Summer & Winter	Average dissimilarity = 61.95				
Species	**Av.Abund (Summer)**	**Av.Abund (Winter)**	**Av.Diss**	**Contrib %**	**Cum %**
Pseudobranchiomma zebuensis	1.82	1.62	1.91	3.09	3.09
Syllis sp.	2.33	1.23	1.77	2.87	5.95
Scolelepis sp.	0.93	1.35	1.61	2.6	8.55
Haplosyllis spongiphila	1.25	1.24	1.54	2.49	11.04
Lumbrineris nipponica	2.26	1.79	1.43	2.3	13.35
Micropodarke dubia	1.07	1.05	1.39	2.24	15.58
Prionospio bocki	1.14	1.2	1.34	2.16	17.75
Leitoscoloplos pugettensis	1.03	1.07	1.33	2.14	19.89

3.5. Environmental Correlation

Based on CCA analysis of dominant species and environment, the sediment type, depth, and DO all had a significant influence (Figure 4, Table 6). In particular, the water depth showed a correlation with many dominant species. In addition, silt, clay, and TOC had similar positions in bioplots and showed correlations among species. Through spearman rank correlations between environmental variables and dominant species, *Pseudobranchiomma zebuensis*, *Scolelepis* sp., *L. nipponica*, *C. spinosa*, *Syllis* sp., and *N. latericeus* correlated with water depth. *P. zebuensis* was negatively correlated with Mz and positively correlated with gravel percentage. DO was associated with *Scolelepis* sp., *L. nipponica*, *Syllis* sp., and *S. bombyx* (Table 7). In interspecies correlations, *P. zebuensis* had a positive correlation with *H. spongiphila* and *M. dubia*, but a negative correlation with *L. nipponica* and *C. spinosa*. *N. latericeus* had a positive correlation with *L. nipponica*, *C. spinosa*, and *Syllis* sp.

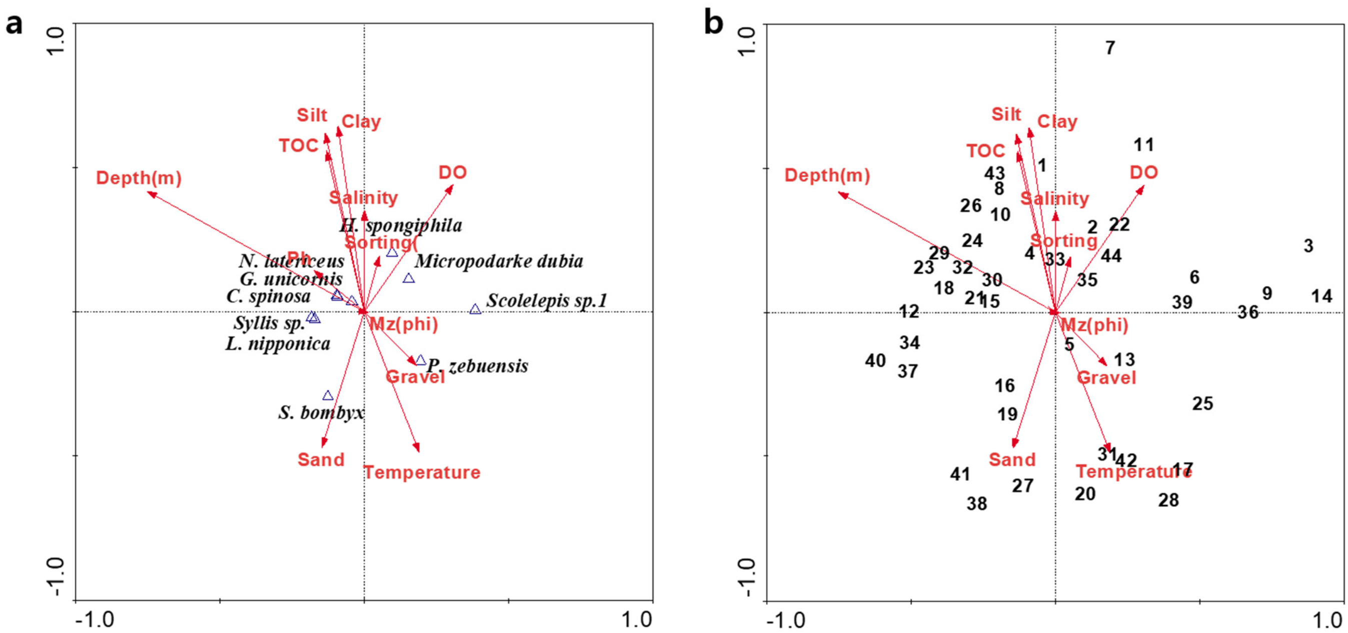

Figure 4. (**a**) Canonical correspondence analysis (CCA) biplot of the 10 most abundant polychaete species and 12 environmental variables. (**b**) Biplot of the sampling sites (1–11, 1902; 12–22, 1906; 23–33, 1908; 34–44, 1912) and 12 environmental variables at Ulleungdo island (Polychaete species: *P. zebuensis*, *Pseudobranchiomma zebuensis*; *H. spongiphila*, *Haplosyllis spongiphila*; *L. nipponica*, *Lumbrineris nipponica*; *C. spinosa*, *Chaetozone spinosa*; *N. latericeus*, *Notomastus latericeus*; *M. dubia*, *Micropodarke dubia*; *S. bombyx*, *Spiophanes bombyx*; *G. unicornis*, *Glycera unicornis*).

Table 6. Summary of the canonical correspondence analysis (CCA) results.

Environmental Variables	Axis 1	Axis 2	Axis 3	Axis 4
Depth	−0.649	0.319	−0.113	−0.084
Temperature	0.165	−0.375	−0.076	0.045
Salinity	0.001	0.269	0.066	−0.155
DO	0.265	0.337	0.028	−0.392
Gravel	0.155	−0.142	−0.254	0.199
Sand	−0.127	−0.362	0.245	−0.254
Silt	−0.117	0.474	−0.069	−0.152
Clay	−0.078	0.491	−0.074	−0.198
Mz	0.014	−0.002	0.006	−0.323
Sorting	0.046	0.148	−0.236	0.015
TOC	−0.113	0.427	−0.096	0.090
Eigenvalues	0.298	0.132	0.064	0.026
Species-environment correlations	0.863	0.765	0.638	0.635
Cumulative percentage variance	-	-	-	-
of species data	26.7	38.6	44.4	46.7
of species-environment relation	54.4	78.6	90.3	95

Table 7. Spearman rank correlation between the environmental and dominant species (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

	Tem	Sal	DO	Grav	Sand	Silt	Clay	Mz(phi)	Sorting Value	TOC	*P. zebuensis*	*Scolelepis* sp.	*H. spongiphila*	*L. nipponica*	*C. spinosa*	*Syllis* sp.	*N. latericeus*	*M. dubia*	*S. bombyx*
Depth (m)	−0.645 ***	0.108	0.252	−0.01	−0.319 *	0.441 **	0.443 **	0.245	0.338 *	0.286	−0.398 **	−0.351 *	0.034	0.512 ***	0.541 ***	0.348 *	0.62 ***	−0.105	−0.218
Temperature (°C)		−0.279	−0.72 ***	0.137	0.072	−0.311 *	−0.332 *	−0.231	−0.128	−0.123	0.276	−0.082	−0.08	−0.016	−0.295	0.134	−0.306 *	0.007	0.362
Salinity (psu)			0.234	−0.25	0.219	0.243	0.192	0.291	−0.184	−0.056	−0.095	0.060	−0.018	0.080	0.208	0.155	0.085	−0.011	−0.11
DO (mg/L)				0.175	−0.34 *	0.039	0.041	−0.065	0.333 *	0.338 *	−0.057	−0.24	0.043	0.117	0.055	0.112	0.092	0.049	−0.048
Gravel (%)					−0.642 ***	−0.56 ***	−0.558 ***	−0.802 ***	0.451 **	−0.367 *	0.381 *	−0.147	0.125	−0.040	−0.153	0.177	0.019	0.108	0.324 *
Sand (%)						−0.019	−0.021	0.33 *	−0.788 ***	−0.039	−0.143	0.284	−0.255	0.002	0.076	−0.145	−0.232	−0.210	−0.015
Silt (%)							0.98 ***	0.837 ***	0.211	0.68 ***	−0.281	−0.071	0.159	0.118	0.199	−0.056	0.203	0.118	−0.267
Clay (%)								0.821 ***	0.218	0.68 ***	−0.258	−0.064	0.195	0.102	0.194	−0.091	0.178	0.167	−0.291
Mz (ø)									−0.127	0.504 ***	−0.348 *	−0.018	−0.030	0.114	0.217	−0.167	0.036	0.005	−0.284
Sorting (ø)										0.123	0.065	−0.273	0.136	0.071	−0.116	0.025	0.058	0.089	0.095
TOC (%)											−0.216	−0.14	0.226	0.153	0.243	0.093	0.264	0.112	−0.109
P. zebuensis												0.177	0.384 *	−0.319 *	−0.47 **	−0.107	−0.132	0.59 ***	0.049
Scolelepis sp.													−0.081	−0.489 ***	−0.328 *	−0.399 **	−0.226	0.188	−0.363 *
H. spongiphila														−0.184	−0.187	0.005	0.295	0.634 ***	−0.284
L. nipponica															0.536 ***	0.675 ***	0.45 **	−0.274	0.054
C. spinosa																0.386 **	0.496 ***	−0.34 *	0.137
Syllis sp.																	0.657 ***	−0.079	0.251
N. latericeus																		0.161	−0.127
M. dubia																			−0.362 *

4. Discussion

In Ulleungdo, warm and cold currents flow around the island, and due to the combined action of these currents, the ocean is rich in nutrients and hosts a variety of marine animals [29]. In addition, the difference between summer and winter in the aquatic environment was affected by the changes in climate and seasonality of the currents. In our study, the dominant polychaete species, *Notomastus latericeus*, was reported in the tropics. Changes in the aquatic environment may alter the distribution of benthic polychaete species. In benthic regions where favorable temperatures are exceeded, some species stop growing and fail to reproduce or migrate pelagic eggs and larvae [60]. Therefore, studying benthic animals that are less mobile and respond sensitively to environmental changes is necessary. In particular, polychaetes are primarily used in biological and environmental research since they include species that indicate differential distributions in response to environmental changes [61]. To confirm environmental changes in the future, polychaetes should be continuously monitored and observed.

In previous studies, the major polychaetes identified in the subtidal zone of the East Sea coast were *Spiophanes bombyx*, *Scoloplos armiger*, *Lumbrineris longifolia*, *Magelona japonica*, and *Prionospio* sp., and TOC was $\geq$0.6% and Mz was $\geq$2.5 ø [28,54,62]. Compared with Ulleungdo, the East Sea coast had different dominant species and both TOC and Mz were high. A strong correlation existed between organic matter and particle size, and the higher the Mz, the higher the organic matter content [63]. These environmental variations led to differences in species composition and food intake methods and preferences. The dominant families in Ulleungdo were Spionidae, Sabellidae, and Syllidae. Spionidae and Sabellidae are suspension feeders and Syllidae are predator feeders. Polychaete feeding types are determined based on the relationship between feeding-related motility form and food particle size [64,65]. Generally, suspension feeders are abundant in sandy habitats and deposit feeders are predominant in muddy sediments [66]. Although the two groups co-occur frequently, some spionids may modify their nutritional habits based on food availability and high sediment mobility [67]. Carnivorous polychaete species may adopt more search-and-capture activities for food, balancing metabolic rates with increased predation risk [68,69]. Carvalho (2005) found that polychaete carnivores were more prevalent in habitats characterized by coarse sand (inlet areas and upper-middle lagoons). An association between carnivorous mode and coarse sandy bottoms in coastal waters has been reported [70–72]. In the survey area, the highest number of spionids was found in st16, indicating this area is a good environment for Spionidae to inhabit, and is a preferred environment.

Ulleungdo and Dokdo are located in the open seas of the East Sea and the characteristics of the coastal sediments are similar [73]. The sediments in the coastal waters were coarse grain with high sand and gravel content with low silt and clay content [74]. Regarding Ulleungdo, the silt percentage increased as the water depth increased, and this sedimentary change provided a significant change in benthic composition. Polychaetes of the family Syllidae were predominant on both Dokdo and Ulleungdo, and these ecological features are mainly found in coarse sand [75]. Ulleungdo and Dokdo have a large number of marine invertebrate species and various types of polychaetes exist. Ulleungdo is considered an extension of Dokdo and an important area to understand the ecology of the East Sea.

Regarding the correlation between environmental variables in the survey area, the water depth was largely associated with the sediment type. In particular, the polychaete density in the deep-water sites was lower than in other sites. However, the species diversity index was higher compared with other sites and the number of species was high, indicating this area is not completely dominated by a few species but is an environment where several species can coexist. In shallow water, the percentage of gravel and sand was high, however, in the deep area, the percentage of clay and silt increased. In biodiversity surveys, the assessment of diversity indices is essential to identify the community structure of the natural ecosystem [76,77]. The average polychaete species diversity index in the surveyed area was 2.45 + 0.49, which was higher than that of other regions in Korea (Gamak Bay−1.66, Samcheonpo−1.65, Dangdong Bay−0.84, Hupo−2.39) [78–81]. In the surveyed area, the sedimentation patterns were relatively diverse, which seems to have affected the diversity index. Mandal (2015) reported that sedimentary composition also affects species number and diversity index [82]. Also, the water depth increases, the water temperature decreases, the particle size decreases, and the TOC content tends to increase. Therefore, the benthic polychaete community at Ulleungdo was formed by these complex influences. In this study, deterioration in the quality or quantity of sampled individuals due to the use of a 1 mm mesh size presents limitations in data analysis, but understanding polychaete community patterns even under these conditions is important to explain the habitats of these complex environments.

Polychaetes are an important biomarker taxon for predicting changes in the marine environment [78]. In general, studies on the occurrence of opportunistic species, the effects of environmental pollution, and the bioaccumulation of chemical pollutants, have shown biologically diverse aspects and bioaccumulation of chemical contaminants [38,79,80]. Based on correlation analysis and CCA, dominant species in the survey area were correlated with water depth. *Pseudobranchiomma zebuensis* and *Scolelepis* sp. prefer shallow water, and *Lumbrineris nipponica*, *Chaetozone spinosa*, *Syllis* sp., and *Notomastus latericeus* prefer deep water. *P. zebuensis* and Scolelepis sp. are suspension feeder species, associated with shallow water and feeding through a filter in these areas is advantageous. The feeding types of polychaetes can be used importantly to understand benthic ecosystems, and it is necessary to accumulate more data in the future.

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