Seasonal changes of zooplankton community around Dokdo in the East Sea

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Abstract

Aim: The aim of this study was to investigate the seasonal changes in distribution, composition and abundance of zooplankton community in relation with hydrography such as temperature and salinity in the East Sea.

Methodology: Seasonal changes of zooplankton community were studied at 12 stations near Dokdo in the East Sea. Zooplankton were seasonally sampled in 2011. Water temperature and salinity were simultaneously measured at the zooplankton sampling sites.

Results: The mean surface water temperature was highest in summer, lowest in winter and intermediate in spring and fall. The mean surface water salinity was highest in winter and spring, lowest in summer and intermediate in fall. Total 215 species belonging to 65 families were identified. Zooplankton mean densities gradually increased from winter to fall. Total species number was lowest in winter and highest in summer. Copepods prevailed as dominant zooplankton groups in all seasons. The mean densities of dominant zooplankton species varied with seasons.

Interpretation: Zooplankton communities varied with season, particularly water masses were driven by water currents as a main factor controlling zooplankton community composition, abundance and distribution.

Key words: Dokdo, Hydrography, Seasonal changes, Zooplankton

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Introduction

The East Sea is located at the northeastern Asian continent and the west of Pacific Ocean. It is well known as a semi-enclosed marginal sea (Chough *et al.*, 2000). The sea is divided into two parts, northern and southern (Chough *et al.*, 2000; Talley *et al.*, 2006). The northern part of East Sea is characterized by cold water, originating from North Korea Cold Current (NKCC), a branch of Liman Current (Cough *et al.*, 2000; Talley *et al.*, 2006). The southern part of sea is characterized by warm water, influenced by East Korea Warm Current (EKWC), a branch of Tsushima Warm Current (Chang *et al.*, 2002; Ashjian *et al.*, 2005; Kim *et al.*, 2016).

Dokdo is centrally located in the southern East Sea/Japan Sea. The hydrography around this island is influenced mainly by three water masses the East Sea Intermediate Water (ESIW), the East Sea Proper Water (ESPW) and the Tsushima Warm Current (TWC) (Chang *et al.*, 2002). ESIW and ESPW are characterized by cold (1–5°C) and less saline water (<34.00 psu) (Park *et al.*, 2016a). TWC is characterized by more saline (>34.00 psu) and warm water (>15°C) (Chang *et al.*, 2004; Kim *et al.*, 2004).

Seasonal changes of hydrographic conditions such as water currents, temperature and salinity influence the distribution and structure community of zooplankton around Dokdo (Hirakawa *et al.*, 1995; Park and Choi, 1997; Chiba and Saino, 2003; Ashjian *et al.*, 2005; Park *et al.*, 2016a). Distribution of planktonic organisms, particularly zooplankton are determined largely by water currents (Pinca and Dallot, 1997; Iguchi, 2004;

Pepin *et al.*, 2011). Water currents bringing either warm- or cold-water affect zooplankton composition and abundance in the East Sea because each species of zooplankton has a preferable range of water temperature (Park *et al.*, 1991; Krause *et al.*, 1995).

Water salinity along with water temperature determines the distribution of living organisms. Water salinity varies gradually over weeks or months due to seasonal precipitation or evaporation (Johnson and Allen, 2012; Richardson, 2008; Varadharajan and Soundarapandian, 2013). Changes in salinity determine the distribution and composition of zooplankton community because each species has a different ability to tolerate water salinity changes (Mauchline, 1998). Some zooplankton species such as *Acartia tonsa* and *Centropages hamatus* are less tolerant towards changing salinity (Lance, 1963; 1964). Meanwhile, *Acartia longiremis* and *Pseudocalanus* sp. have wide range of salinity levels (Rochet and Grainger, 1988).

The present study was carried out to investigate the seasonal changes in distribution, composition and abundance of zooplankton community in relation with hydrographies of the East Sea.

Materials and Methods

The East Sea is located in the vicinity of Dokdo (37°00'–37°30'N to 131°30'–132°10'E) (Fig. 1). Zooplankton were collected during winter (February–March), spring (May), summer (August–September) and fall (November) in 2011.

Zooplanktons were collected with a Bongo net of diameter 60 cm and mesh size 330 µm, equipped with a flow

Fig. 1 : Location of sampling stations around Dokdo in the East Sea.

meter at the mouth of the net to determine volume of water passing through the net during sampling. A Bongo net was double-obliquely towed from approximate up to 200 m depth (or from maximum depth if the bottom depth was shallower than 200 m) to surface layer. Temperature and salinity were simultaneously recorded during zooplankton sampling with CTD (SeaBird Co.). Seasonal vertical characteristics of water temperature and salinity at all stations around Dokdo were profiled at 1, 10 and 50 m depth.

After sampling zooplankton, samples were preserved in 70% ethanol immediately for enumeration and species identification. In laboratory, zooplankton biomass was determined by displacement volume method then, samples were sequentially split using a plankton splitter into final aliquots or subsamples containing about 300-500 specimens. Zooplankton samples were identified to species level, if possible, under a dissecting microscope using Bogorov Counting Tray.

Seasonal variation of zooplankton community was analyzed for Species richness (d), Shannon Diversity Index (H) and Evenness index (J'). Cluster analysis and non-metric multidimensional scaling (nMDS) were computed using Bray-Curtis similarity index to examine similarity among seasons. nMDS ordination having a stress value <0.05 means excellent to interpreting data; <0.1 means good to interpreting data; <0.2 means data useable for interpreting data. And >0.2 means could be challenging to interpreting data (Clarke, 1993).

Data of species abundance were transformed by log-transformed ($\log(x+1)$) to reduce bias due to extremely abundance species (Field *et al.*, 1982; Legendre and Legendre, 1998). Differences of zooplankton community between groups (seasons) were tested with one-way analysis of similarity (One-way ANOSIM) and similarity percentages (SIMPER). When p -value <0.1% and R -value were close to one, it was represented as significant differences between groups (Clarke and Warwick, 2001).

Results and Discussion

Seasonal vertical profile of temperature and salinity at all stations around Dokdo indicated seasonal variation at each depth layer (Fig. 2, 3). During winter, water temperature was lowest and ranged from 8.70 to 11.18°C at three depth layers. Water temperature was highest during summer, ranging from 23.0 to 26.1°C at 1 and 10 m depth and 7.9 to 14.4°C at 50 m depth. During spring and fall, water temperatures ranged from 16.17 to 18.91°C at 1 and 10 m depth, while water temperature at 50 m depth ranged from 11.14 to 14.44°C during spring and 14.29 to 18.56°C during fall. Water temperature at ca. 200 m were similar at all stations and season, indicating ~1°C.

The horizontal distribution pattern of water salinity at all depth layers varied with season (Fig. 4). The mean water

salinities were highest in winter and spring, ranging from 33.5 to 34.9 psu at three-depth layers. The mean water salinities were lowest in summer. In particular, water salinities at 1 and 10 m depth ranged from 32.2 to 33.5 psu, while those were relatively higher at 50 m depth, ranging from 33.95 to 34.32 psu. Water salinities in fall ranged from 33.0 to 33.7 psu at three-depth layers. Approximately, salinities at 200 m depth or at maximum depth of sampling stations were higher (>34.00 psu) than shallower water depths in all seasons.

A total of 215 species belonging to 65 families in eight phyla were identified. Total species number of zooplankton varied with season. Total species number was highest in summer (200 species), followed by fall (130 species) and spring (102 species), and lowest in winter (82 species). The seasonal pattern of mean density was reverse to total species number. Seasonal mean density of zooplankton was highest in fall (463.1 inds.m⁻³), followed by summer (287.6 inds.m⁻³) and spring (240.5 inds.m⁻³), and was lowest in winter (165.2 inds.m⁻³) (Fig. 5).

Species richness was highest in summer (13.5), followed by fall (12.3) and spring (8.7), and lowest in winter (7.5). Diversity index was highest in summer (3.2), followed by fall (2.7) and spring (2.4), and lowest in winter (2.2). Evenness index was relatively higher in summer (0.7) than other seasons (0.6) (Fig. 6).

In addition, the zooplankton community were significantly different between seasons ($R > 0.85$, $p = 0.001$). These average dissimilarities varied from 58.6% (spring vs fall) to 75.5% (winter vs summer) (Table 1). Moreover, the clustering and ordination (nMDS) analyses indicated that neighboring stations had relatively higher similarity induces than stations at farther distances (Fig. 7, 8).

Marine zooplankton were constituted by diverse marine organisms (Mackas and Tsuda, 1999). Their diversity tend to have peaks in the subtropical and temperate regions of northern hemisphere such as the East Sea (Park and Choi, 1997; Kang *et al.*, 2002; Rebstock and Kang, 2003; Ashjian *et al.*, 2005; Rombouts *et al.*, 2009).

The spatial distribution of zooplankton densities varied

Table 1: Summary of one-way ANOSIM and SIMPER analysis between seasons

Group	One-way ANOSIM		SIMPER Average dissimilarity (%)
	R-value	p-value	
Winter vs Spring	0.981	0.001	67.00
Winter vs Summer	0.989	0.001	75.47
Winter vs Fall	0.995	0.001	69.74
Spring vs Summer	0.975	0.001	69.63
Spring vs Fall	0.881	0.001	58.63
Summer vs Fall	0.850	0.001	64.12

Fig. 2 : Seasonal vertical profile of temperature (upper) and salinity (bottom) around Dokdo in the East Sea. Colored lines and symbols indicate sampling.

Fig. 3 : Seasonal horizontal distribution of temperature at 1 m depth (upper row), 10 m depth (middle row) and 50 m depth (bottom row) around Dokdo in the East Sea.

Fig. 4 : Seasonal horizontal distribution of salinity at 1 m depth (upper row), 10 m depth (middle row) and 50 m depth (bottom row) around Dokdo in the East Sea.

with stations and seasons (Fig. 9). The highest and lowest zooplankton densities mostly occurred at stations around Dokdo and on the northern part of Dokdo. During winters, the highest zooplankton density occurred at station B1 (316.3 inds. m^{-3}) and the lowest at station DD4 (58.3 inds. m^{-3}). During spring, zooplankton density was highest near Dokdo at station DD3 (430.1 inds. m^{-3}) and lowest at station B3 (89.3 inds. m^{-3}) in the northern stations of Dokdo Islets. During summers, zooplankton density was highest at station A3 (486.1 inds. m^{-3}) and lowest at station B5 (93.8 inds. m^{-3}) which were located in the north of Dokdo. Similar to zooplankton distribution pattern in spring, zooplankton density in fall was highest at station DD4 (801.5 inds. m^{-3}) which was located near Dokdo and lowest at station B1 (56.5 inds. m^{-3}).

Zooplankton are ectothermic marine organism with short generation time (Richardson, 2008; Rombouts *et al.*, 2009). Any environmental change, either long- or short-term changes densities (Rombouts *et al.*, 2009). The seasonal pattern of zooplankton densities is generally characterized by a peak in spring and low in winter (Hirota and Hasegawa, 1999; Chiba and Saino, 2003; Dolganova and Zuenko, 2004). However, in this study, high densities in fall incorporates the previous studies (Kang *et al.*, 2002; Kang *et al.*, 2004; Walkusz *et al.*, 2009; Jo *et al.*, 2016).

Seasonal changes in zooplankton densities are probably influenced by warm and saltier waters from the East Korea Warm Current as a branch of Tsushima Warm Current (Iguchi, 2004).

Tsushima Warm Current flows northward to the East Sea, bringing warm and saline waters in fall and weakly in winter (Cho and Kim, 1996; Zhang *et al.*, 2000; Ashjian *et al.*, 2006). During fall, appearance of warm water is indicated by temperature lower than summer but higher than winter ($\sim 18^{\circ}C$), and salinities higher than summer but lower than winter and spring (~ 33 psu). Zooplankton densities around Dokdo in the East Sea were high in warm-water and low in cold-water (Park and Choi, 1997). Park *et al.* (1998) reported that seasonal fluctuation of zooplankton densities was influenced by water temperature in the East Sea.

A total of 15 major taxa of zooplankton were dominated in the East Sea around Dokdo. Copepods were predominant during the entire seasons ranging from 46.9 to 75.4% of total zooplankton. The second dominant group of amphipods, except in summer, comprised 26.3% in spring. Other groups varied from 11.4 to 0.02% (Fig. 10). Six species contributed major proportions of zooplankton densities in winter and spring, nine species in summer and ten species in fall (Table 2), respectively.

In winter, copepods were the most dominant zooplankton group, constituting 56.4% of total zooplankton. The dominant copepod species were *Metridia pacifica*, *Calanus sinicus* and *Mesocalanus tenuicornis*, while the dominant non-copepods species were *Themisto* sp. juvenile, *Conchoecia* spp. and *Atlantia* spp. The mean densities of all dominant species ranged from 6.5 to 36.2 inds. m^{-3} and reached 4.0 to 24.8% of total zooplankton. In spring, copepods were dominant group, constituting 46.9% of total zooplankton. The dominant copepods species were *Oithona*

Fig. 5 : Mean density and number of species of zooplankton around Dokdo in the East Sea during the study period

Fig. 6 : The diversity indices of zooplankton community around Dokdo in the East Sea during the study period (■) species richness; (●) diversity index; (Δ) evenness index.

Fig. 7 : Cluster similarity of zooplankton between stations and seasons.

atlantica, *Metridia* sp. copepodite and *C. sinicus*. Amphipods as a second dominant group were dominated by *Themisto* sp. juvenile, while other dominant species were *Oikopleura* and calyptopis of euphausiids. The mean densities of dominant species ranged from 9.3 to 59.8 inds.m⁻³ and contributed 3.8 to 23.5% of total zooplankton. During summer, copepods were

dominant, comprising 50.1% of total zooplankton. The dominant copepods species were *Acartia pacifica*, *O. atlantica*, *C. sinicus*, *M. tenuicornis* and *Paracalanus parvus*. In summer, amphipods were replaced by *Doliolum* spp. as the second dominant taxa. Other dominant species were zoeae of luciferid spp., *Oikopleura* and sagittid juvenile. The mean densities of these dominant

species ranged from 10.5 to 31.3 inds.m⁻³ and 3.4 to 11.2% of total zooplankton.

In the present study, the most dominant zooplankton taxa around Dokdo in the East Sea was copepods, representing 47-75% of total zooplankton and 50 to > 80% in previous studies (Hirakawa *et al.*, 1995; Kang *et al.*, 2002; Rebstock and Kang, 2003). Other dominant taxa were amphipods and doliolids (Park *et al.*, 1998; Chiba and Saino, 2003). They prevailed as secondary dominant groups in the temperate sea with a high percentage, being comprised > 11%, particularly in the East Sea around Dokdo (Berner and Reid, 1961; Ikeda, 1990; Park *et al.*, 2016a).

In fall, similar to other seasons, copepods were out numbered, charging 75.4% of total zooplankton the dominant species from this group were *Paracalanus parvus*, *Oncaea venusta*, *Paracalanus aculeatus*, *C. sinicus*, Euchaetid spp. copepodite, *O. atlantica* and calanoid copepodites. *Themisto* sp. juvenile was a subdominant species, followed by *Conchoecia* spp. and *Doliolum* spp. The mean densities of these dominant species ranged from 17.0 to 100.4 inds.m⁻³ and 3.5 to 14.3% of total zooplankton.

Fluctuation in water temperature influences not only zooplankton densities but also species number. Increase or decrease of species number is contributed by temperature changes (Park *et al.*, 1998). Change in species number is significantly correlated with water temperature (Park *et al.*, 2016a). Temperature change results in the possibility of co-occurrence of warm and cold water species, further increasing the number of zooplankton species, particularly in summer (Park and Choi, 1997). As Dokdo is located in the temperate waters, zooplankton composition mostly consist of temperate species, which prefer warm-water condition (Park *et al.*, 2016a). Also, immigrating warm-adapted species can increase species number in zooplankton community (Beaugrand *et al.*, 2010).

Rising sea surface temperatures provoke changes in zooplankton community composition towards warm-water species (Lewandowska *et al.*, 2014). During warm-water condition above 15°C (Park *et al.*, 1998), warm-adapted species such as small size copepods (*Oithona atlantica*, *Acartia pacifica*, *Oncaea venusta*, and *Paracalanus parvus*) (Morgan *et al.*, 2003; Turner, 2004; Ashjian *et al.*, 2005; Kang, 2011) and gelatinous zooplankton (*Doliolum* sp.) are dominant (Berner and Reid, 1961; Richardson, 2008; Park *et al.*, 2016b). These species occur

Fig. 8 : Non-metric multidimensional scaling (nMDS) of zooplankton between stations and seasons.

Fig. 9 : Seasonal spatial distribution of zooplankton densities in the East Sea.

mainly during spring, summer and fall at shoal and warm water areas nearby Dokdo. Further, juvenile of *Themisto* sp. were found at the shallow layer near Dokdo, while adults are present in colder water at deep layer offshore (Nishimura, 1965; Ikeda, 1990).

On the other hand, decreasing seawater temperature also has an effect on zooplankton composition distribution. During winters, zooplankton community is dominated by some large sized species, such as *Metridia* spp., *Themisto* spp. and euphausiids (Gislason and Silva, 2012; Chiba et al., 2015). *Metridia* spp. are well known as a dominant species in the northern hemisphere, particularly *M. pacifica* in the East Sea/Japan Sea (Morioka et al., 1977; Hirakawa et al., 1992; Park et al., 2016b). These predominant species are greatly abundant at the stations off Dokdo, approximately 200 m depth and temperature less than 5°C in winter (Mackas and Tsuda, 1999).

This species has been known to prefer cold-water condition of temperature lower than 9°C and as an indicator species of cold water in the East Sea (Morioka et al., 1977; Hirakawa et al., 1992; Park et al., 2016a). While, as water temperature reduces, warm-water zooplankton such as *Doliolum* spp. and *A. pacifica* begin to disappear, however, *Themisto* sp. and *O. atlantica* may survive till the next season (Nishimura, 1965; Kang, 2011).

Seasonal appearance of dominant taxa : The dominant species in all seasons were represented by large sized species (*Themisto* sp. juvenile and *Metridia pacifica*), small sized copepods (*Oithona atlantica*, *Oncaea venusta*, *Acartia pacifica* and *Paracalanus parvus*) and gelatinous zooplankton (*Doliolum* spp.) (Fig. 11). *Themisto* sp. juvenile and *O. atlantica* seasonally fluctuated with high mean density in spring. The density of *M. pacifica* was higher than other species in winter, while that of *O.*

Fig. 10 : Seasonal changes of relative proportion of dominant zooplankton groups around Dokdo in the East Sea.

Fig. 11 : Seasonal variations of appearance dominant species around Dokdo in the East Sea.

Table 2 : Seasonal dominant species in contributing zooplankton densities around Dokdo in the East sea

Species	Mean density (inds.m ⁻³)	Percentage of contribution(%)	Species	Mean density (inds.m ⁻³)	Percentage of contribution(%)
Winter			Spring		
<i>Metridia pacifica</i>	36.2	24.8	<i>Themisto sp. juvenile</i>	59.8	23.5
<i>Themisto sp. juvenile</i>	30.0	20.1	<i>Oithona atlantica</i>	50.1	19.5
<i>Calanus sinicus</i>	15.2	9.9	<i>Oikopleura spp.</i>	25.8	9.0
<i>Conchoecia spp.</i>	18.4	9.9	<i>Euphausiid calyptopis</i>	13.9	5.7
<i>Atlanta spp.</i>	11.0	7.4	<i>Metridia sp. copepodite</i>	21.5	5.0
<i>Mesocalanus tenuicornis</i>	6.5	4.0	<i>Calanus sinicus</i>	9.3	3.8
Fall			Summer		
<i>Paracalanus parvus</i>	100.4	14.3	<i>Doliolum spp.</i>	31.3	11.2
<i>Oncaea venusta</i>	70.7	14.8	<i>Acartia pacifica</i>	24.3	7.4
<i>Paracalanus aculeatus</i>	58.4	14.3	<i>Oithona atlantica</i>	15.2	4.8
<i>Calanus sinicus</i>	38.8	7.4	<i>Calanus sinicus</i>	15.1	5.3
<i>Euchaetid spp. copepodite</i>	27.0	5.9	<i>Luciferid spp. zoea</i>	15.1	4.4
<i>Themisto sp. juvenile</i>	21.4	5.0	<i>Mesocalanus tenuicornis</i>	18.8	5.1
<i>Oithona atlantica</i>	18.9	4.6	<i>Oikopleura spp.</i>	13.7	4.6
<i>Calanoid spp. copepodite</i>	21.0	3.8	<i>Paracalanus parvus</i>	11.1	3.8
<i>Conchoecia spp.</i>	18.5	4.4	<i>Sagittid spp. juvenile</i>	10.5	3.4
<i>Doliolum spp.</i>	17.0	3.5			

venusta was higher in fall. The occurrence pattern of *A. pacifica*, *Doliolum* spp. and *P. parvus* varied seasonally. *A. pacifica* did not occur in winter and spring, however was found in peak during summer. Similarly, *Doliolum* spp. not only appeared in winter, however, dominated in summer. *P. parvus* was absent in spring, but dominant in fall.

This study clearly indicates seasonal changes in diversity, composition, distribution of zooplankton community from the domination of cold-water species (e.g. *M. pacifica*) in winter to warm-water species (*A. pacifica*, *O. venusta* and *Themisto* sp.) and gelatinous zooplankton species (*Doliolum* spp.) in spring through fall. High species number, densities and dominant species in warm-water conditions explain that water temperature has a positive correlation with zooplankton community composition and distribution (Park et al., 1998; Han et al., 1995). However, variance in salinities (32-34 psu) was not related with the abundance and distribution of zooplankton community directly because all these species, particularly the dominant species were neritic and oceanic species, which inhabited saline water having salinity > 30 psu (Park et al., 1997; Park et al., 2016a). Our results corroborates with the previous records on zooplankton communities (Park et al., 1997, 1998, Han et al. 1995). Thus, from this study it can be concluded that the seasonal trends of hydrographies in the East Sea/Japan Sea controlled zooplankton community abundance, composition and distribution. These trends were regulated by water masses, temperature and salinity.

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