Distribution and indicator species of zooplankton in the East Sea, Yellow Sea and Northern East China Sea in winter

Paper received: 11.01.2019

Revised received: 25.03.2019

Accepted: 30.04.2019

Authors Info

J.Y. Lee¹, W. Park^{2*}, S.Y. Moon³
and H.K. Cha⁴

¹Northwest Pacific Action Plan Marine Environmental Emergency Preparedness and Response Regional Activity Center (NOWPAP MERRAC), Korea Research Institute of Ships & Ocean Engineering (KRISO), Daejeon, 34103, Korea

²Department of Marine Biology, Pukyong National University, Busan, 48513, Korea

³Fisheries Resource Survey Center, National Institute of Fisheries Science, Tongyoung, 53063, Korea

⁴National Institute of Fisheries Science, Busan, 46083, Korea

*Corresponding Author Email : wpark@pknu.ac.kr

Edited by

Professor Chung Il Lee

Reviewed by

Professor Hyun Jei Park
Dr. Jung Nyun Kim

Abstract

Aim: Zooplankton are distributed by hydrographic factors such as temperature and salinity. The research aims to investigate the distribution patterns of zooplankton and indicator species of water bodies, and to understand the relationship between zooplankton distribution and water bodies in Korean waters in winter.

Methodology: Zooplankton, samples were collected and temperatures and salinities were recorded at 130 stations around Korean peninsula in the Yellow Sea and the northern East China Sea (ECS), using a Bongo net and CTD in winter, 2016. Research areas using K-mean clustering based on temperatures and salinities were divided into six water bodies: the North Korea Cold Current (NKCC), the East Korea Warm Current (EKWC), the Jeju Warm Current (JWC), the Yellow Sea Warm Current (YSWC), the Yellow Sea (Y1), and mixed water. The indicator indices for water bodies were calculated using INSPAN (Indicator Species Analysis).

Results: NKCC, YSWC and Y1 were represented by high proportions of cold water species of 81, 44 and 41 species, respectively, while EKWC and JWC were relatively dominated by warm water species of 99 and 102 species. The water bodies of Yellow Sea and the northern ECS were greatly similar, but the East/Japan Sea was significantly distinguished. With the Indicator value and distribution, indicator species for water bodies were identified: *Scolecithricella minor* in the NKCC, *Candacia bipinnata*, *Clausocalanus furcatus*, and *Pleuromamma gracilis* in the EKWC, *Scolecithricella longispinosa* and *Euchaeta plana* in the JWC, *Centropages abdominalis* in the Y1.

Interpretation: Distributions of zooplanktons and the similarity of community structures were determined by the interaction of water bodies. Zooplankton species can be used as indicator of water bodies because of their dependence on ocean currents.

Key words: East Sea, Indicator species analysis, Zooplankton

The research aimed to investigate the distribution patterns of zooplankton and indicator species of water bodies, and to understand the relationship between the zooplankton distribution and water bodies in Korean waters in winter.

Distribution of zooplankton, especially similarity of community structures, were determined by the interaction of ocean currents and winds. Zooplankton might be used as an indicator of water bodies due to their dependence on ocean currents.

How to cite : Lee, J.Y., W. Park, S.Y. Moon and H.K. Cha: Distribution and indicator species of zooplankton in the East Sea, Yellow Sea and Northern East China Sea in winter. *J. Environ. Biol.*, **40**, 871-883 (2019). DOI : [http://doi.org/10.22438/jeb/40/5\(SI\)/SI-07](http://doi.org/10.22438/jeb/40/5(SI)/SI-07)

Introduction

The Korean peninsula is enclosed by the East Sea, the East China Sea and the Yellow Sea, which are characterized by different physical and biological features (Rebstock and Kang, 2003). In the East Sea, the East Korean Warm Current (EKWC) and North Korean Cold Current (NKCC) create a well-defined sub-polar front (Yoon, 1982; Isoda *et al.*, 1992; Kim *et al.*, 1998). The EKWC which is a branch of Kuroshio Warm Current (KWC) supplies heat and salts to Korean waters by flowing northward (Yasui *et al.*, 1967), and the NKCC which is a branch of Oyashio Cold Current provides high nutrients.

In the Southern Sea of Korea, the northward flowing warm water flows into the Yellow Sea and the Korean Strait after passing through the northern ECS. To the east, the northern ECS boards on Kyushu, and to the west, it boards the mainland of China (Lee, 1992). The hydrography of northern ECS is characterized by Taiwan Warm Current (TaWC) originated in the KWC, Jeju Warm Current (JWC) as a branch of TaWC (Nitani, 1972; Fang *et al.*, 1991; Teague *et al.*, 2003) and coastal water such as the Yangtze Diluted Water (YDW) (Lie *et al.*, 2002; Beardsley *et al.*, 1985). Also, the Yellow Sea Cold Bottom Water (YSCBW) and the Yellow Sea Warm Current (YSWC) are formed in the ECS (Nitani, 1972). In particular, a strong thermohaline front forms across the south of Jeju Island and separates the coastal water from the JWC.

The Yellow Sea consists of YSCBW, YSWC, the Korea Coastal Current and YDW, overlying shallow continental shelf with average depth of approximate 44 m (Uda, 1934; Lee, 1968; Lie, 1984). Each water mass has its own distinct characteristics and interaction with each other (Teague *et al.*, 2003).

Functioning of marine ecosystem is strongly affected by zooplankton community (Dur *et al.*, 2007). Also, the structuring of zooplankton communities is dependent on large scale physical processes such as transport of water masses by current in various ecosystems (Hwang and Wong, 2005; Hwang *et al.*, 2006; Tseng *et al.*, 2008). In the East/Japan Sea, variety of zooplankton species appear by sub-polar front not only warm water species, but cold water species (Park *et al.*, 1998). The Northern East China Sea (ECS), the gate of warm water moving northward, comprises high diversity with a tropical and sub-tropical species (Jang *et al.*, 2012), while Yellow Sea characterizes low diversity, but high biomass.

Among zooplankton, copepods are major food of fish larvae and express a most dominant zooplankton group in marine ecosystem (Lan *et al.*, 2004). In the East/Japan Sea and northern ECS, copepods are dominated, while Sagittidae spp. juveniles are abundant in the Yellow Sea (Rebstock *et al.*, 2003). Some copepod species indicate a certain water mass (Brodsky, 1950; Hwang *et al.*, 2006). *Centropages abdominalis* and *Metridia*

pacifica are cold water species (Brodsky, 1950), while *Clausocalanus arcuicornis*, *C. furcatus*, *Scolecithrix danae* and *Paracalanus aculeatus* belong to warm water species (Hsieh *et al.*, 2004; Hwang *et al.*, 2006).

Zooplankton communities vary with varying water masses and few comparisons of biological features of three seas have already been published. Keeping in view of the above, this study aimed to investigate the community structure and indicator species of zooplankton around the Korea peninsula.

Materials and Methods

Sampling : Zooplanktons were collected from 130 stations in Korean waters during winter season of 2016. (Fig. 1). Zooplanktons were collected using a Bongo net (the mouth diameter of 80 cm and the mesh size of 333 μ m). The net was towed double-obliquely hauling up to near the bottom to the surface with a flow meter. If the depth of water > 200 m, the net was towed to maximum 100 m. Zooplanktons were preserved in 70% ethyl alcohol. Vertical temperature and salinity profiles were measured with a CTD (SBE 9 plus) at 1 m depth interval at the sampling stations.

In laboratory, samples were scanned before analysis under a stereomicroscope. Approximate by 300-500 zooplankton organisms were splitted for analysis using a Motoda splitter and then enumerated in a Bogorov counting tray. Copepods were identified to species level and other zooplanktons were identified to the lowest taxonomical level if possible.

Fig. 1 : Map of sampling stations in Korean waters. Each symbol indicates sampling areas in Korean waters in winter 2016.

Data analysis : Species diversity (H') was calculated by Shannon and Wiever (1963). Cluster analysis using Bray-Curtis similarity matrix was used to analyze the similarity of zooplankton communities by stations at 60% similarity level. To find a difference between communities, One-way ANOSIM (analysis of similarity) was conducted with PRIMER (version 6.1.6) (Clarke et al., 2001). Spearman rank correlation coefficient was used to compare the sea surface water temperature, sea surface water salinity and the densities of dominant and indicator species in Korean waters using SPSS 12.0K.

Indicator species analysis : Korean waters were divided by sea surface temperature and salinity using K-means clustering. Vertical profiles of sea surface temperature and salinity were investigated with ODV (Ocean Data View 4). Prior to investigate species representing water masses, indicator species value was calculated by Dufrene and Legendre (1997) and over 60% of indicator species value was selected as indicator species. The Indicator value (Ind-Val) of individual species was calculated as by the following equation:

$$\text{Ind-Val} = \text{RA}_{kj} \times \text{RF}_{kj} \times 100$$

$$\text{RA}_{kj} = \frac{\text{Mean number of individuals of species } j \text{ across sites of group } k}{\text{Sum of the mean numbers of individuals of species } j \text{ overall group}}$$

$$\text{RF}_{kj} = \frac{\text{The number of sites in cluster } k}{\text{Total number of sites in that cluster } k}$$

Where, RA is the relative abundance of species in group k , RF is the relative frequency (presence/absence) of species j in group k . Monte-Carlo method was used to test the significance of Ind-Val

by randomly permuting the data and recalculating Ind-Val. The result was deemed significant at <0.05 with PC-ORD.

Results and Discussion

Oceanographic characteristics: Sea surface temperature ranged between 4.5–16.5°C, it was highest in the eastern part of ECS and lowest in the northern Yellow Sea. Surface salinity ranged between 31.89–34.71psu, it was highest at the eastern Jeju Island and lowest in the western sea of ECS (Fig. 2).

Korean waters were divided into six water bodies: (A), (B), (C), (D), (E), and (F), consisting of 15, 36, 30, 20, 19 and 10 stations, respectively. Group (C) was characterized by the highest sea surface temperature and salinity whereas Group (E) and (F) was characterized by lowest sea surface temperature and salinity (Fig. 3; Table 1).

In the East Sea, warm current and cold current clearly varied within 37.25°N. Also, cold current appeared at water depth deeper than 50 m with lowest temperature of 1.26°C. Warm water had a highest temperature of 12.63°C. In the Yellow Sea, water masses were relatively homogenous. In the northern ECS, warm hypersaline water and cold hyposaline water were strongly separated within 125.5°E. Warm hypersaline water had a highest temperature and salinity of 16.41°C and 34.66 psu, while cold hyposaline water had a lowest temperature and salinity of 8.95°C and 32.42 psu (Fig. 4).

Water bodies consisted of 6 currents: Group (A) as NKCC; group (B) as EKWC; group (C) as JWC; group (E) as YSWC and group (F) as original water bodies of Yellow Sea and

Fig. 2 : Horizontal distribution of temperature and salinity at 10 m depth in winter 2016. (a) Temperature, (b) Salinity.

Fig. 3 : Temperature-Salinity diagram of clustering groups in winter 2016.

Y1. In addition, complex currents distributed around the JWC were defined as mixed water (Fig. 5).

Distribution of water bodies in Korean waters: The East Sea is deepest with a wide and varied vertical range of temperature due to sub-polar front made of EKWC and NKCC. EKWC transported Tsushima Warm Current (TsWC) with high salinity and temperature along the eastern coast. Under EKWC, NKCC within 1-4°C prevailed from 50 to 100 m depth along the coastal water of Gangwon Province in February (Cho and Kim, 1994; Choi *et al.*, 2012). In the East/Japan Sea, the EKWC and NKCC creating sub-polar front is located at 38-39°N (Yoon, 1982; Isoda *et al.*, 1992; Kim *et al.*, 1998). In the present study, sub-polar front was formed more southward than where was reported at 37°N due to enhanced NKCC in winter (Park *et al.*, 2007). Also, sea surface layer prevailed due to warm water over 10°C, while sea bottom was occupied by cold water below 4°C in the sub-polar front region.

Fig. 4 : Cross sections of temperature and salinity along three solid lines. (a) East Sea, (b) Yellow Sea, (c) Northern East China Sea.

Table 1 : Average temperature and salinity of each clustering groups in winter 2016

Clustering	Average temperature (°C)	Average salinity (psu)
(A)	8.55	34.07
(B)	11.28	34
(C)	14.53	34.39
(D)	9.53	32.86
(E)	7.8	32.51
(F)	6.09	32.62

Fig. 5 : Distributions of the water masses. (A): NKCC, (B): EKWC, (C): JWC, (D): Mixed water, (E): YSWC, (F): Y1.

Northern ECS is a route of northward moving warm water. Warm water such as JWC makes a thermohaline front with YDW (Lie *et al.*, 2001). JWC flows into the Jeju Strait after turning clockwise around Jeju Island, with over 10°C, 33.5-34.0 psu (Lie *et al.*, 1999; Lie *et al.*, 2000, 2001). Upon investigation of tracking Jeju currents, the JWC was distinguished from Kuroshio branch water located in the east coast of Jeju Island, and partially affects the TsWC through Korea Strait (Lie *et al.*, 2000). Also, Yangtze river runoff accounts for more than 80% of freshwater, released a range of 9,900-10,200m³/s in northern ECS (Riedlinger *et al.*, 1995). Similar to previous studies, northern ECS produced thermohaline front with various water bodies, such as JWC and mixed water influenced by coastal water.

During winter, the Yellow Sea is affected by northwest winds, southward China coastal water and Korean coastal water (Hsueh, 1988; Riedlinger *et al.*, 2000; Naimie *et al.*, 2001). The YSWC enhancing during winter flows northward to the Yellow Sea with heat and saline (Hwang *et al.*, 2014). In our research, YSWC

was characterized by low salinity and temperature, which were not coincided with previous studies. However, mean sea surface water temperature and salinity in the KCC in the Yellow Sea were 6°C and 32.5, which was similar to previous study (Koh *et al.*, 2014).

Species composition and abundance : A total of 199 species of zooplankton belonging to ten phyla were identified. Of these, 170 species were arthropods and 126 species were copepods. The species number was highest (102) in JWC followed by 99 species in EKWC, 81 species in NKCC, 44 species in YSWC, and 41 species in Y1.

Zooplankton densities ranged between 7.6-926.5 inds.m⁻³. The mean density of zooplankton was highest (351.4 inds.m⁻³) in EKWC followed by NKCC, JWC, YSWC and Y1 (115.1 inds.m⁻³). Species diversity indices ranged from 0.91 to 3.12. Average of the index was highest in EKWC (2.67), followed by NKCC, JWC, YSWC and Y1 (2.01). Diversity was not proportional to the biomass (Fig. 6).

The most dominant species in NKCC were *Pseudocalanus newmani*, *Metridia pacifica* and *Oithona atlantica*, and cold water copepods comprising 96% were dominated. Warm water copepods were relatively high in JWC (28%) and EKWC (24%). In EKWC, dominant species were *Pseudocalanus minutus*, *Oithona plumifera* and *Metridia pacifica*. In JWC and Y1, dominant species was *Calanus sinicus*. In YSWC, dominant species were *Calanus sinicus*, *Oithona atlantica* and *Paracalanus parvus* s.l. (Table 2; Fig. 7), respectively.

In the East Sea, cold water species such as *M. pacifica*, *P. newmani*, *O. atlantica* and *P. parvus* s.l. charged 46.2%. Warm water copepods of *M. tenuicornis*, *Clausocalanus pergens*, *Ditrichocorycaeus affinis* and *C. arcuicornis* occupied 14.4% in winter (Chiba *et al.*, 2003). In this study, cold water copepods such as *P. newmani*, *M. pacifica* and *O. atlantica* were dominated, coinciding with previous studies of Chiba *et al.* (2003) and Kang *et al.* (2007). The prevailing cold water species may result from NKCC due to sampling layer deeper than 100 m depth.

C. sinicus is dominated in the ECS (Chen *et al.*, 1992) and *P. parvus* s.l. is abundant in off China coastal water (Chen *et al.*, 1974). Also, *P. aculeatus*, *C. sinicus*, Ostracoda and

Fig. 6 : Horizontal distribution of zooplankton density (inds. m⁻³) and species diversity indices in Korean waters in winter 2016. (a) Density, (b) Diversity indices.

Table 2 : Mean abundance and composition of dominant mesozooplankton by water masses in winter 2016

Current	Species	Mean abundance (inds.m ⁻³)	Composition (%)
NKCC	<i>Pseudocalanus newmani</i>	54.41	19.84
	<i>Metridia pacifica</i>	33.73	12.3
	<i>Metridia</i> sp. copepodite	23.87	8.7
	<i>Oithona atlantica</i>	19.66	7.17
	<i>Neocalanus</i> spp. copepodite	15.24	5.56
EKWC	<i>Pseudocalanus minutus</i>	70.28	19.30
	<i>Metridia</i> sp. copepodite	26.47	7.27
	<i>Oithona plumifera</i>	23.05	6.33
	<i>Metridia pacifica</i>	22.71	6.24
	Calanoida spp. copepodite	16.65	4.57
JWC	<i>Calanus</i> sp. copepodite	33.16	28.57
	<i>Calanus sinicus</i>	9.57	8.25
	Euchaetidae spp. copepodite	8.80	7.59
	Calanoida spp. copepodite	7.76	6.69
	Sagittidae spp. juvenile	7.28	6.27
YSWC	<i>Calanus</i> sp. copepodite	21.87	20.76
	<i>Calanus sinicus</i>	18.83	17.88
	<i>Oithona atlantica</i>	18.23	17.31
	Sagittidae spp. juvenile	16.40	15.57
	<i>Paracalanus parvus</i> s.l.	4.85	4.61
Y1	Sagittidae spp. juvenile	25.49	22.11
	<i>Calanus</i> sp. copepodite	19.52	16.93
	<i>Calanus sinicus</i>	17.96	15.58
	Calanidae spp. copepodite	6.19	5.37
	Calanoida spp. copepodite	5.73	4.97

Fig. 7 : Compositions of warm and cold water species of 30 dominant copepods by water masses in winter 2016.

Siphonophora were dominated in winter in northern ECS (Park et al., 2000). *P. aculeatus* is reported as a warm indicator species of Kuroshio branch current (Hsieh et al., 2004). Likewise, effect of JWC made relatively high density of *P. aculeatus* with a high proportion of warm water copepods, and also JWC was dominated by *C. sinicus* and chaetognath juvenile.

Acartia bifilosa, *A. omorii*, *C. sinicus*, *D. affinis*, *Eurytemora pacifica*, *Pavocalanus crassirostris* and *P. indicus* were dominated in the Yellow Sea (Kim et al., 1991). In particular,

C. sinicus, *P. parvus* s.l., *O. atlantica*, *D. affinis* and *O. similis* were abundant during winter (Lim et al., 2009). In this study, *C. sinicus* was found to be the dominant species in YSWC and Y1. In YSWC, high population of *P. parvus* s.l. was due to the effect of warm water coming from northern ECS.

Zooplankton communities : nMDS analysis indicated that zooplankton communities in NKCC, EKWC and JWC were distinctly separated, and several stations of JWC were included in YSWC, Y1, and mixed water (Fig. 8). As a result of SIMPER analysis, NKCC and JWC showed highest dissimilarity, while YSWC and Y1 showed the lowest dissimilarity. In pairwise tests, combination among YSWC, Y1 and mixed water were not significantly different. The NKCC did not differ significantly from the EKWC and the JWC was not significantly distinguished from mixed water. Combinations for others were significantly different (Table 3).

Zooplankton community structure : The East/Japan Sea, northern ECS and the Yellow Sea are well associated. The northern ECS and the Yellow Sea interact with YSWC and coastal water, varying with seasons (Ichikawa et al., 2002; Lee et al., 2007; Chen 2009). Zooplankton assemblages and water mass distributions are associated (Chen et al., 2015). Zooplankton communities between the Yellow Sea and northern ECS showed 60% dissimilarity in fall (Chen et al., 2015), while those between two seas were similar in study. This difference may be influenced

Fig. 8 : Result of MDS grouping in winter.

Table 3 : Results of SIMPER and ANOSIM pair-wise tests for difference on mesozooplankton community between groups in winter 2016

Groups	versus groups	SIMPER	Pairwise Tests	
		Average dissimilarity	R statistics	p-level
NKCC	EKWC	68.66	0.115	3.6
	JWC	87.02	0.829	0.1
	YSWC	83.81	0.89	0.1
	Y1	86.44	0.894	0.1
EKWC	Mixed water	86.69	0.559	0.1
	JWC	81.8	0.576	0.1
	YSWC	80.34	0.68	0.1
	Y1	83.53	0.709	0.1
JWC	Mixed water	83.9	0.453	0.1
	YSWC	75.5	0.385	0.1
	Y1	76.95	0.364	0.1
	Mixed water	74.95	0.106	0.2
YSWC	Y1	58.44	0.105	9.6
	Mixed water	71.45	0.031	29.4
Y1	Mixed water	72.28	-0.018	54.5

Table 4 : Results of Spearman rank correlation coefficient between dominant species and temperature and salinity in winter. '-' means p-value, >0.05

Current	Species	Temperature		Salinity	
		r	p	r	p
NKCC	<i>Pseudocalanus newmani</i>	-0.116	-	0.306	<0.001
	<i>Metridia pacifica</i>	0.089	-	0.439	<0.001
	<i>Metridia</i> sp. copepodite	-0.120	-	0.297	<0.001
	<i>Oithona atlantica</i>	-0.253	<0.01	0.086	-
	<i>Neocalanus</i> spp. copepodite	-0.105	-	0.316	<0.001
EKWC	<i>Pseudocalanus minutus</i>	0.105	-	0.442	<0.001
	<i>Metridia</i> sp. copepodite	-0.120	-	0.297	<0.001
	<i>Oithona plumifera</i>	-0.119	-	0.017	-
	<i>Metridia pacifica</i>	0.089	-	0.439	<0.001
	<i>Calanoida</i> spp. copepodite	-0.304	<0.001	-0.234	<0.01
JWC	<i>Calanus</i> sp. copepodite	0.057	-	-0.244	<0.01
	<i>Calanus sinicus</i>	-0.336	<0.001	-0.407	<0.001
	<i>Euchaetidae</i> spp. copepodite	0.793	<0.001	0.760	<0.001
	<i>Calanoida</i> spp. copepodite	-0.304	<0.001	-0.234	<0.01
	<i>Sagittidae</i> spp. juvenile	-0.296	<0.001	-0.466	<0.001
YSWC	<i>Calanus</i> sp. copepodite	0.057	-	-0.244	<0.01
	<i>Calanus sinicus</i>	-0.336	<0.001	-0.407	<0.001
	<i>Oithona atlantica</i>	-0.253	<0.01	0.086	-
	<i>Sagittidae</i> spp. juvenile	-0.296	<0.001	-0.466	<0.001
	<i>Paracalanus parvuss.l.</i>	0.220	<0.05	0.142	-
Y1	<i>Sagittidae</i> spp. juvenile	-0.296	<0.001	-0.466	<0.001
	<i>Calanus</i> sp. copepodite	0.057	-	-0.244	<0.01
	<i>Calanus sinicus</i>	-0.336	<0.001	-0.407	<0.001
	<i>Calanidae</i> spp. copepodite	-0.097	-	0.013	-
	<i>Calanoida</i> spp. copepodite	-0.304	<0.001	-0.234	<0.01

by YSWC and the Korea coastal current, prevailing during winters (Kondo, 1985). YSWC plays an important role in transporting heat and salt to the Yellow Sea (Ichikawa *et al.*, 2002; Lie *et al.*, 2000), and KCC flows southward along west Korea due to strong north wind in winter (Koh *et al.*, 2014).

Zooplankton communities of the East Sea separated from other seas are determined by the path of currents. EKWC and JWC originate from KWC (Rebstock *et al.*, 2003). However, two water bodies showed different physical properties (Lie *et al.*, 1994). KWC makes two main branches, one is TaWC, flowing to

Fig. 9 : Distribution of indicator species: (a) *Candacia bipinnata*, (b) *Pleuromamma gracilis*, (c) *Euchaeta plana*, (d) *Scolecithricella longispinosa*, (e) *Themisto gaudichaudii*, (f) *Euphausia pacifica*, (g) *Ditrichocorycaeus affinis*, (h) *Scolecithricella minor*, (i) *Corycaeus affinis*, (j) *Calanus sinicus*, (k) *Paracalanus parvus* s.l., (l) *Centropages abdominalis*, (m) *Oithona atlantica*, (n) *Oncaea venusta*.

Table 5 : Results of Spearman rank correlation coefficient between indicator species and temperature and salinity. '-' means p-value, >0.05

Current	Species	Temperature		Salinity	
		r	p	r	p
NKCC	<i>Scolecithricella minor</i>	0.227	<0.01	0.084	-
EKWC	<i>Candacia bipinnata</i>	0.529	<0.001	0.725	<0.001
	<i>Calanus sinicus</i>	-0.336	<0.001	-0.407	<0.001
	<i>Paracalanus parvus</i> s.l.	0.220	<0.05	0.142	-
	<i>Ditrichocorycaeus affinis</i>	0.411	<0.001	0.313	<0.001
	<i>Clausocalanus furcatus</i>	0.328	<0.001	0.541	<0.001
	<i>Pleuromamma gracilis</i>	0.290	<0.001	0.423	<0.001
JWC	<i>Oncaea venusta</i>	0.713	-	0.789	<0.001
	<i>Euchaeta plana</i>	0.472	<0.001	0.174	<0.001
	<i>Scolecithricella longispinosa</i>	0.584	<0.001	0.321	<0.05
	<i>Oithona atlantica</i>	-0.253	<0.01	0.086	-
YSWC	<i>Oithona atlantica</i>	-0.253	<0.01	0.086	-
	<i>Themisto gaudichaudi</i>	-0.264	<0.01	-0.456	<0.001
Y1	<i>Centropages abdominalis</i>	-0.122	-	-0.176	<0.05
	<i>Euphausia pacifica</i>	-0.318	<0.001	-0.505	<0.001

Table 6 : Indicator species index in winter 2016. (Ind-Val, Indicator value)

JWC					
Species	Ind-Val	p-value			
<i>Oncaea venusta</i>	78.6	<0.001			
<i>Euchaeta plana</i>	76.4	<0.05			
<i>Scolecithricella longispinosa</i>	73.7	<0.001			
<i>Oithona atlantica</i>	66.8	<0.05			
NKCC			EKWC		
Species	Ind-Val	p-value	Species	Ind-Val	p-value
<i>Pseudocalanus newmani</i>	66.6	-	<i>Calanus sinicus</i>	76.5	<0.05
			<i>Oncaea venusta</i>	73.8	-
			<i>Paracalanus parvus</i> s.l.	73.7	<0.05
			<i>Ditrichocorycaeus affinis</i>	68.5	<0.05
			<i>Clausocalanus furcatus</i>	63.9	<0.05
			<i>Pleuromamma gracilis</i>	62	<0.01
			<i>Pseudocalanus minutus</i>	60.3	-
YSWC			Y1		
Species	Ind-Val	p-value	Species	Ind-Val	p-value
<i>Oithona atlantica</i>	84.3	<0.01	<i>Centropages abdominalis</i>	86.6	<0.001
<i>Ditrichocorycaeus affinis</i>	69.8	-	<i>Euphausia pacifica</i>	77.8	<0.001
<i>Themisto gaudichaudi</i>	65.8	<0.05			
<i>Sagitta nagae</i>	63.8	-			

the northern ECS and another one is TsWC, flowing to the East/Japan Sea (Guan *et al.*, 1982). Throughout the path, characteristics of TaWC and TsWC changed, and it affected JWC and EKWC, respectively. Although the East/Japan Sea was associated with northern ECS through the Korea Strait, community structures of zooplankton between the two seas were different in the present study.

Correlation zooplankton with temperature and salinity: *P. newmani* and *M. pacifica*, which were dominant in NKCC, were positively correlated with salinity during the study. *O. atlantica* was negatively correlated with temperature. In EKWC, *P. minutes* and *M. pacifica* were positively correlated with salinity. In JWC, *C. sinicus* had a negative correlation with temperature and salinity. In YSWC, *O. atlantica* was negatively correlated with temperature,

while *P. parvus* s.l. was positively correlated (Table 5).

S. minor, indicator species of NKCC, was positively correlated with sea surface temperature. In EKWC, *C. bipinnata* had a strong positive correlation with sea surface temperature and salinity. *D. affinis*, *C. furcatus* and *P. gracilis* were positively correlated with sea surface temperature and salinity. *P. parvus* s.l. was positively correlated with sea surface salinity. *C. sinicus* was negatively correlated with temperature. In JWC, *E. plana* and *S. longispinosa* were positively correlated with sea surface temperature and salinity, while *O. venusta* was positively correlated with only sea surface salinity. *O. atlantica*, which was dominant species in both JWC and YSWC, was negatively correlated with sea surface temperature. In Y1, *C. abdominalis* was negatively correlated with sea surface salinity, and another indicator species, *E. pacifica*, had a negative correlation with temperature and salinity (Table 6).

Indicator species : Following the Indicator species analysis, *S. minor* was considered as an indicator species of NKCC and was dominated in northern East Sea. In EKWC, *C. sinicus*, *P. parvus* s.l. and *D. affinis* were broadly distributed in Korea, while *C. furcatus*, *C. bipinnata* and *P. gracilis* were distributed and dominated in southern East Sea. In JWC, *O. atlantica* dominated in Korean waters, while *O. venusta* was found in the East Sea and northern ECS. *E. plana* was distributed in the Yellow Sea and northern ECS, and highest in the vicinity of Jeju Island. The densities of *S. longispinosa* were highest in the eastern part of northern ECS and the Korea Strait. *Themisto gaudichaudii* which was an indicator species of the YSWC was broadly distributed in Korean water. In Y1, *C. abdominalis* and *E. pacifica* were broadly distributed in Korea and highest in the Yellow Sea. *E. pacifica* was most abundant in the Yellow Sea (Table 6, Fig. 9).

In this study, Korean water was divided into six water bodies to find the indicator species. Except for mixed water, five water bodies had indicator species. In the East Sea, *S. minor* which is an indicator species of sub-arctic water (Hooff et al., 2006) was an indicator species of NKCC and found in the East Sea and the southern sea of Korea (Jeong et al., 2014; Chiba et al., 2003). *S. minor* was most abundant in the northern East/Japan Sea in the present study. *S. minor* can be an indicator species of NKCC. KWC features high water temperature and salinity, and formed the EKWC throughout the Tsushima Island (Rebstock et al., 2003). *C. bipinnata*, *C. furcatus* and *P. gracilis* were indicator species of KWC in the southern part of Japanese water (Noda et al., 1998). In the present study, these three species were positively correlated with sea water temperature and salinity, and could be indicator species of EKWC which was branch of the KWC. *C. sinicus*, *P. parvus* s.l. and *D. affinis* were broadly distributed in Korea, thus these species cannot be considered an indicator species.

In the East China Sea, Hsieh et al., (2004) reported *O. venusta* and *S. longispinosa* as indicator species of TaWC.

Distribution of *S. longispinosa* coincided with the path of JWC flowed from northern ECS to Korea Strait turning clockwise around Jeju Island. In addition, *S. longispinosa* was usually found off Yangtze river when salinity was high (Cheng et al., 2014). Following the studies, *S. longispinosa* can be considered to be a strong indicator species of JWC. Another indicator species, *E. plana*, was broadly distributed in the Korean water, but abundant only in the areas affected by JWC. *E. plana* is a warm water species and was found to be abundant in the western part of Jeju Island (Park et al., 1992). *O. atlantica* was broadly distributed in Korea and cold water species (Chiba et al., 2003), thus it can not consider to be an indicator species of JWC which is characterized by high temperature and salinity.

The Yellow Sea has two currents, and *T. gaudichaudii* was the indicator species of YSWC. *T. gaudichaudii* was one of the most abundant amphipod species of southern hemisphere (Mackey et al., 2012), particularly in Antarctic and sub-antarctic (Piatkowski, 1985). In this study, *T. gaudichaudii* showed a negative relationship with temperature and salinity. In northern Yellow Sea, *C. abdominalis* was relatively higher in the cold waters and occurred in the northern part of Yellow Sea (Kang et al., 2008). This species was found in cold-neritic seas (Jang et al., 2012). Y1 features lowest sea surface temperature and salinity, the environment where *C. abdominalis* occurs. Another indicator species, *E. pacifica* was broadly distributed in Korea, and abundant in the southern Yellow Sea. However, krill swarms were patchily distributed (Powell and Okubo, 1994). Thus, it is hard to survey quantitative analysis of the krill and to select an indicator species.

Three sides of Korean peninsula are surrounded by seas with different physical and biological characteristics driven by water currents: NKCC, EKWC, JWC, YSWC, Y1, and mixed water. The water bodies of the Yellow Sea and northern ECS were highly similar, but East Sea Sea was distinguished from others. Indicator species varied with varying water bodies, and the similarity of zooplankton community structures varied with the interaction of water masses.

Acknowledgment

This work was supported by a Research Grant of Pukyong National University(2017 year).

References

- Beardsley, R.C., R. Limeburner, H. Yu and G.A. Cannon: Discharge of the Changjiang (Yangtze River) into the East China Sea. *Cont. Shelf Res.*, **4**, 57-76 (1985).
- Brodsky, K.A.: Calanoida of the Far Eastern Seas and Polar Basin of the USSR. Keys to the Fauna of the USSR. The Zoological Institute of the Academy of Sciences of the USSR, **35**, 1-440 (1950).
- Chen, C.T.A.: Chemical and physical fronts in the Bohai, Yellow and East China Seas. *J. Mar. Syst.*, **78**, 394-410 (2009).

- Chen, H.Y. and Y.L.L. Chen: Quantity and quality of summer surface net zooplankton in the Kuroshio current-induced upwelling northeast of Taiwan. *TAO*, **3**, 321-334 (1992).
- Chen, H. and G. Liu: Zooplankton community structure in the Yellow Sea and East China Sea in autumn. *Brazilian J. Oceanogr.*, **63**, 455-468 (2015).
- Chen, Q.C., S.Z. Zhang and C.S. Zhu: On planktonic copepods of the Yellow Sea and the East China Sea. II. Cyclopoida and Harpacticoida. *Stud. Mar. Sin.*, **9**, 27-76 (1974).
- Cheng, F., M. Wang, C. Li and S. Sun: Zooplankton community analysis in the Changjiang River estuary by single-gene-targeted metagenomics. *CJOL*, **32**, 858-870 (2014).
- Chiba, S. and T. Saino: Variation in mesozooplankton community structure in the Japan/East Sea (1991–1999) with possible influence of the ENSO scale climatic variability *Prog. Oceanogr.*, **57**, 317-339 (2003).
- Cho, Y.K. and K. Kim: Two modes of the salinity-minimum layer water in the Ulleung Basin. *La mer*, **32**, 271-278 (1994).
- Choi, M.Y., D.S. Moon, D.H. Jung and H.J. Kim: Seasonal distribution of water masses and spatio-temporal characteristics of nutrients in the coastal areas of Gangwon Province of the Korean East Sea in 2009. *J. Korean Soc. Mar. Environ. Energ.*, **15**, 76-88 (2012).
- Clarke, K.R. and R.M. Warwick: A further biodiversity index applicable to species lists: Variation in taxonomic distinctness. *Mar. Ecol. Prog. Ser.*, **216**, 265-278 (2001).
- Dufrene, M. and P. Legendre: Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecol. Monogr.*, **67**, 345-366 (1997).
- Dur, G., J.S. Hwang, S. Souissi, L.C. Tseng, C.H. Wu, S.H. Hsiao and Q.C. Chen: An overview of the influence of hydrodynamics on the spatial and temporal patterns of calanoid copepod communities around Taiwan. *J. Plankton Res.*, **29**, 97-116 (2007).
- Fang, G., B. Zhao and Y. Zhu: Water volume transport through the Taiwan Strait and the continental shelf of the East China Sea measured with current meters. *Elsevier Oceanogr. Ser.*, **54**, 345-358 (1991).
- Guan, B. and H. Mao: A note on circulation of the East China Sea. *Chin. J. Oceanol. Limnol.*, **1**, 5-16 (1982).
- Hooff, R.C. and W.T. Peterson: Copepod biodiversity as an indicator of changes in ocean and climate conditions of the northern California current ecosystem. *Limnol. Oceanogr.*, **51**, 2607-2620 (2006).
- Hsieh, C.H.H., T.S. Chiu and C.T. Shih: Copepod diversity and composition as indicators of intrusion of the Kuroshio Branch Current into the Northern Taiwan Strait in Spring 2000. *Zool. Stud.*, **43**, 393-403 (2004).
- Hsueh, Y.: Recent current observations in the eastern Yellow Sea. *J. Geophys. Res. Oceans*, **93**, 6875-6884 (1988).
- Hwang, J.H., S.P. Van, B.J. Choi, Y.S. Chang and Y.H. Kim: The physical processes in the Yellow Sea. *Ocean Coast Manag.*, **102**, 449-457 (2014).
- Hwang, J.S. and C.K. Wong: The China coastal current as a driving force for transporting *Calanus sinicus* (Copepoda: Calanoida) from its population centers to waters off Taiwan and Hong Kong during the winter northeast monsoon period. *J. Plankton Res.*, **27**, 205-210 (2005).
- Hwang, J.S., S. Souissi, L.C. Tseng, L. Seuront, F.G. Schmitt, L.S. Fang and T.P. Wei: A 5-year study of the influence of the northeast and southwest monsoons on copepod assemblages in the boundary coastal waters between the East China Sea and the Taiwan Strait. *J. Plankton Res.*, **28**, 943-958 (2006).
- Ichikawa, H. and R.C. Beardsley: The current system in the Yellow and East China Seas. *J. Oceanogr.*, **58**, 77-92 (2002).
- Isoda, Y., S. Saitoh and M. Mihara: Seasonal variations of SST patterns in the Japan Sea. Umi to Sora, **68**, 113-124 (1992).
- Jang, M.C., S.H. Baek, P.G. Jang, W.J. Lee and K.S. Shin: Patterns of zooplankton distribution as related to water masses in the Korea strait during winter and summer. *Ocean Polar Res.*, **34**, 37-51 (2012).
- Jeong, H.G., H.L. Suh, W. Lee and H.Y. Soh: Seasonal variation of the neustonic zooplankton community in southern waters of Korea. *Ocean Sci. J.*, **49**, 167-181 (2014).
- Kang, J.H., W.S. Kim, H.J. Jeong, K. Shin and M. Chang: Why did the copepod *Calanus sinicus* increase during the 1990s in the Yellow Sea? *Mar. Environ. Res.*, **63**, 82-90 (2007).
- Kang, J.H. and W.S. Kim: Spring dominant copepods and their distribution pattern in the Yellow Sea. *Ocean Sci. J.*, **43**, 67-79 (2008).
- Kim, K., K.R. Kim, J.Y. Chung, H.S. Yoo and S.G. Park: Characteristics of physical properties in the Ulleung Basin. *J. Oceanol. Soc. Korea*, **26**, 83-100 (1991).
- Kim, S.W. and Y. Isoda: Interannual variations of the surface mixed layer in the Tsushima current region. *Umi to Sora*, **74**, 11-22 (1998).
- Koh, C.H. and J.S. Khim: The Korean tidal flat of the Yellow Sea: Physical setting, ecosystem and management. *Ocean Coast. Manag.*, **102**, 398-414 (2014).
- Kondo, M.: Oceanographic investigations of fishing grounds in the East China Sea and the Yellow Sea, 1: Characteristics of mean temperature and salinity distributions measured at 50 m and near the bottom. *Bull. Seikai Reg. Fish. Res. Lab.*, **62**, 19-66 (1985).
- Lan, Y.C., C.T. Shih, M.A. Lee and H.Z. Shieh: Spring distribution of copepods in relation to water masses in the northern Taiwan Strait. *Zool. Stud.*, **43**, 332-343 (2004).
- Lee, C.K.: The drift bottle experiment in the east of the Yellow Sea (the west coast of Korea) during the year of 1962-1966. *Bull. Fish. Res. Develop. Agency*, **3**, 29-41 (1968).
- Lee, D.I. and J.K. Kim: Numerical simulation of residual currents and tow salinity dispersions by Changjiang discharge in the Yellow Sea and the East China Sea. *J. Korean Soc. Mar. Environ. Energ.*, **10**, 67-85 (2007).
- Lee, S.W.: The Maritime of Coast of Korea. Jib-mun-dang (1992).
- Lie, H.J.: A note on water masses and general circulation in the Yellow Sea (Hwanghae). *J. Oceanol. Soc. Korea*, **19**, 187-194 (1984).
- Lie, H.J. and C.H. Cho: On the origin of the Tsushima Warm Current. *J. Geophys. Res.: Oceans*, **99**, 25,081-25,091 (1994).
- Lie, H.J.: Ocean circulation in the western and middle part of the East China Sea (second year). KORDI Rep. BSPE 98708-00-1141-1 (1999).
- Lie, H.J.: and C.H. Cho: Recent advances in understanding the circulation and hydrography of the East China Sea. *Fish. Oceanogr.*, **11**, 318-328 (2002).
- Lie, H.J., C.H. Cho, J.H. Lee, S. Lee and Y. Tang: Seasonal variation of the Cheju warm current in the northern East China Sea. *J. Oceanogr.*, **56**, 197-211 (2000).
- Lie, H.J., C.H. Cho, J.H. Lee, S. Lee, Y. Tang and E. Zou: Does the Yellow Sea Warm Current really exist as a persistent mean flow? *J. Geophys. Res.: Oceans*, **106**, 199-210 (2001).
- Lim, D.H., W. D., Yoon, J. W. Yang and Y. Lee: The seasonal fluctuation of zooplankton in the Yellow Sea. *J. Korean Soc. Mar. Environ. Saf.*, **183-188** (2009).

- Mackey, A.P., A. Atkinson, S.L. Hill, P. Ward, N.J. Cunningham, N.M. Johnston and E.J. Murphy: Antarctic macrozooplankton of the southwest Atlantic sector and Bellingshausen Sea: Baseline historical distributions (Discovery Investigations, 1928–1935) related to temperature and food, with projections for subsequent ocean warming. *Deep Sea Res., Part II*, **59**, 130–146 (2012).
- Naimie, C.E., C.A. Blain and D.R. Lynch: Seasonal mean circulation in the Yellow Sea a model generated climatology. *Cont. Shelf Res.*, **21**, 667–695 (2001).
- Nitani, H.: Beginning of the Kuroshio, in Kuroshio- its physical aspects, University of Tokyo Press, Tokyo (1972).
- Noda, M., I. Ikeda, S. Ueno, H. Hashimoto and K. Gushima: Enrichment of coastal zooplankton communities by drifting zooplankton patches from the Kuroshio front. *Mar. Ecol. Prog. Ser.*, **170**, 55–65 (1998).
- Park, C. and J. Seo: Characteristics of zooplankton distribution and degree of its coupling with distribution of water masses in the northern East China Sea in summer and winter. *The Yellow Sea*, **6**, 1–11 (2000).
- Park, C., C.R. Lee and J.C. Kim: Zooplankton community in the front zone of the East Sea (the Sea of Japan), Korea: 2. Relationship between abundance distribution and Seawater temperature. *Korean J. Fish. Aquat. Sci.*, **31**, 749–759 (1998).
- Park, J.S., S.S. Lee, Y.S. Kang, B.D. Lee and S.H. Huh: Distribution of indicator species of copepods and chaetognaths in the southeastern area of the Yellow Sea and their relationship to the characteristics of water masses. *Korean J. Fish. Aquat. Sci.*, **25**, 251–264 (1992).
- Park, K.A., D.S. Ullman, K. Kim, J.Y. Chung and K.R. Kim: Spatial and temporal variability of satellite-observed subpolar front in the East/Japan Sea. *Deep Sea Res., Part I*, **54**, 453–470 (2007).
- Piatkowski, U.: Distribution, abundance and diurnal migration of macrozooplankton in Antarctic surface waters. *Meeresforschung- Reports on Marine Res.*, **30**, 264–279 (1985).
- Powell, T.M. and A. Okubo: Turbulence, diffusion and patchiness in the sea. *Philos. Trans. R. Soc., B*, **343**, 11–18 (1994).
- Rebstock, G.A. and Y.S. Kang: A comparison of three marine ecosystems surrounding the Korean peninsula: Responses to climate change. *Prog. Oceanogr.*, **59**, 357–379 (2003).
- Riedlinger, S.K. and G. Jacobs: Study of the dynamics of wind-driven transports into the Yellow Sea during winter. *J. Geophys. Res. Oceans*, **105**, 695–708 (2000).
- Riedlinger, S. and R. Preller: Validation test report for the Yellow Sea shallow water analysis and forecast system. Draft NRL Report, Stennis Space Center, MI. (1995).
- Shanks, A.: An Identification Guide to the Larval Marine Invertebrates of the Pacific Northwest. Oregon State Univ. Press. (2001).
- Shannon, C.E. and W. Weaver: The measurement theory of communication. University of Illinois Press, Urbana (1963).
- Teague, W.J., G.A. Jacobs, D.S. Ko, T.Y. Tang, K.I. Chang and M.S. Suk: Connectivity of the Taiwan, Cheju, and Korea Straits. *Cont. Shelf Res.*, **23**, 63–77 (2003).
- Tseng, L.C., S. Souissi, H.U. Dahms, Q.C. Chen and J.S. Hwang: Copepod communities related to water masses in the southwest East China Sea. *Helgoland Mar. Res.*, **62**, 153 (2008).
- Uda, M.: The results of simultaneous oceanographical investigations in the Japan Sea and its adjacent waters in May and June, 1932. *J. Imper. Fish. Exper. Stat.*, **5**, 57–190 (1934).
- Yasui, M.: Oceanographic studies of the Japan Sea (1)-Water characteristics. *Oceanogr. Magaz.*, **19**, 177–192 (1967).
- Yoo K.I.: Zooplankton studies of the Yellow Sea in Korea. *Yellow Sea Res.*, **4**, 31–37 (1991).
- Yoon, J.H.: Numerical experiment on the circulation in the Japan Sea. *J. Oceanogr. Soc. Japan*, **38**, 81–94 (1982).