Thesis for the Degree of Master of Science

Zooplankton community of Ross Sea, Antarctic Ocean in Austral summer

by

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February 2021

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(남반구 여름철 남극해 로스해의 동물플랑크톤 군집)

Advisor: Prof. Won Gyu Park

by

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Abstract

The pattern of zooplankton community is influenced by the hydrographic conditions of where they exist. Zooplankton community was investigated at 14 stations in the ice shelf of Ross Sea in Antarctic Ocean in January 2019. Zooplankton were collected by using a Ring Net (1 m diameter with 330 μm mesh) and Bongo Net (0.6 m diameter with 505 μm mesh) from near the bottom to the surface. Water temperature, salinity, and Chl-*a* concentration were simultaneously measured at all sampling stations. Sea surface temperature ranged from -0.15°C to 0.12°C and bottom temperature ranged from -1.88°C to 0.87°C. Salinity ranged from 33.9 to 34.7 psu and Chl-*a* concentration between sampling stations ranges from 0.31 to 1.58 mg.m^{-3}. A total of 138 taxa belonging to 7 phyla were identified during the study period. Mean densities ranged from 130 inds.m^{-3} to 2,167 ind.m^{-3}. Among taxa, copepods were dominated, comprising 36% of zooplankton density. *Calanus propinquus, Calanus* spp. copepodites, *Metridia* spp. copepodites, *Metridia gerlachei*, Eucalanidae spp. copepodites, *Oithona* spp. copepodite, *Muggiacea* spp., *Conchoecia* spp., Gammaridae spp. juvenile, and *Euphausia superba* were dominant species. This study indicated that there was no significant relationship between dominant species density, sea surface temperature, salinity, and Chl-*a* concentration.

Keywords: Zooplankton, density, hydrography, Ross Sea, Antarctic Ocean.

남반구 여름철 남극해 로스해의 동물플랑크톤 군집

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요 약

동물플랑크톤 군집 패턴은 그들이 존재하는 곳의 해황 조건에 영향을 받는다. 동물플랑크톤 군집은 2019 년 1 월 남극 로스해 빙붕의 14 개 정점에서 조사되었다. 동물플랑크톤은 링 네트(망구 1 m, 망목 330 μm)와 봉고네트(망구 0.6 m, 망목 505 μm)를 사용해 저층부터 표층까지 채집되었다. 수온, 염분, 그리고 Chl-*a* 농도는 모든 정점에서 동시에 측정되었다. 해수면 온도는 -0.15℃에서 0.12℃, 저층 온도는 -1.88℃에서 0.87℃의 범위를 보였다. 염분은 33.9 에서 34.7 psu 범위를 보였으며, 조사 정점 간 Chl-*a* 농도는 0.31 에서 1.58 $mg.m^{-3}$을 보였다. 조사 기간 동안 총 49 개의 분류군에 속하는 138 종이 확인되었으며, 평균 밀도는 130 $ind.m^{-3}$ 에서 2,167 $ind.m^{-3}$ 이었다. 요각류가 전체 동물플랑크톤 밀도의 36%를 차지하며 우점하였다. *Calanus propinquus, Calanus* spp. copepodites, *Metridia* spp. copepodites, *Metridia gerlachei*, Eucalanidae spp. copepodites, *Oithona* spp. copepodite, *Muggiacea* spp., *Conchoecia* spp., Gammaridae spp. juvenile, 그리고 *Euphausia superba* 가 우점종이었다. 본 연구는 우점종들의 밀도와 해수면 온도, 염분, 그리고 Chl-*a* 농도 사이에 유의미한 관계가 존재하지 않음을 나타낸다.

Keyword: 동물플랑크톤, 밀도, 해황, 로스해, 남극해

1. Introduction

Ross Sea is a deep bay of the Southern Ocean located over the Antarctic continental shelf from 170°E to 158 °W, and has been characterized as being the most productive area of the Southern Ocean (Arrigo *et al*., 2008; Smith and Comiso, 2008). The circulation of the Ross Sea is dominated by a strong westward current whose flow is strongly influenced by three submarine ridges that runs approximately in southwest-northeast direction (Dinniman *et al*., 2003). It is one of the seas on Earth that remains relatively unaffected by human activities (Ballard *et al*., 2012). It has low pollution and introduction of invasive species. It has nutrient laden water, which supports an abundance of zooplankton (Tremblay and Smith, 2007).

Zooplankton is a critical component of ecosystem, plays a vital role in energy transfer, and serves as a basic food source for larvae and juvenile fishes in the marine ecosystem (Campbell *et al*., 2009; Saiz and Calbet, 2011; Steinberg and Landry, 2017). The overall biomass of zooplankton in the Ross Sea may be exceptionally low when compared to other Antarctic systems. Total zooplankton biomass in the Ross Sea was < 1 % in the Croker Passage of the Antarctic Peninsula (Deibel and Daly, 2007) due to intense predation pressure by the Antarctic krill and Antarctic silverfish (Ainley *et al*., 2007, 2015). Low biomass in Ross Sea is due to the temporal decoupling of primary and secondary production (Tagliabue and Arrigo, 2003). In addition to its low abundance, zooplankton community of the Ross Sea is of low diversity and low reproduction rates (Knox *et al*.,1994). In Ross Sea, herbivorous mesozooplankton are mainly represented by *Calanus propinquus* and *Calanoides acutus*, while Antarctic Krill (*Euphausia superba*) and the mollusk (*Limacina helicina*) are the major mesozooplankton species (Hecq *et al*., 2000). *Metridia gerlachei* and *Oithona similis* are the other dominant species to fulfill the bulk of zooplankton in Ross Sea, Antarctica (Hecq *et al*., 2000).

Pattern of zooplankton community is greatly influenced by the hydrographic condition where they live. Changes of environmental parameters such as water temperature, salinity, Chl-*a* concentration and water current can influence zooplankton communities and distribution (Hirakawa *et al*., 1995). The hydrographic and biological conditions of the Ross Sea are dominated by meteorology (temperature and wind) through its sea-ice dynamics (e.g., advection, formation, and melt) and upper-ocean stratification. In the Southern Ocean, seawater temperature and variability in sea-ice extent are increasing day by day (Bracegirdle *et al*., 2008; Turner *et al*., 2014) although magnitude and direction of environmental changes differ among regions around Antarctica. It is predicted that zooplankton communities and distribution are very much influenced by these changes (Constable *et al*., 2014).

Although zooplankton are the most important factor in regulating food web dynamics in Ross Sea (Wallis *et al*., 2016) but surprisingly, there are few studies about zooplankton abundance and distribution in Ross Sea. The aims of this study were to investigate zooplankton community in Ross Sea, Antarctic Ocean in Austral summer and to understand relationship between zooplankton community and environment conditions in Ross Sea.

2. Materials and methods

2.1. Sample site and methods:

The study area is located from 71º75'-73º58'S to 170º65'-175º44'E in Ross Sea, Antarctica. Zooplankton were collected at 14 stations during January 2019 (Fig. 1) by using Ring Net (1 m diameter with 330 μm mesh) and Bongo Net (0.6 m diameter with 505 μm mesh) from near the bottom to the surface. A flowmeter was mounted in the mouth of the net to register the volume of water filtered. Collected zooplankton was poured into a bottle with water and was frozen immediately.

Profiles of water temperature, salinity, Chl-*a* concentration were simultaneously recorded during zooplankton sampling at each station by deploying a SeaBird SBE911 plus CTD which was mounted on a SeaBird resette sampler (Bestley *et al*., 2018).

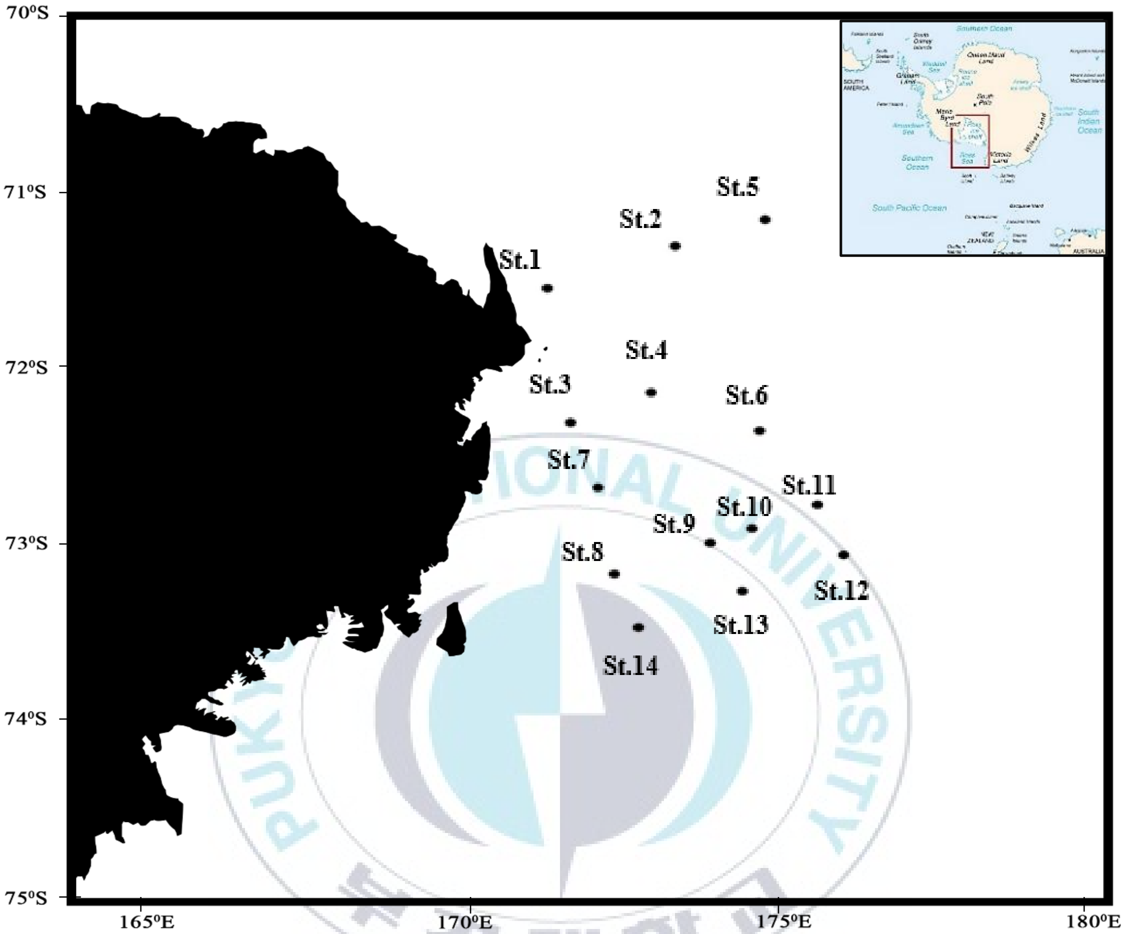

Fig.1. Location of sampling stations in Ross Sea, Antarctic Ocean.

2.2. Analysis of samples:

Zooplankton analysis

Before biomass determination, the percentage of zooplankton and non-zooplankton was estimated with naked eyes. Then the total zooplankton volume was determined by using settling bottle method. The samples were poured into graduated cylinder of 50-100 ml, and then sieved by a smaller mesh size (smaller than the net used to collect the samples). The water volume was obtained in the measuring jar. Finally, zooplankton volume was determined by the subtraction of the sample volume and obtained water volume in the measuring jar. Standing stock values were converted into per cubic meter and was calculated as follows:

$$\text{Volume of zooplankton (ml/m}^3\text{)} = \frac{\text{Total volume of zooplankton (ml)}}{\text{Volume of water filtered (m}^3\text{)}}$$

Zooplanktons were identified and counted to species level under a dissecting microscope (Olympus SZX2-ILLK) after dividing into different groups with a Motoda type splitter. Counting was done by using Bogorov counting tray.

2.3. Data analysis

Variation of zooplankton community was analysed in terms of species richness, Shannon diversity index of zooplankton, and evenness index. Community patterns were explored by using Primer (Version 6.1.12) to know the patterns in zooplankton communities. A dissimilarity between all sampling stations was constructed by using Bray-Curtis Cluster Analysis based on differences in the percentage composition of the dominant species (Bray and Curtis, 1957). Stations were plotted on a two-dimensional ordination plot using Non-metric Multidimensional Scaling (nMDS) method (Kruskal and Wish,1982; Ludwig and Reynolds, 1988) to estimate similarity (and dissimilarity) in zooplankton community structure among stations. SIMPER analysis was applied to estimate the difference of zooplankton community between groups. In addition, horizontal structure of hydrography was determined by using SURFER v10 programs.

3. Results

3.1. Environmental conditions:

Sea surface temperature in Ross Sea are chilling (-1.5°C), deep water has temperatures as low as - 2·13°C but remain unfrozen because ocean's salty water lowers the freezing point. At 5 m depth water temperature at sampling stations was regarded as sea surface temperature (SST). SST varied with ranges from -0.15 to 0.12 °C. At 50 m depth, SST ranged from -0.35 to -1.74°C, -0.43 to -1.79°C at 100 m depth and -1.88 to 0.87°C at 200 m depth, respectively. Surface and bottom water temperatures were different. Seawater temperature decreases as depth increases (Fig. 2).

Salinity in Ross Sea ranges from 33 to 35 psu. The salinity was very similar in every sampling station, but depth wise salinity showed some differences. At 5 m depth, salinity varied from 33.9 to 34.3 psu; at 50 m depth, salinity was 34.2 to 34.5 psu; at 100 m depth, salinity ranges from 34.3 to 34.6 psu and at 200 m depth, salinity ranges from 34.5 to 34.7 psu (Fig. 3). Seawater was more saline as depth increases.

Chl-*a* concentration between sampling stations ranges from 0.31 to 1.58 $mg.m^{-3}$. Average Chl-*a* concentration was 1.13 $mg.m^{-3}$ (Fig.4).

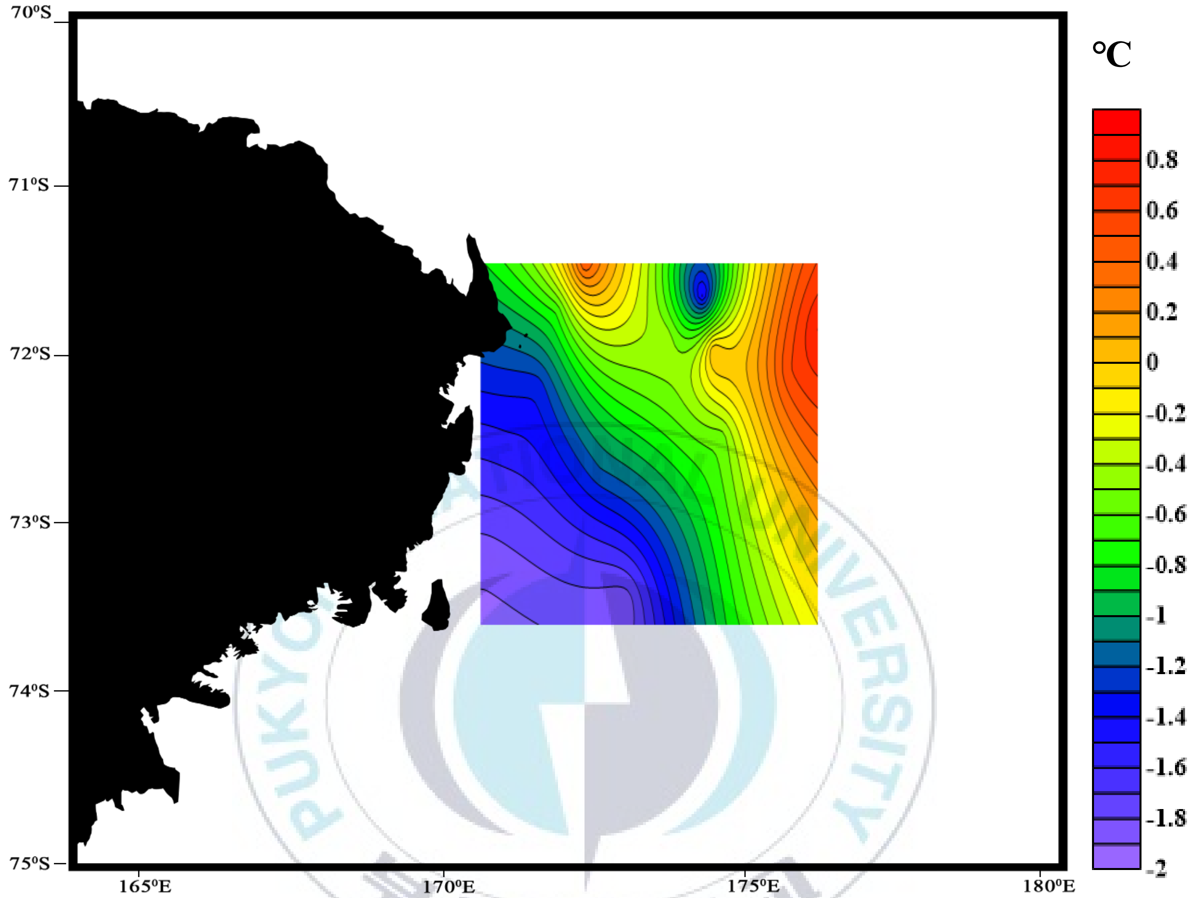

Fig.2. Horizontal distribution of temperature in Ross Sea, Antarctic Ocean.

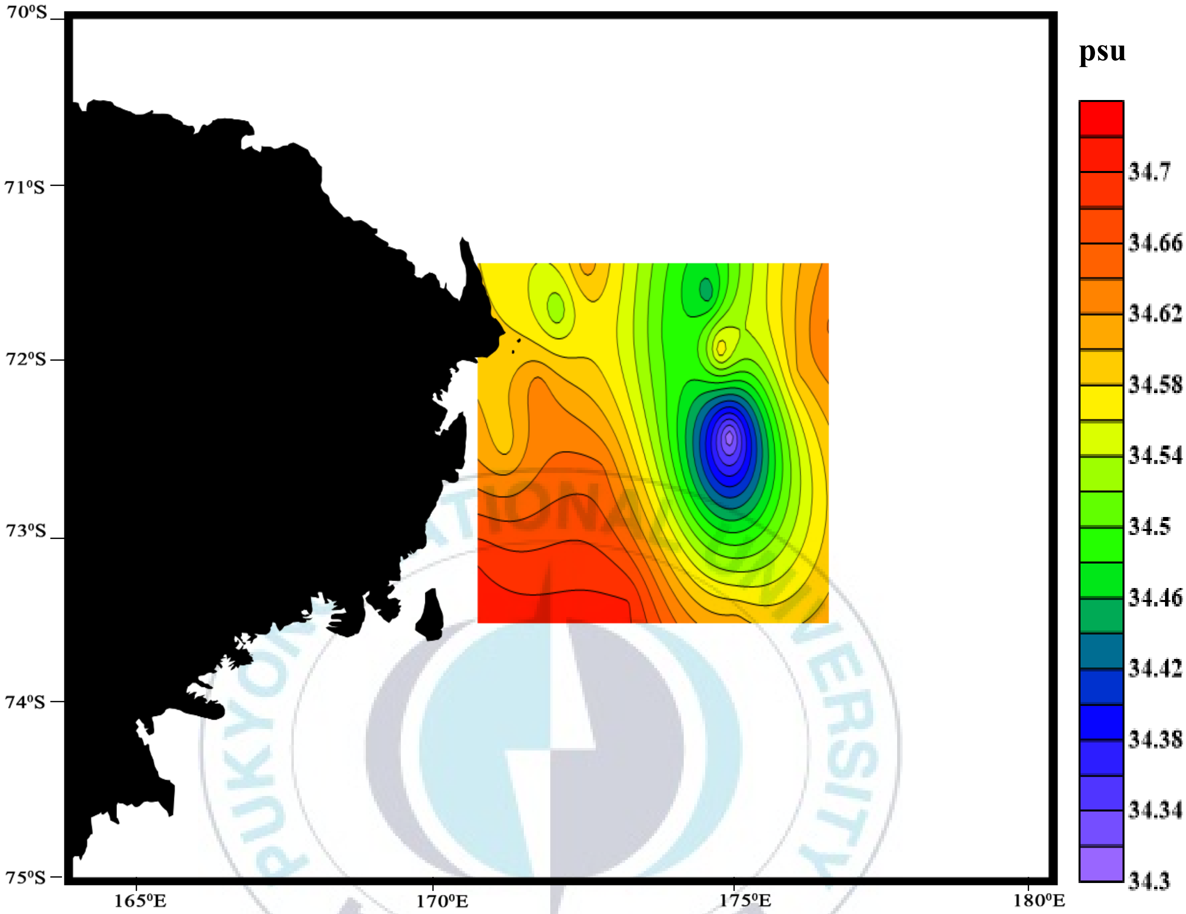

Fig.3. Horizontal distribution of salinity in Ross Sea, Antarctic Ocean.

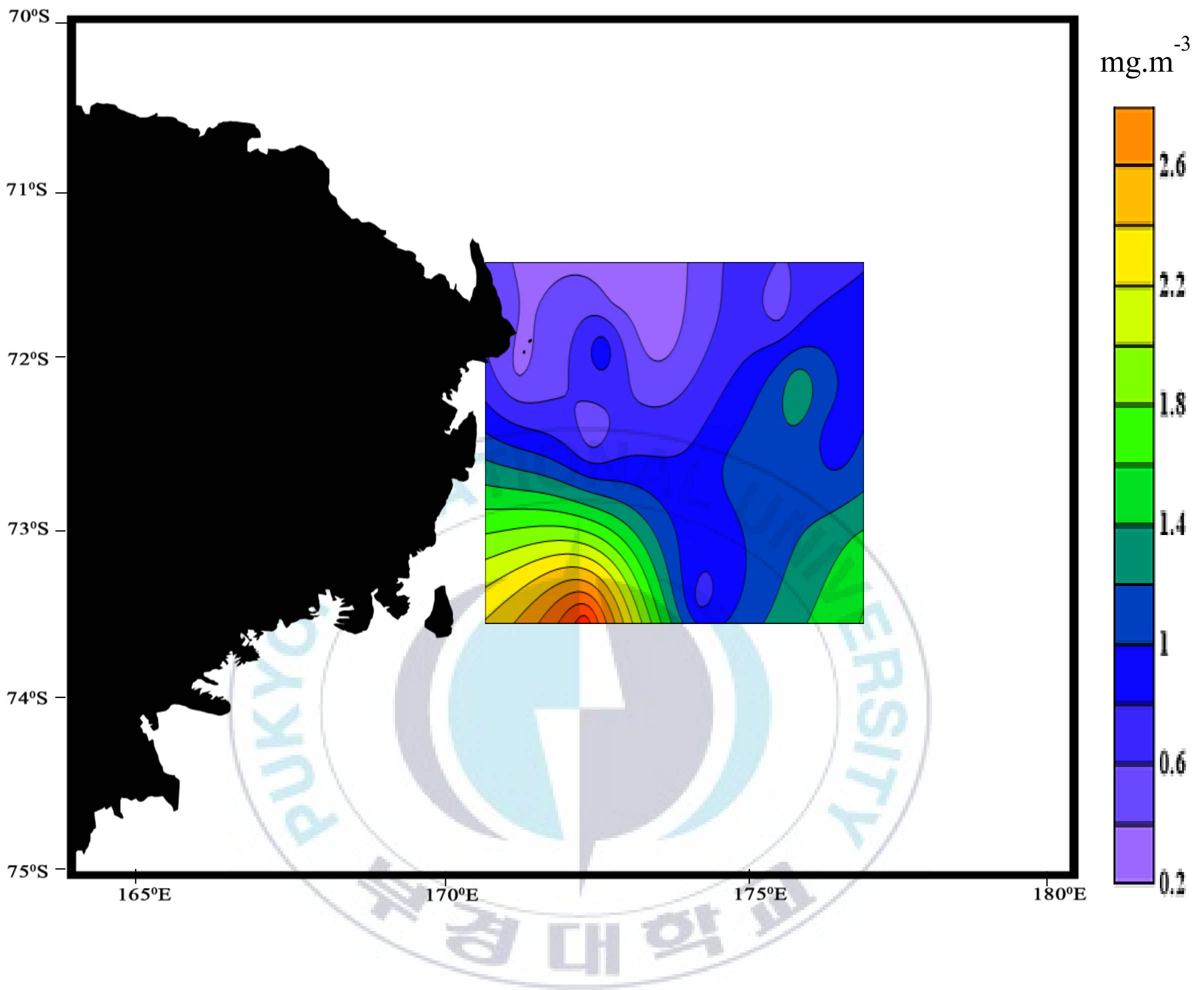

Fig. 4. Horizontal distribution of Chl-*a* concentration in Ross Sea, Antarctic Ocean.

3.2. Zooplankton community:

A total of 138 taxa belonging to seven phyla were identified during the study period. Total species number of zooplanktons varied with stations. The species number was highest at St.10, but zooplankton density was inversely related to species number. Highest zooplankton density was found at St.2 which was about 2,167 inds.m^{-3} (Fig.5); indicated that highest number of species was found in one station, but density was highest at another station.

Species richness was highest at St.5 (15.5) and lowest at St.6 (4.5). Evenness was highest at St.7 and lowest at St.1, respectively. Highest species diversity was found at St.5 and lowest at St.6 (Fig.6).

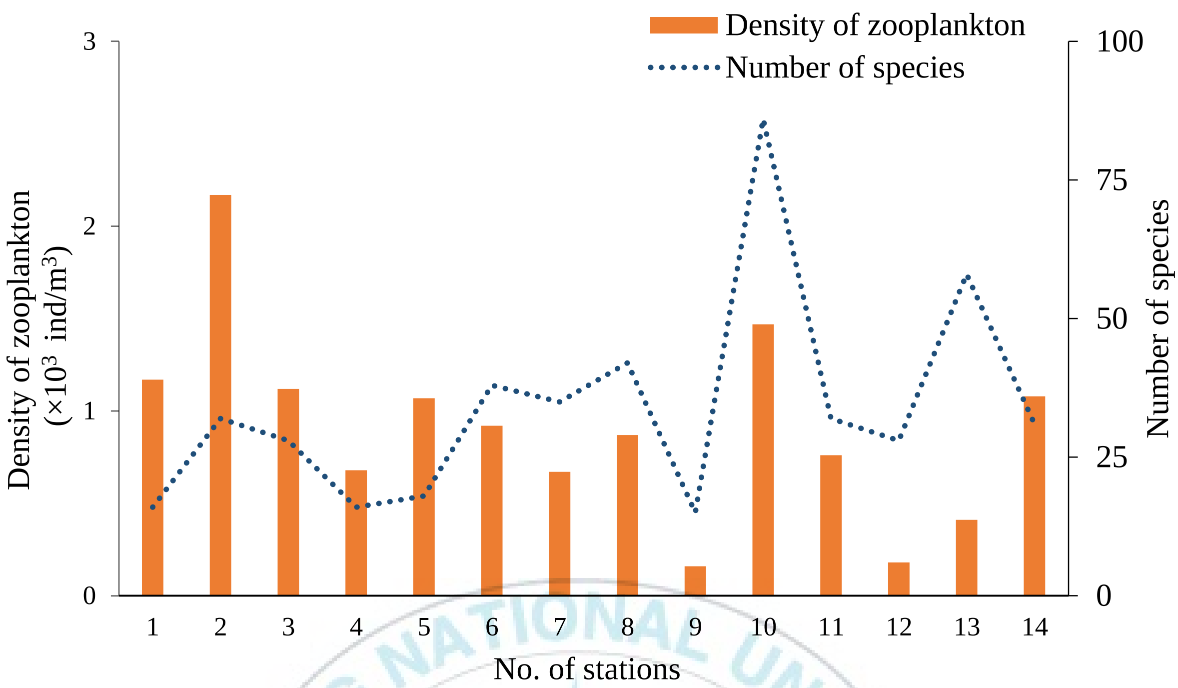

Fig.5. Density and number of species of zooplankton in Ross Sea, Antarctic Ocean.

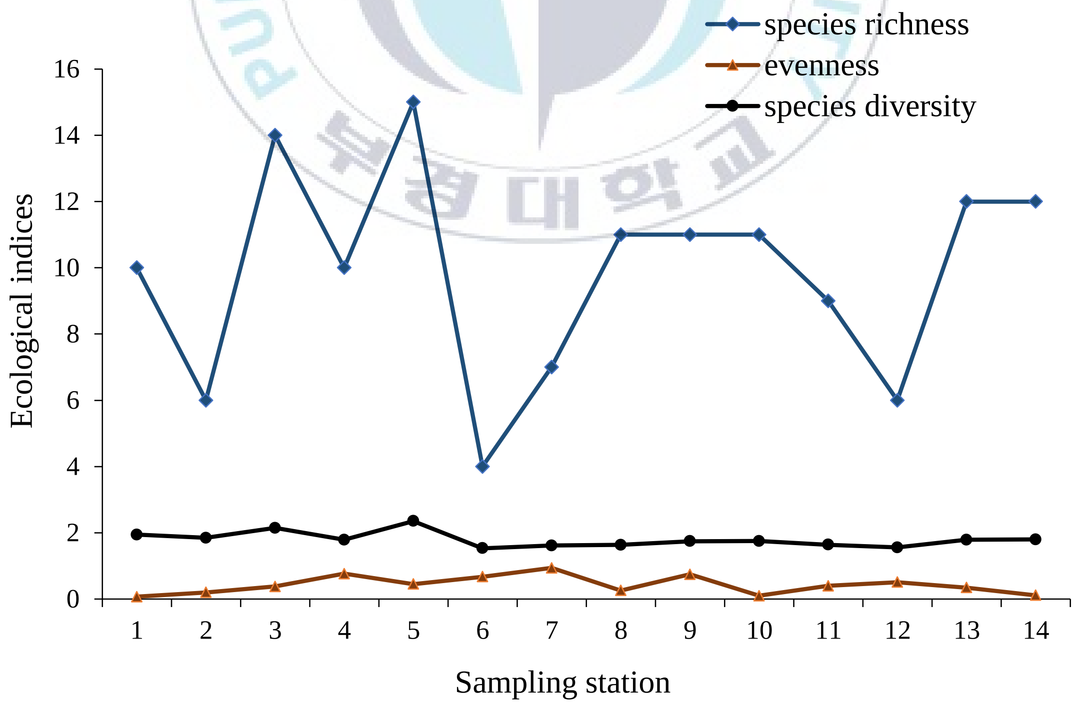

Fig.6. Diversity indices of zooplankton community in Ross Sea, Antarctic Ocean.

3.3. Multivariate analysis:

To quantify the similarities and dissimilarities from the study area and period, cluster analysis and 2-dimentional ordination plots from Non-metric Multidimensional Scaling (nMDS) were used on basis of zooplankton density. The cluster analysis based on the correlation coefficient of each station represented three different clusters with highest similarity of zooplankton community at St.13 and St.14 (73.3%), followed by St.4 and St.5, St.11 and St.12 with average similarity comprised 55.8% and 54.5%, respectively (Fig.7).

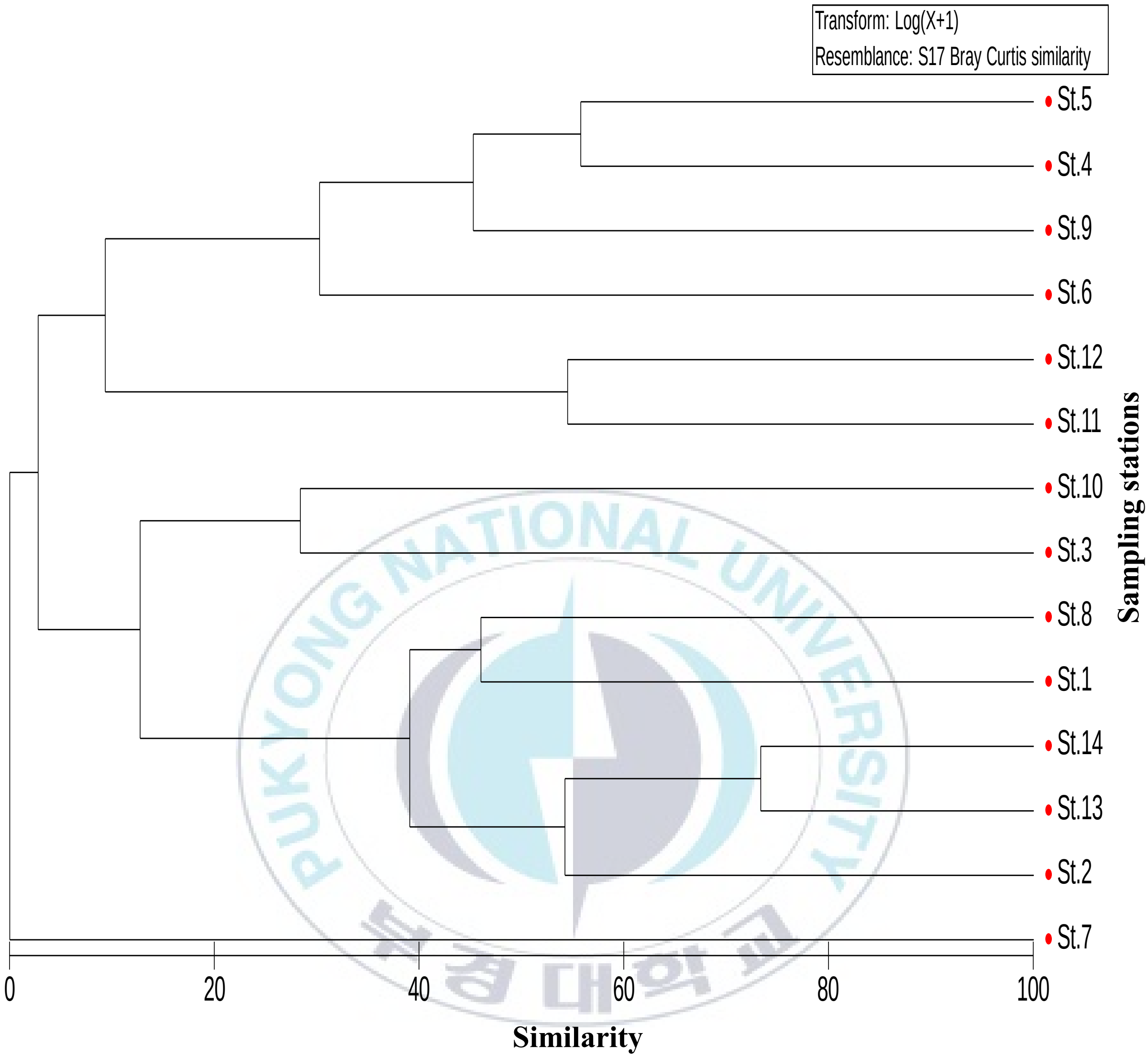

Fig.7. Clustering similarity of zooplankton density between stations in Ross Sea, Antarctic Ocean.

nMDS diagram showed closeness distance in all stations with percentage similarity 80%, except St.7 as it had highest evenness index (Fig.8). Stress co-efficient value in nMDS diagram was 0.13 (stress < 0.2) that means it is possible to interpret similarity between stations, but as the group is very small, ANOSIM analysis is not possible to interpret between stations. Analysis similarity percentage (SIMPER) indicated zooplankton community between groups were significant difference with average dissimilarity varied from 47.0% to 64.1% (Table 1).

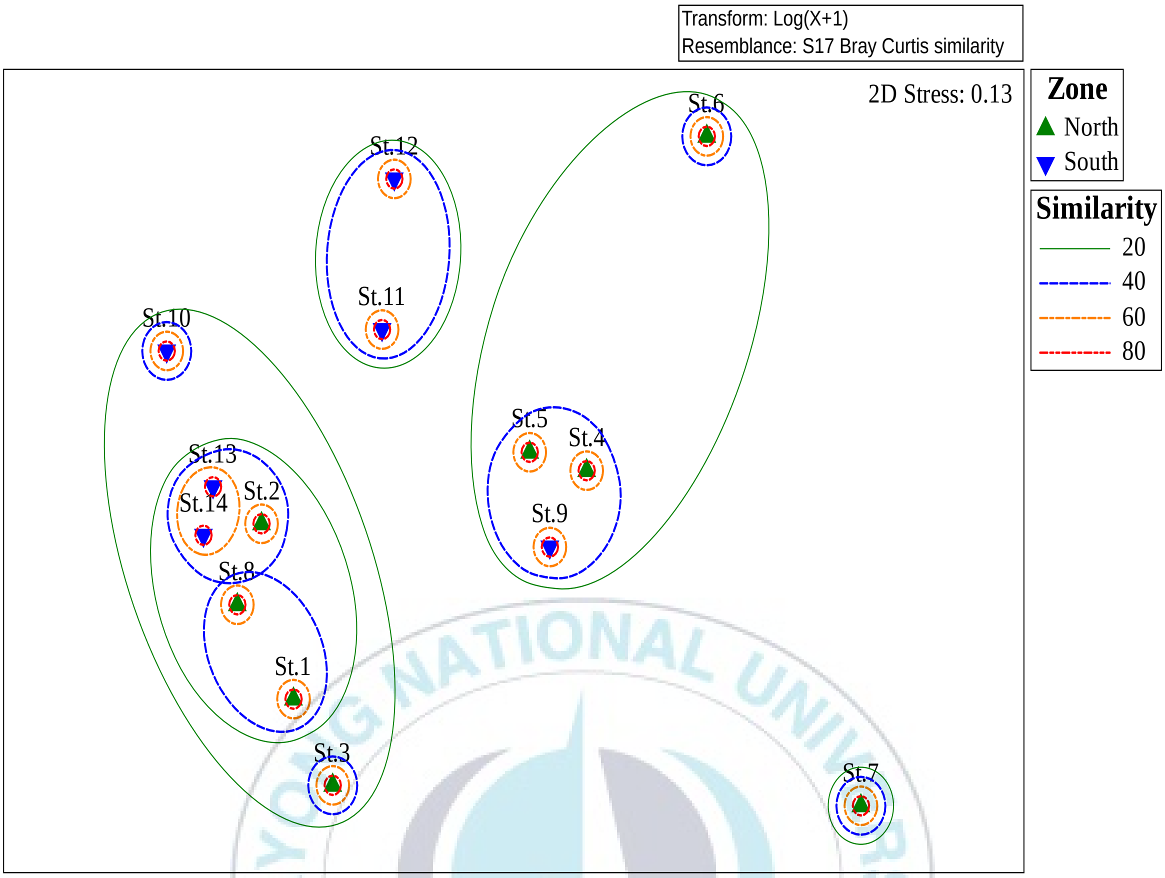

Fig.8. Non-metric multidimensional scaling (nMDS) of zooplankton density between stations.

Table 1: Summary of SIMPER analysis between locations

Group	SIMPER Average dissimilarity (%)
North-East	56.44
North-West	47.52
South-East	46.98
South-West	64.12

3.4. Distribution of dominant taxa:

Among the various groups of zooplankton examined, the following were dominant components of zooplankton population: Copepoda, Ostracoda, Cirripedia, Euphausiacea, Gastropoda, Cnidaria, Annelida and Amphipoda. Based on the proportion of zooplankton groups around Ross Sea, copepods were predominant throughout all stations comprising 36% of total zooplankton density, followed by Ostracoda (22%), Cirripedia (16%), Gastropoda (6%), Annelida (2%), Cnidaria (2%) and Amphipoda (1%), respectively (Fig.9).

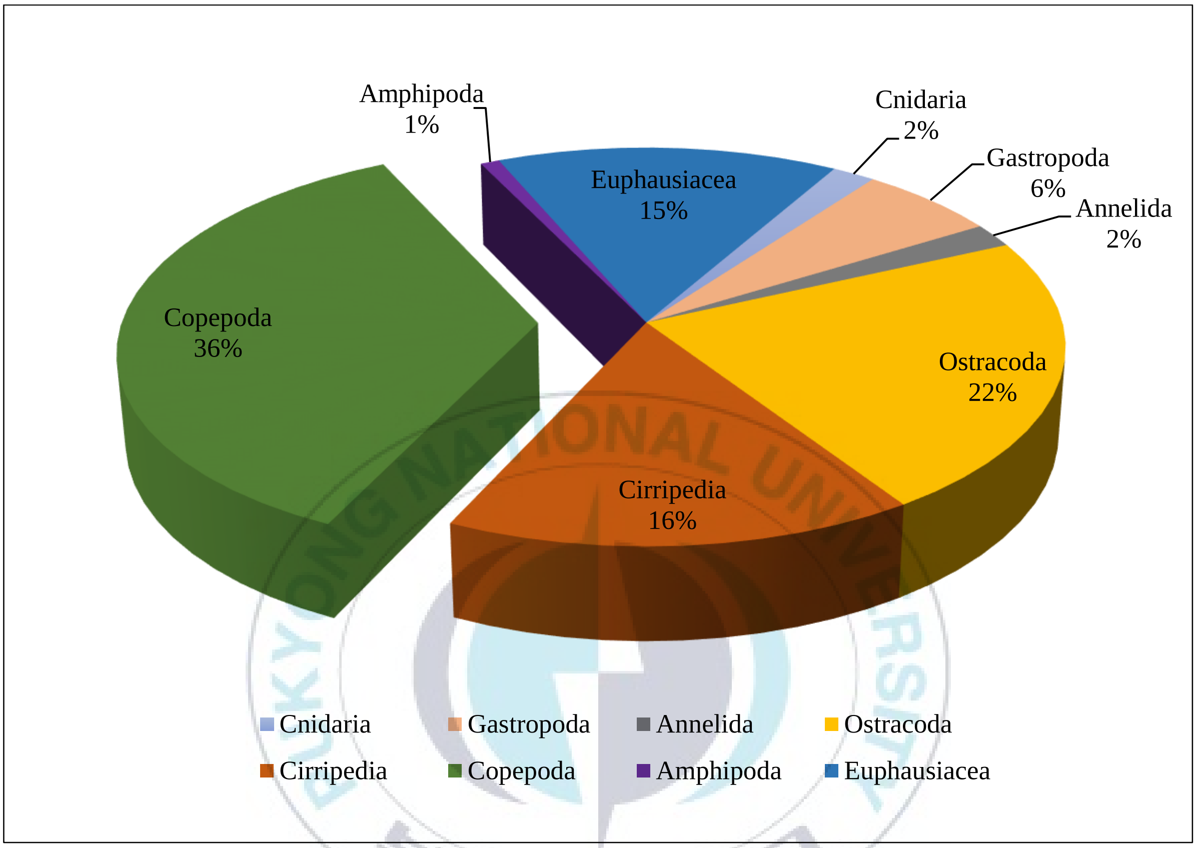

Fig.9. Composition of zooplankton mean density in the Ross Sea in January 2019.

Calanus propinquus, *Calanus* spp. copepodites, *Metridia* spp. copepodites, *Metridia gerlachei*, Eucalanidae spp. copepodites, Oithonidae spp. copepodite, *Muggiacea* spp., *Conchoecia* spp., Gammaridae spp. juvenile, and *Euphausia superba* were the dominant species.

Calanus propinquus was the most abundant species throughout all stations ranging from 10.5 to 406 inds.m^{-3}, and being constituted about 37% of total dominant zooplankton density (Fig.10). Density of *Metridia gerlachei* ranged from 10.0 to 153.4 inds.m^{-3} (18%), *Metridia* spp. copepodites ranges from 2.3 to 51.6 inds.m^{-3}(14%), *Calanus* spp. copepodite ranges from 0.0 to 36.7 inds.m^{-3} (12%), Oithonidae spp. copepodite ranged from 2.1 to 19.0 inds.m^{-3} (7%), *Conchoecia* spp. ranges from 0.0 to 16.5 inds.m^{-3} (6%) , Euchaetidae spp. copepodite ranged from 0.0 to 8.8 inds.m^{-3} (1%) respectively.

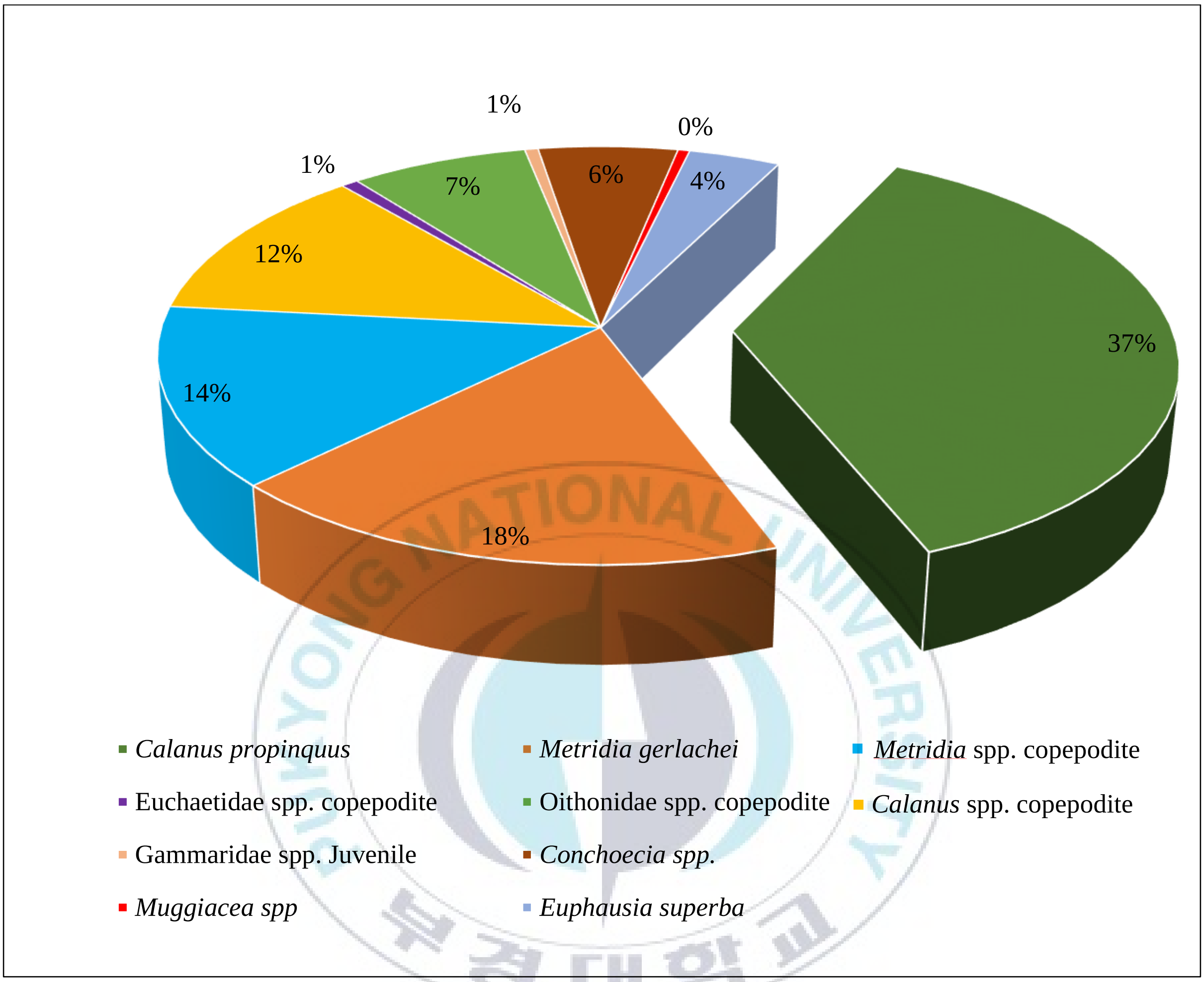

Fig.10. Percentage contribution of dominant zooplankton species in Ross Sea, Antarctic Ocean.

3.5. Distribution of zooplankton densities:

Zooplankton density varied with sampling stations. Zooplankton density was highest at St.2 (2,167 inds.m^{-3}); where temperature was -1.87°C, and lowest at St.6 (130 inds.m^{-3}); where the temperature was 0.61°C (Fig.11). Most of the stations had lower temperature, but had no negative impact on density of zooplankton. In salinity and Chl-*a* concentration, density of zooplankton has correlation but not more significant.

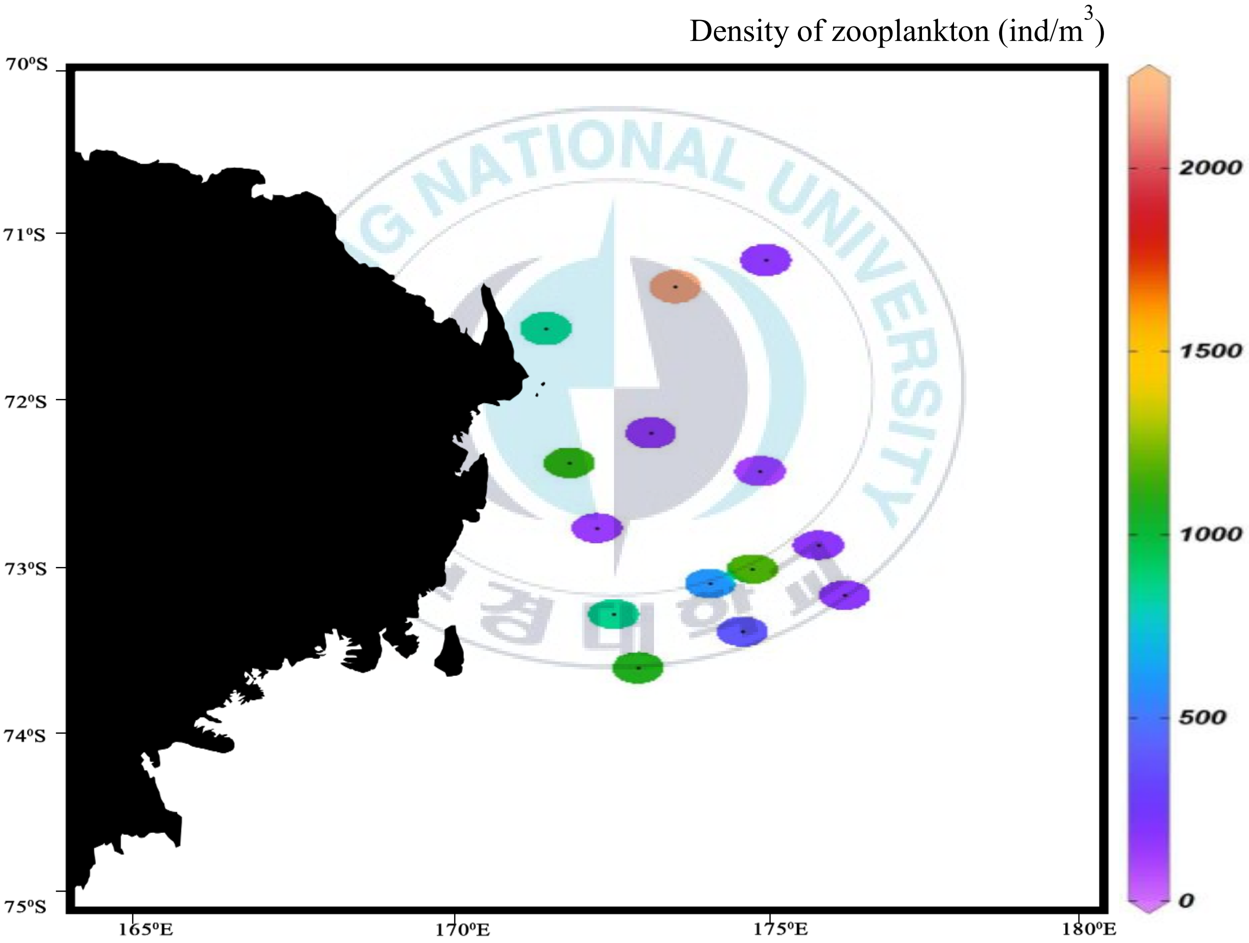

Fig.11. Distribution of zooplankton densities among sampling stations.

3.6. Correlation between environmental parameter and zooplankton:

Density of *Calanus propinquus*, Oithonidae spp. copepodite, Euchaetidae spp. copepodite, *Muggiacea* spp. were positively correlated with sea surface temperature (r = 0.11, 0.03, 0.12, 0.03; $p < 0.05$), but not more significantly. There was no significant relationship with salinity and Chl-*a* concentration ($p > 0.05$) (Table.2). For other dominant species, there were no significant relationship between density, sea surface temperature, salinity, and Chl-*a* concentration.

Table 2: Correlation between temperature, salinity, Chl-*a* concentration and the density of dominant species (Pearson correlation analysis)

Parameters	Temperature		Salinity		Chl-*a* conc.	
Density	***r***	***p***	***r***	***p***	***r***	***p***
Calanus propinquus	0.11	0.01	-0.25	0.39	-0.23	0.43
Calanus spp. copepodite	-0.21	0.01	-0.38	0.18	-0.31	0.27
Metridia gerlachei	-0.01	0.98	-0.26	0.34	-0.28	0.33
Metridia spp. copepodite	-0.08	0.77	-0.26	0.38	-0.29	0.32
Oithonidae spp. copepodite	0.03	0.01	-0.24	0.41	-0.15	0.61
Euchaetidae spp. copepodite	0.12	0.01	-0.08	0.77	-0.09	0.76
Gammaridae spp. juvenile	0.04	0.91	-0.07	0.81	-0.08	0.78
Conchoecia spp.	0.09	0.76	-0.21	0.56	-0.27	0.36
Muggiacea spp.	0.03	0.01	-0.24	0.48	-0.34	0.48
Euphausia superba	-0.07	0.88	-0.36	0.59	-0.24	0.54

4. Discussion

The abundance and biomass of zooplankton in the Ross Sea are extremely variable and overall biomass of zooplankton are comparatively low (Deilbel and Daly *et al*., 2007). In Ross Sea, zooplankton community and observed abundances remains between 120 and 360 inds.m^{-3} during summer (Stevens *et al*., 2015). Zooplankton assemblage was dominated by copepods during summer in Antarctic Ocean (Hopkins *et al*.,1987). Copepods dominated the zooplankton composition in west of the Antarctic Peninsula (Croker Passage), the northwestern Weddell Sea, and the southern Ross Sea, comprising averagely 78 and 90% of total abundance and biomass on February (Hopkins 1985, 1987; Hopkins and Torres 1988; Walker *et al*., 2017). In this study, results showed that copepods were predominant among zooplankton community.

Calanus propinquus, *Calanoides acutus*, *Metridia gerlachei*, *Rhincalanus gigas*, *Euchaeta antarctica*, *Euchirella rostromagna* were the dominant species of copepods during austral summer in Waddell Sea (Elliot *et al*., 2009 and Hopkins *et al*.,1987, Boysen-Enne *et al*., 1991). Present study coincided with this result in some extent. In present study, some species are not observed (*Rhincalanus gigas*, *Euchirella rostromagna* etc.) and most of the species were in copepodite stage because samples were collected in January, zooplankton grows faster in late March and April and reached larger body lengths.

At Croker Passage, *Euphausia superba* dominates the pelagic biomass, and subdominant species are *Metridia gerlachei, Calanoides acutus* and *Euchaeta antarctica* at 1000 m depths (Hopkins 1985). Compared to Ross sea, Crocker Passage has more diverse fauna because of geographical and hydrological consideration and inclusion of deep-water species. Abundance and biomass of zooplankton can vary due to several factors such as food availability (phytoplankton concentration), different growth rate etc (Deilbel and Daly *et al*.,2007). Overall zooplankton biomass in this study was comparatively low, because of having different growth rate, lack of large bodied zooplankton (Euphausiids) in samples, and also sample stations were relatively shallow similar to those of previous studies (Knox *et al*., 1996; Hicks *et al*., 1974). Zooplankton migrates to deeper region in order to protect themselves from visual predator and large zooplankton species were found in the deeper parts of Croker Passage on the Antarctic Peninsula (Hopken 1985; Foster *et al*.,1987; Pane *et al*.,2004; Smith *et al*.,2017). Therefore, there is a high chance of getting more zooplankton biomass in deeper parts of Ross Sea.

Distribution of zooplankton density was directly related with environmental factors (Liu *et al*., 2012). Increase or decreases of species number were regulated by temperature changes (Park *et al*., 1998). Temperature and depth play an important role in zooplankton distribution either vertical or, horizontal (Richardson *et al*., 2008). In present study, highest densities of zooplankton occurred at the stations, which is characterized by shallow depth water with lower temperature (Fig.11). Changes in species composition may have strong relationship with fluctuation of water temperatures (Hillebrand *et al*., 2012). Low temperature influences zooplankton composition and zooplankton were dominant by large species such as *Calanus* spp, *Metridia* spp, *Paraeuchaeta antarctica*, *Rhincalanus nasutus*, Euphausiids, *Themisto* spp. (Atkinson *et al*., 2004; Hopkin 1987), which also coincided with present study.

Sea-ice is the dominant feature of the Antarctic marine ecosystem (Meier and Stroeve, 2012; Comiso *et al*., 2003). In Ross Sea, temperature is on the average low, around 1 ºC (34 ºF) during the austral summer. Small copepods are abundant within the sea ice, while amphipods, copepods and euphausiids are abundant at the ice - water interface (Arndt and Swadling, 2006). These findings are similar to present study result as most of the stations had lower temperature; but had no negative impact on density of zooplankton. In case of salinity, density of zooplankton show correlation; but not more significant. Dominant species of present studies has been known to prefer to cold-water condition and known as indicator species of appearance in Ross Sea (Rivkin *et al*., 1991).

Largest phytoplankton bloom is dominated by *P. antarctica* in the southwestern part of Ross Sea that forms in spring and summer (late October or, early November) and Phytoplankton bloom that forms in summer (late December or, January) mainly dominated by diatoms (Arrigo and McClain, 1994) when sea-ice meltwater fluxes and solar isolation have increased sufficiently. In the McMurdo Sound, the bloom increases in size with over 5 $mg.m^{-3}$ Chl-*a* concentration throughout December then began to decline in January with Chl-*a* concentration falling below 1 $mg.m^{-3}$ in the southwest areas (Arrigo *et al*., 2004). In Ross Sea, average Chl-*a* concentration was 1.13 $mg.m^{-3}$ which is similar with the previous results.

This study indicated that, there was no correlation with zooplankton density, water temperature, salinity, and Chl-*a* concentration. The high species number, dominant taxa and high zooplankton density at lower temperature explains that water temperature have a positive correlation with zooplankton density and distribution but not more significant (Han *et al*., 1995). On the other hand, variance in salinity (33.9 to 34.7 psu) did not affect directly on density and distribution of zooplankton community in Ross Sea because all of these dominant species can tolerate wide range of salinity (euryhaline species). Further investigation is needed to better understand the zooplankton community in Ross Sea, Antarctic Ocean and to figure out relationships between zooplankton abundance and environmental parameter more accurately.

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