Ocean Sci. J. (2016) 51(3):447–454
http://dx.doi.org/10.1007/s12601-016-0040-x

Article

Available online at http://link.springer.com
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pISSN 1738-5261
eISSN 2005-7172

Distribution of Chaetognaths (Aphragmophora: Sagittidae) in Korean Waters

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Received 31 March 2015; Revised 11 May 2016; Accepted 14 July 2016

Abstract – The distribution of chaetognaths was investigated at 10 stations in the southern part of Korean waters (line S), at six stations in the eastern part of Korean waters (line E) and at 8 stations in the western part of Korean waters (line W). Ten species were present at the stations at line S and *Flaccisagitta enflata* and *Zonosagitta bedoti* were dominant among these species. Mean densities at line S ranged from 7 inds.m^{-3} to 27 inds.m^{-3}. Five chaetognath species were found at the stations at line E and *Zonosagitta nagae* and *Parasagitta elegans* were the most abundant. Mean densities ranged from 1 to 10 inds.m^{-3}. Four chaetognath species were present at line W and *Aidanosagitta crassa* and chaetognath juveniles were dominant in this line. Mean densities ranged from 21 to 199 inds.m^{-3}. The density of chaetognaths was highest at line W while the diversity of chaetognaths was highest at line S. Individuals of chaetognaths were divided into two groups, a group of line E and a mixed group of lines W and E. This study suggests that *F. enflata* is a warm water species; *Z. nagae* is a mixed water species; *P. elegans* is a cold water species; and *A. crassa* is a less saline water species. The mtCOI of *F. enflata*, which was a dominant species in the sampling area, was analyzed. *F. enflata* that are present in waters around Korean were genetically divided into two groups, which may be influenced by various oceanic factors.

Key words – chaetognaths, distribution, Korean waters, genetic group

1. Introduction

Chaetognaths are well known as important constituents in most marine planktonic communities because they are primary predators of copepods and play a role in the transfer of energy from copepods to higher trophic levels (Alvariño 1990; Bone et al. 1991). The abundance of chaetognaths is often second to copepods among marine zooplankton (Gibbons 1992; Shannon and Pillar 1986).

Chaetognaths are distinctively affected by hydrographic conditions such as salinity, temperature and dissolved oxygen with their species-specific horizontal and vertical distribution (Pierrot-Bults 1991; Terazaki and Miller 1986). As a result, chaetognaths are used to categorize water masses (Johnson 2003). Water masses in the ocean may be indicated by a biological indicator, namely a dominant species (Ohnishi 2014). In Korean waters, dominant species were *Aidanosagitta crassa* in the Yellow Sea, *Flaccisagitta enflata* in the southern sea of Korea, and *Aidanosagitt elegans* in the East/Japan Sea (Park 1970).

The Korean peninsula is surrounded by three water areas. The East/Japan Sea is influenced by the warm and saline Tsushima Warm Currents (TWC), a branch of the Kuroshio Current and the North Korea Cold Current, a branch of the Liman Current. The East China Sea is influenced by the TWC. In summer, the southern sea of Korea appears less saline because of the Yangtze river carries freshwater into the East China Sea. Moreover in Yellow Sea, fresh water from river in mainland of China was transported by Kuroshio Current (Oh and suh 2006; Jang et al. 2012).

Flaccisagitta enflata is an epiplanktonic species of temperate and tropical waters. It occurs in both open and coastal Korean waters. Various currents and oceanic features on all sides of the Korean peninsula could be effect genetic population of *F. enflata*.

The aim of this study is to investigate (1) the abundance and composition of chaetognaths, (2) the horizontal distribution patterns of chaetognaths in relation to or correlated with water masses and (3) the distribution of *F. enflata* based on genetic group.

2. Materials and Methods

Sampling was carried out at 16 stations in August 2013

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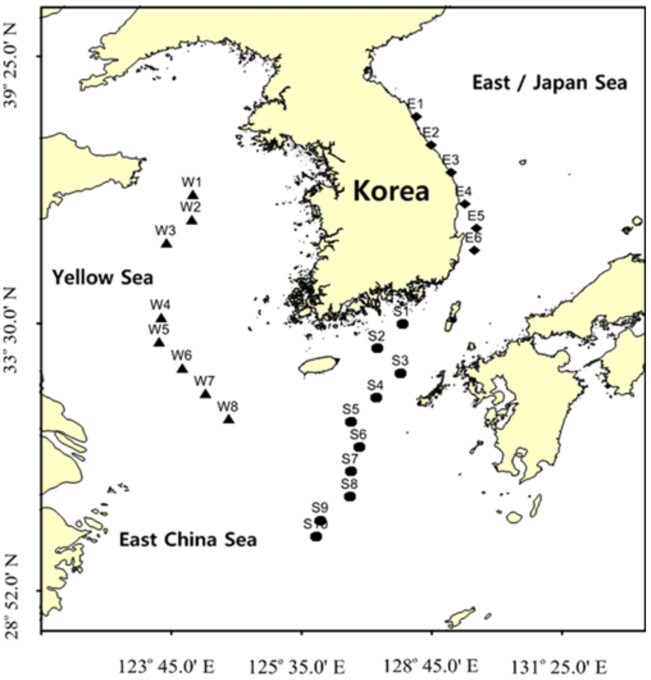

Fig. 1. Sampling stations in Korean waters. Each symbol indicate sampling areas of the southern part (●) and eastern part (◆) of Korean waters in August 2013 and western part (▲) of Korean waters in August 2014

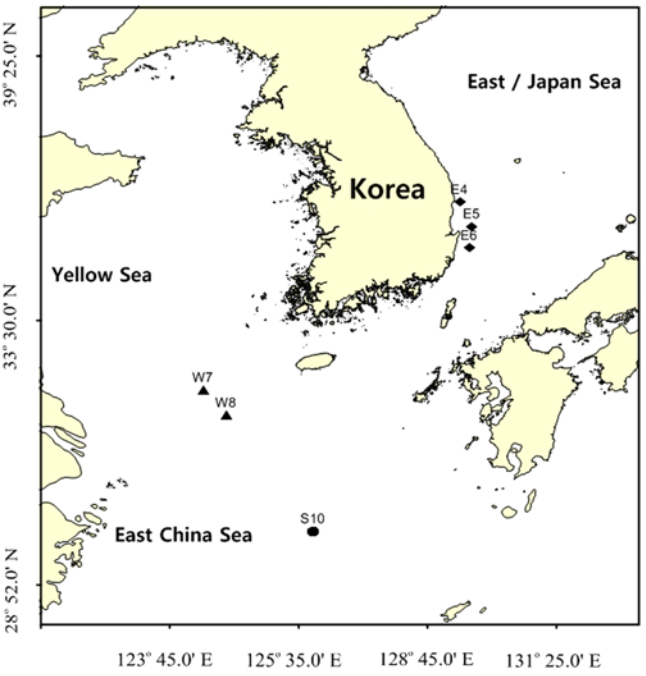

Fig. 2. Sampling stations where the individuals of *Flaccisagitta enflata* for mtCO1 analysis was collected

and at 8 stations in August 2014 along three lines (Fig. 1); line S (10 stations in the southern part of Korean waters), line E (6 stations in the eastern part of Korean waters), and line W (8 stations in the western part of Korean waters).

Zooplankton were obliquely collected using a Bongo net and RN80 with a mesh size of 333 μm. Samples were immediately fixed with 70% alcohol. Chaetognaths were identified to species level under a stereomicroscope with the aid of previous literature on the subject (Chihara and Murano 1997; Park 1970; Kim 1987). Water temperature and salinity from the surface to the maximum sampling depths were measured using a CTD. Spearman rank correlation coefficient was used to compare the surface water temperature, surface water salinity and the densities of dominant chaetognaths.

Flaccisagitta enflata was found at 6 stations in August 2013 and 2014 (Fig. 2). Genomic DNA of 13 *F. enflata* was extracted using an AquaPrep Genomic DNA extraction kit (Bioneer). Cytochrome *c* oxidase subunit I gene (COI) was amplified by polymerase chain reaction (PCR) using universal primers (Folmer et al. 1994). Each PCR of 30 μl total volume contained 10X EX buffer 3 μl, 2.5 mM dNTP 2 μl, forward primer 10p mole 1 μl, reverse primer 10p mole 1 μl, Taq polymerase (TAKAR, Japan) 0.2 μl, template DNA 4 μl, distilled water 18.8 μl. Amplification was conducted in a PTC-200 thermocycler (MJ RESEARCH) with the following profile: initial denaturation at 94°C for 5 min, followed by 40 cycles of denaturation at 94°C for 30 s, annealing at 42°C for 30 s, extension at 72°C for 1 min, followed by final extension at 72°C for 5 min. The products were analyzed using electrophoresis (Major science, USA) in 1% agarose gel. Sequence alignments were lined up using the Genedoc program. All sequences were verified by BLAST searching GenBank. Multiple alignments for genes

Table 1. GenBank accession number of Phylum Chaetognatha analyzed for this study

No.	Species	Accesion number	Sampling location	No.	Species	Accesion number	Sampling location
1	Flaccisagitta enflata	KF977332 KF977331	China Sea	2	Flaccisagitta hexaptera	JN258018 JN258019	Indian Ocean
		JN258010 JN258011 JN258012	Indian Ocean				
		GQ368400	Antarctic Peninsula Atlantic Sargasso Sea				

were made using Clustal W program. The phylogenetic tree was performed using the MEGA 5 program (Tamura et al. 2013).

To plot a genetic tree among allied species, GeneBank nucleotide sequence data base of *Flaccisagitta enflata* was utilized (Table 1).

3. Results

The highest surface water temperature was shown at line S (~29°C), while the lowest temperature was observed at lines E and W. Bottom temperature was lowest in line E and partial cold water was found in line W (Fig. 3). Surface salinity was lowest in lines S and W. Bottom salinity was approximately 34.6 psu in line S and lowest in line W (Fig. 4).

A total of 14 species of chaetognaths were present (Table 2). The species number was highest in line S while it was lowest in line W. The density was highest in line W (21.3–199.3 inds.m^{-3}), but lowest in line E (0.27–10.4 inds.m^{-3}) (Fig. 5).

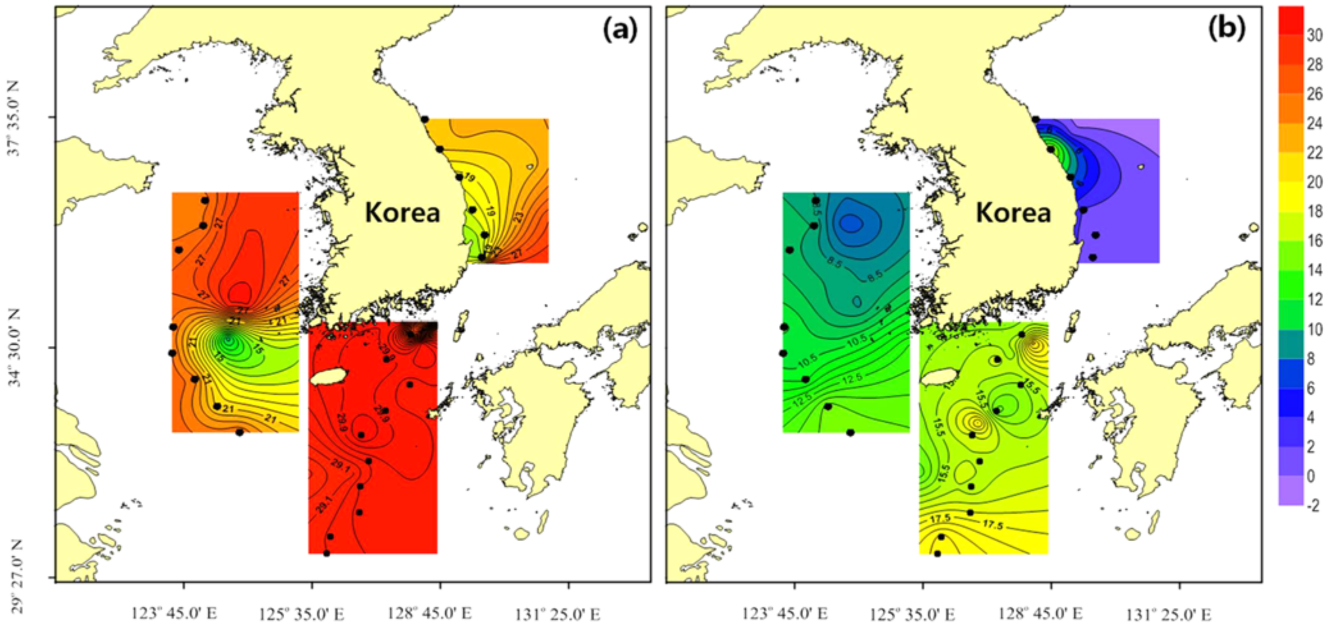

Fig. 3. Horizontal distribution of temperature at the surface and bottom layers in August 2013 and 2014 (a) Surface, (b) Bottom

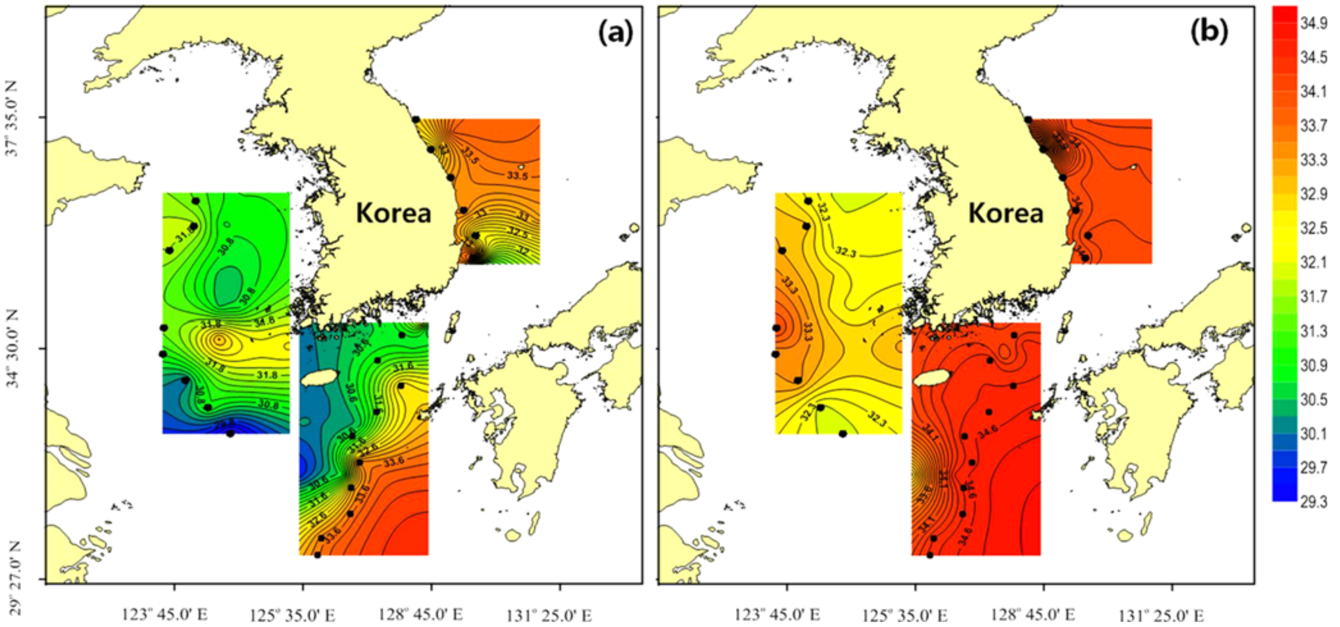

Fig. 4. Horizontal distribution of salinity at the surface and bottom layers in August 2013 and 2014 (a) Surface, (b) Bottom

Table 2. Mean density and composition of chaetognath species in the lines S and E in August 2013 and W in August 2014

	Mean density (inds.m^{-3})			Composition (%)		
	Line S	Line E	Line W	Line S	Line E	Line W
Flaccisagitta enflata	12.9	< 1	1.3	85.4	5.6	1.0
Aidanosagitta crassa	< 1	/	83.3	0.7	/	68.7
Parasagitta elegans	/	1.3	/	/	2.6	/
Zonosagitta nagae	/	2.4	3.4	/	43.7	2.8
Bathysdella edentata	< 1	/	/	/	/	/
Flaccisagitta hexptera	< 1	/	/	0.6	/	/
Ferosagitta ferox	< 1	/	/	1.3	/	/
Pterosagitta draco	< 1	/	/	2.3	/	/
Sagitta bipunctata	< 1	/	/	< 1	/	/
Serratosagitta pacifica	< 1	/	/	0.13	/	/
Zonosagitta bedoti	< 1	/	/	2.9	/	/
Pseudosagitta lyra	/	< 1	/	/	/	/
Chaetognath spp. juvenile	< 1	1.5	33.2	4.7	27.1	27.4

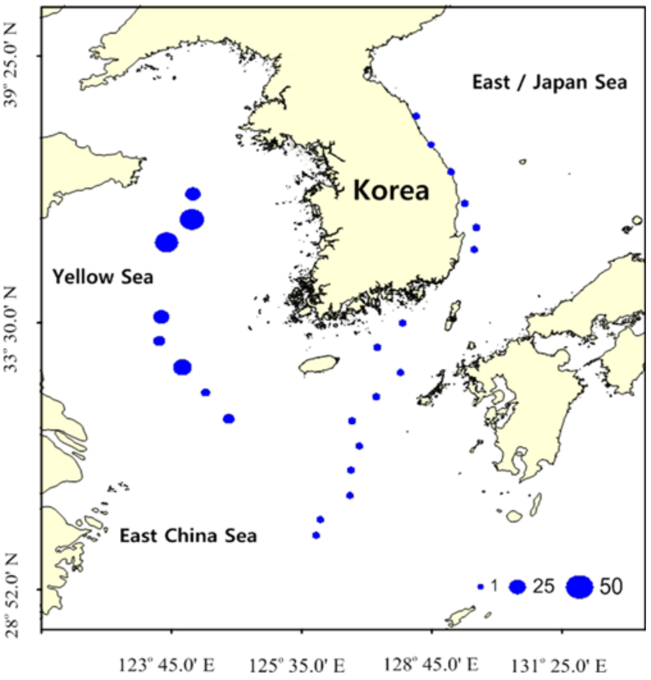

Fig. 5. Horizontal distribution of chaetognath densities (inds.m^{-3}) in Korean waters in August 2013 and 2014

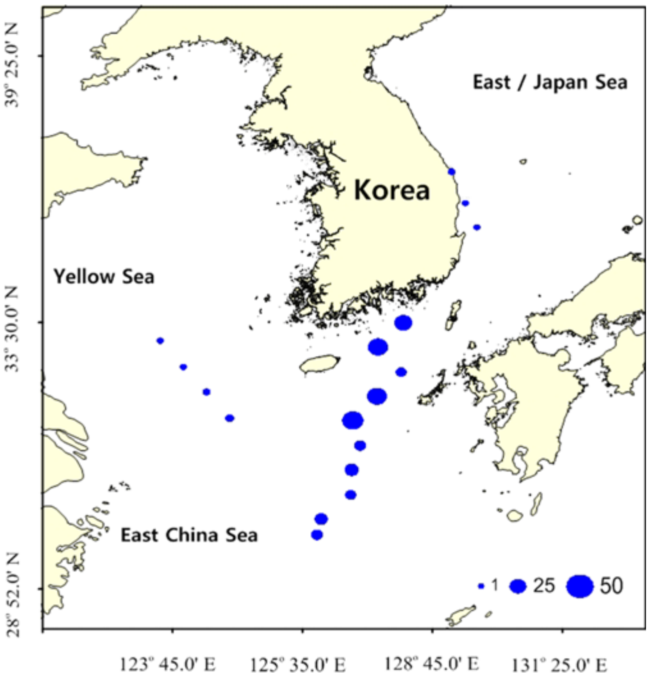

Fig. 6. Distribution of *Flaccisagitta enflata* in the lines S and E in August 2013 and W in August 2014

Flaccisagitta enflata was the most dominant species and occurred in all lines. *F. enflata* was most abundant at line S (Fig. 6). During the entire study period, mean densities ranged from 0.31–12.93 inds.m^{-3}. *Zonosagitta nagae* was the second most dominant species with density ranges from 2.43 to 3.36 inds. m^{-3} and occurred in lines W and E with the highest density at station W8 (Fig. 7). *Parasagitta elegans* was the third most dominant species, but appeared only in line E. The mean densities of *P. elegans* during the study period ranged from 0.05 to 3.41 inds.m^{-3}. The densities were relatively higher at the higher latitudes of line E (E4, E5 and E6), but lower at the lower latitudes of line E (E1, E2, E3) (Fig. 8). The fourth most dominant species, *Aidanosatta crassa* manifested density ranges from 0.11 to 83.29 inds.m^{-3} and appeared at lines W and S. The highest density of *A. crassa* was at stations W2 and W3 (Fig. 9).

The density of *F. enflata* revealed a significant correlation

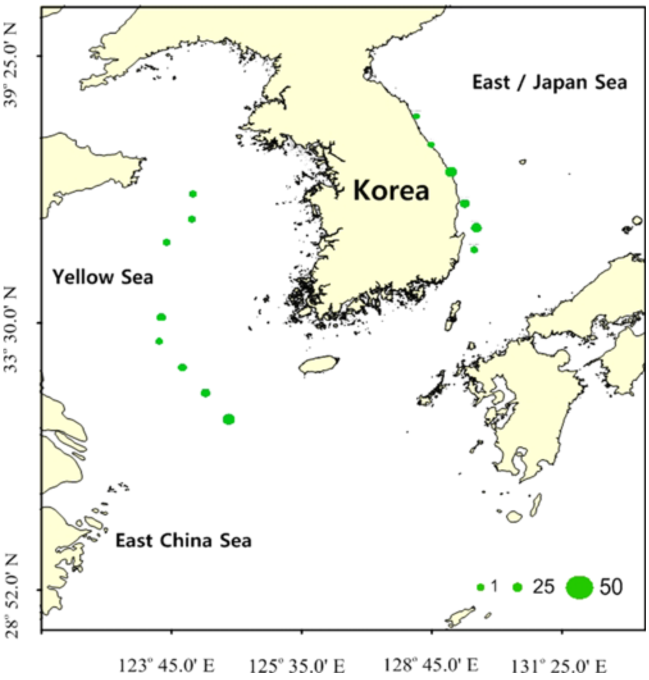

Fig. 7. Distribution of *Zonosagitta nagae* in the lines S and E in August 2013 and W in August 2014

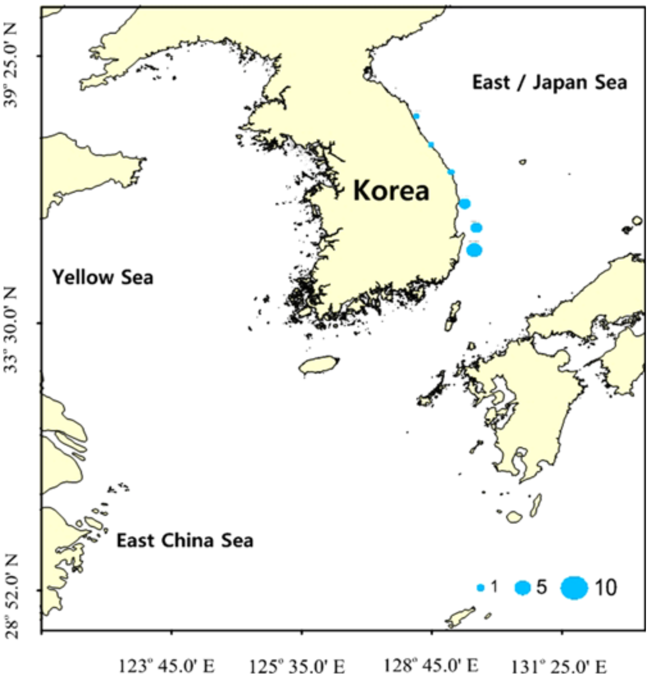

Fig. 8. Distribution of *Parasagitta elegans* in the lines S and E in August 2013 and W in August 2014

with temperature ($r = 0.717$; $p < 0.001$), while no significant correlation was seen with salinity ($r = 0.358$; $p > 0.05$). The density of *Z. nagae* was negatively correlated with temperature and salinity ($r = -0.571$; $p < 0.01$). The density of *P. elegans* revealed a negative correlation with temperature ($r = -0.648$; $p < 0.01$), while no significant correlation with salinity was found ($r = 0.179$; $p > 0.05$). The density of *A. crassa* was not correlated with temperature ($r = -0.16$; $p > 0.05$), but negatively correlated with salinity ($r = -0.641$; $p < 0.01$) (Fig. 10) (Table 3).

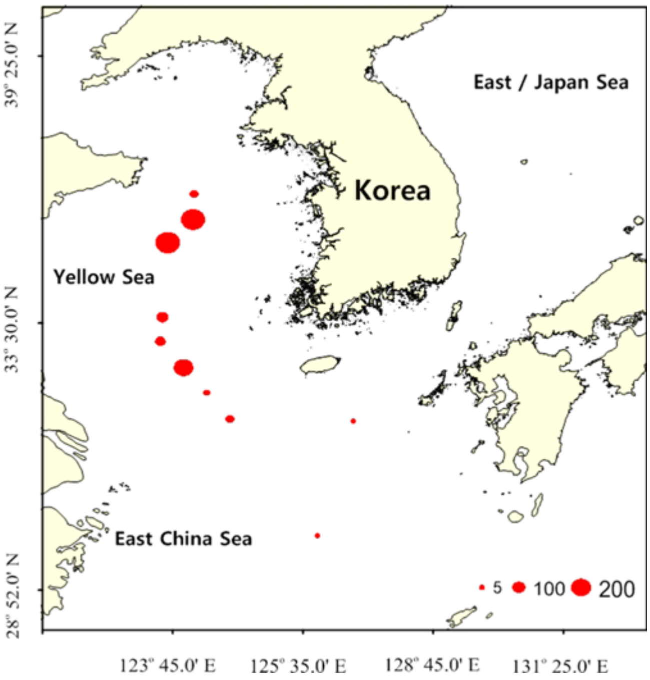

Fig. 9. Distribution of *Aidanosagitta crassa* in the lines S and E in August 2013 and W in August 2014

A PCR reaction was used to obtain a unique 700bp DNA fragment from the COI gene region. The data on the mtCOI sequence of *F. enflata* were compared with the registered sequence of allied chaetognath species in the NCBI GenBank. Sequences of several individuals of *F. enflata* in this study were significantly different from the registered outgroup in GenBank. On present study, *F. enflata* sequence was closely related with registered sequence of *F. enflata* in NCBI. The phylogenetic tree comprised two genetically different groups, a group of station E6 and a mixed group of stations E5, E4, E6, W7 and W8 (Fig. 11).

4. Discussion

The distribution of chaetognaths in Korean waters was previously indicated by Park (1970). Three species were defined separately as an indicator species of water masses in Korean

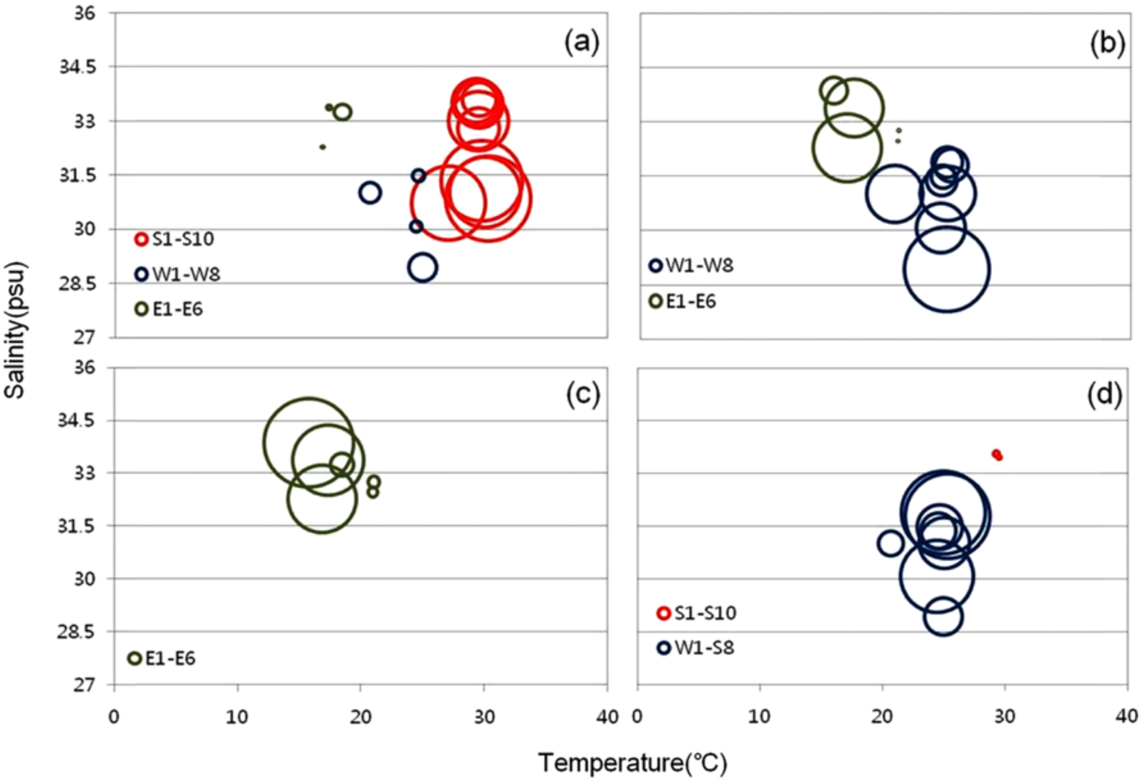

Fig. 10. Temperature and salinity diagram showing the distribution of chaetognaths in study area in August, 2013 and 2014

Table 3. Result of Spearman rank correlation coefficient between dominant species and environmental factors in Korean waters in August 2013 and 2014

Parameters	Temperature		Salinity	
	r	p	r	p
Flaccisagitta enflata	0.717	< 0.001	0.358	> 0.05
Zonosagitta nagae	-0.571	< 0.01	-0.536	< 0.01
Parasagitta elegans	-0.648	< 0.01	0.179	> 0.05
Aidanosagitta crasaa	-0.160	> 0.05	-0.641	< 0.01

waters because their densities were relatively higher at defined water mass levels.

Flaccisagitta enflata is a temperate and warm water species, which is distributed in the Indian Ocean, the Atlantic Ocean and the Pacific Ocean (Tse et al. 2007; Pierrot-Bults 1991).

It is usually a dominant species in warm waters. In the central Equatorial Pacific, influenced by warm waters such as the North Equatorial Current and the South Equatorial Current, *F. enflata* was most abundant, comprising 32.4–61.1% of the chaetognath total population (Terazaki 1996). Similarly, *F. enflata* was the most abundant chaetognath in the coastal sea of Hong Kong (39.7%) (Tse et al. 2007). It has been recorded as a dominant species which is distributed in warm and saline water in Korean waters (Park 1970). In this study, *F. enflata* was the most abundant species at line S, which is influenced by the Kuroshio Current, and a significant correlation with temperature was demonstrated. This result supports the hypothesis that the distribution of *F. enflata* is influenced by warm water such as the Kuroshio Current.

Zonosagitta nagae is an indicator species of a mixed water mass because they live in coastal waters or cold water affected regions (Tokioka 1959). *Z. nagae* is dominant with a high density (9.96 inds.m^{-3}) in Tosa Bay that is influenced by the Kuroshio Current and nearby coastal water (Naga et al. 2008). In the present study, *Z. nagae* appeared with high abundances in lines W and E. *Z. nagae* was distributed at lower temperatures and salinities and this coincided with studies conducted in Tosa Bay.

Parasagitta elegans is capable of enduring a wide range of temperatures. It appears in cold water masses with temperature

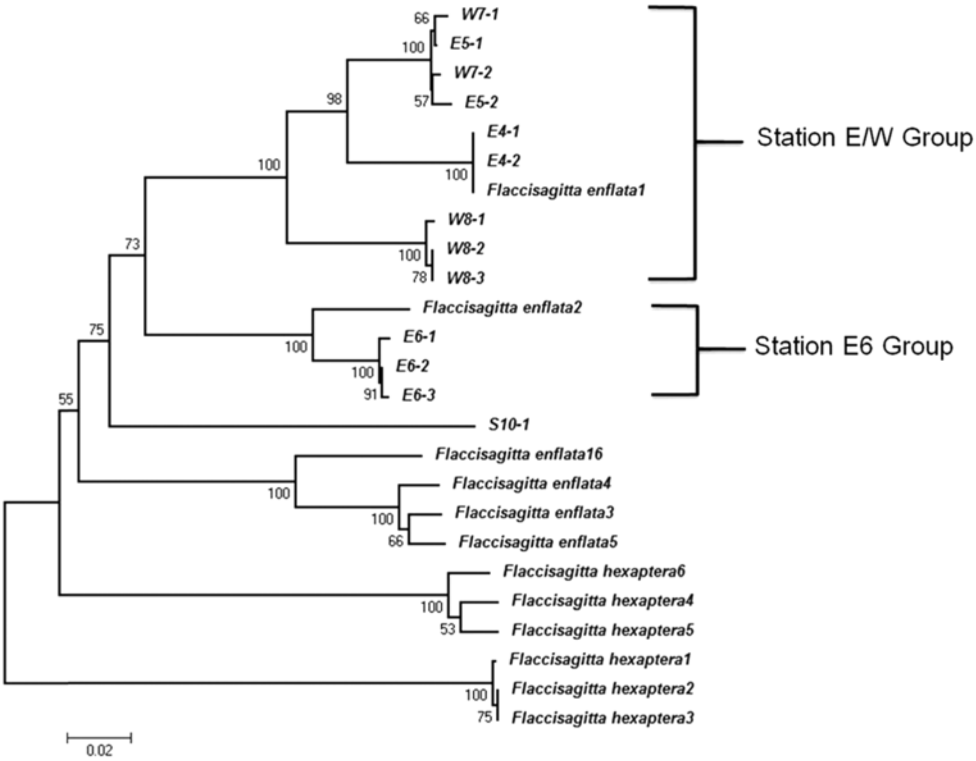

Fig. 11. Phylogenetic relationship of chaetognath species based on mitochondrial genes. The trees were constructed by Neighbor-Joining. Bootstrap values for 1000 replications are shown

ranging from 1.5–20°C (Alvariño 1967). *P. elegans* was the second dominant species in Hokkaido coastal water influenced by Oyasio cold water (Johnson and Terazaki 2003). This species does not appear in Tosa Bay, which is influenced by the Kuroshio Current (Ohnishi et al. 2014). In the present study, *P. elegans* was the second most dominant species and only appeared in line E. The density of *P. elegans* decreased with increasing temperature. This study indicated similar distribution patterns as outlined in previous studies.

Aidanosagitta crasa lives in low saline water such as inshore Japanese waters, the Yellow Sea (Park 1970; Tokioka 1959). In the South China Sea *A. crassa* was the most dominant in summer (Tse et al. 2007). The highest density of *A. crassa* appeared in the mid-eastern part of the Yellow Sea in August because it is usually less saline during this time (Hwang and Choi 1993). In the present study, *A. crassa* was abundant at line W and part of line S, where low salinity coastal water was present.

The currents around the Korean peninsula affect oceanographic features and transport various zooplanktons. Community variations of warm water copepod species have been reported to be transported by the Kuroshio Current (Shiba et al. 2009). Three groups of *F. enflata* have been reported to be distributed between the South Sea of Korea, the Yellow Sea, and the East China Sea (Ju 2014). In the study, *F. enflata* was divided into two genetically different groups. Distribution of *F. enflata* may be influenced by the warm Kuroshio Current off Korean peninsula.

Acknowledgements

This research was a part of the project titled “Long-term change of structure and function in marine ecosystems of Korea”, funded by the Ministry of Oceans and Fisheries, Korea.

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