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Ontogenetic and seasonal changes in the diets of the glowbelly *Acropoma japonicum* Gunther, 1859 in the south-eastern waters of Korea

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ABSTACT

The dietary patterns of the glowbelly *Acropoma japonicum* Gunther, 1859 were studied based on 180 specimens collected during January to December 2006 off the south-eastern coast of Korea. The standard length (SL) of the specimens ranged from 3.0 to 10.3 cm. *A. japonicum* was found to be a benthopelagic predator that primarily consumed copepods and carid shrimps, but also preyed moderately on teleosts and euphausiids. The dietary composition of *A. japonicum* differed between length classes, with copepods and carid shrimps being dominant in the diet of small and large length class, respectively. The diets also were different among seasons, with the difference particularly being evident between warm (summer and autumn) and cold (winter and spring) seasons. Permutational multivariate analysis of variance (PERMANOVA) and analysis of similarities (ANOSIM) revealed significant dietary differences by size and season. These differences in the diets were related to first maturity in female and seasonal changes in water temperature.

Keywords: Caridea, Copepoda, Glowbelly, South-eastern Korea, Stomach contents

Introduction

The glowbelly, *Acropoma japonicum* Gunther, 1859, is a benthopelagic fish (Perciformes: Acropomatidae) that is widely distributed throughout tropical and temperate waters inhabiting the continental shelf from the West Pacific to the Indian Ocean (Nakabo, 2002). Fishes of the family Acropomatidae including *A. japonicum*, constitute approximately 32 species in 7 genera distributed worldwide (Froese and Pauly, 2017), while only 5 species in 3 genera occur in Korean waters (Kim *et al*., 2005). *A. japonicum* is smaller (TL = 15 cm) than other members of the same family found in Korea (Kim *et al*., 2005).

Several of the larger fishes such as *Doederleinia berycoides* grow large enough to be marketed in Korea (NFRDI, 2004). *A. japonicum* however, forms a major component of the trawl bycatch in Korean waters (Park, 2010). In south-western Japan on the other hand, it is commercially used for manufacturing fried fish cake (Okuda *et al*., 2005). *A. japonicum* is regarded as an ecologically important species because of its high abundance and prominence in the diets of other fishes in south-eastern Korean marine ecosystems (Park, 2010; Park *et al*., 2014; Park and Huh, 2017).

Despite the high abundance of *A. japonicum* in the study area, little is known about its ecology or biology. Just a few studies have described its life history (Okuda *et al*., 2005), reproduction (Baeck *et al*., 2012) and morphological features (Javadzadeh *et al*., 2012) and a single paper described the diet and isotopic signatures of *A. japonicum* in the Uwa Sea, Japan (Hamaoka *et al*., 2010). There is, no targeted study on how feeding may change with increasing body size and season in south-eastern Korea. Based on its TROPH value (*i.e.,* secondary and/or tertiary consumers), *A. japonicum* often occupies the intermediate trophic level (Froese and Pauly, 2017). Hamaoka *et al*. (2010) also reported that *A. japonicum* plays an important role in bentho-pelagic coupling food webs, because they feed on a variety of prey organisms from zooplankton to benthic fishes and shrimps. Thus, the information on its diet is essential to understand the trophic relationships within marine ecosystems and knowledge of the feeding ecology of marine predators within the food web will aid in identifying the functional roles of these fishes within marine ecosystems (Wootton, 1990; Brodeur and Pearcy, 1992).

This study attempted to quantify the diet of *A. japonicum* which is abundant in south-eastern sea of Korea. The specific aims of this study were to determine the dietary composition of *A. japonicum* and to identify any size-related and seasonal changes in dietary composition.

Materials and methods

Study area and sampling

Fishing grounds located off the south-eastern waters of Korea (35°17′N, 129°18′E; Fig. 1) exhibit environmental and geographical characteristics that distinguish them from the coastal marine ecosystems of the eastern and southern Korean seas (Park, 1978). The region enjoys favourable environmental conditions in terms of water temperature, salinity and bottom sediments (clay-rich mud and silt mud) and is home to many commercially important benthopelagic fishes such as blackthroat seaperch *Doederleinia berycoides*, Japanese anchovy *Engraulis japonicus*, Tanaka's snailfish *Liparis tanakae*, yellow goosefish *Lophius litulon* and John dory *Zeus faber* (NFRDI, 2004).

Sampling was performed at monthly intervals during the period from January to December 2006. Fish were collected at depths of 30-60 m using a small bottom trawl with 30 mm mesh cod end and 20 m headline length. Trawling was carried out during daylight (between 06: 00 and 12: 00 hrs) at neap tides. Immediately after capture, fish were packed in ice and taken to the laboratory. Standard length (SL) and wet weight were measured to the nearest mm and nearest g, respectively. Stomachs dissected out, preserved in 5% formalin for 24 h and transferred to 70% isopropanol.

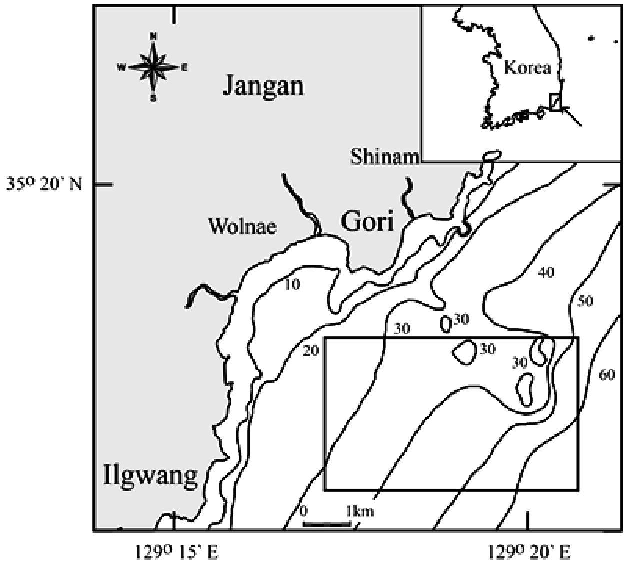

Fig. 1. Location of the study area off the south-eastern coast of Korea. Samples of *Acropoma japonicum* were collected at random locations within the boxed area using small bottom trawl

Stomach content analysis

The prey items were identified as accurately as possible to the species/genus level. The unidentifiable prey items and partly digested material were categorised at higher taxonomic levels (family or order levels). The prevalence of each prey item was quantified with the aid of a dissecting microscope. The numbers and dry weights of each prey item were recorded after drying for 24 h in an electric oven at 80°C.

Cumulative prey curves were constructed for each species to determine whether a sufficient number of stomachs was analysed to describe the diet (Ferry and Cailliet, 1996). To achieve this, the order of dietary data was randomised 100 times and the cumulative number of new prey taxa was recounted for each randomisation. The mean number of prey taxa per stomach (±SD) was plotted against the number of stomachs analysed, with the asymptote of the curve indicating that an adequate number of stomachs were studied.

To infer whether there were any size-related and seasonal variation in the dietary composition, samples were divided into two length classes and four seasons. For size-related analysis, samples were divided into two groups (small and large length classes) based on their size at maturity, *i.e.,* 6.0 cm SL (Baeck *et al*., 2012). Thus, for the analyses, the length classes were defined as small (3.0-5.9 cm SL, n=104) and large (6.0-10.3 cm SL, n=76); the seasons as spring (March-May, n=70), summer (June-August, n=12), autumn (September-November, n=58) and winter (December-February, n=40).

Diet was quantified by frequency of occurrence (%F), numerical percentage (%N) and weight percentage (%W) and the index of relative importance (IRI) (Pinkas *et al*., 1971; Hyslop, 1980). IRI was expressed as percentage (%IRI).

Statistical analysis

Difference in mean SL between cold (winter and spring) and warm (summer and autumn) season was assessed using one-way analysis of variance (ANOVA) with season as fixed effect.

To examine the relative extents to which the dietary compositions of fish were influenced by size and season, stomachs of each of the species were randomly sorted into groups of three to five within each length class in each season (depending on the sample size) and the mean percentage weight data for each of the prey taxa were determined for each of the resultant groups. The weight data were square root transformed to avoid any tendency for the main dietary components to be excessively dominant and Bray-Curtis similarity matrices were constructed (Platell and Potter, 2001). The effects of size and season as well as their interactions were tested using two-way permutational multivariate analysis of variance (PERMANOVA). Two-way crossed analysis of similarities (ANOSIM) were then used to determine the relative importance of length class and season based on the same factors as used in the PERMANOVA (see above). In cases where ANOSIM detected a significant difference, pair-wise ANOSIM comparisons were then used to determine which comparisons between seasonal groups showed significant differences (Clarke *et al*., 2014).

To obtain a graphical ordination of the samples, principal coordinate analysis (PCO) of unconstrained ordinations based on Bray-Curtis similarity was used, employing the mean weight percentage of prey taxa for length classes and seasons. The relative contribution of prey taxa to the differences between length classes and among seasons was assessed using the correlation coefficient. The correlation of prey taxa >0.4 was used as an arbitrary limit of a strong relationship between the dietary composition of each group and prey taxa on the principal coordinate axes.

ANOVA was performed using SYSTAT software (Systat version 18. SPSS Inc., USA). Multivariate analyses were performed using the routines in the PRIMER v7 multivariate statistics package (www.primer-e.com) and the PERMANOVA+ add-on module (Anderson *et al*., 2008; Clarke and Gorley, 2015). For all tests, the significance level was set at $p=0.05$.

Results

General stomach contents

Among 180 specimens of *A. japonicum*, caught during study period, no fishes were collected in June and July (Fig. 2). During colder season, the samples mainly consisted of small individuals, while larger adults were main components between August and October samples (Fig. 2). ANOVA results revealed that mean size (±SD) of *A. japonicum* in warm season (6.7±1.9 cm) was significantly higher than that of cold season (4.7±1.1 cm) (ANOVA, $p<0.05$).

In the 180 stomachs analysed, 34 (18.9%) were empty. A cumulative prey curve for overall diet (number of prey taxa found) reached asymptote (Fig. 3). Thus, the sample sizes were enough to allow us to adequately describe the diet of *A. japonicum* in the study area.

A total of 9 prey taxa were found in the 146 stomachs (Table 1). Copepods were the most common prey item, recording 39.7% occurrence, 71.8% by number, 14.6% by dry weight and 50.8% IRI. At least 7 copepod genera were identified. *Calanus* and *Acartia* were the principal copepod prey items. Carid shrimps were the second largest dietary component, totalling 45.2% occurrence, 12.9% by number, 39.6% by dry weight and 35.2% IRI. The principal shrimp prey species found was *Leptochela sydniensis*. Teleosts and euphausiids accounted for 6.8 and 6% IRI, respectively and all of the remaining prey taxa constituted less than 1% IRI.

Variation in stomach contents by size and season

When the dietary data were examined by length classes, the small length class of *A. japonicum* fed mainly on copepods, euphausiids and carid shrimps, the first two of which declined in importance as the body size of this predator increased (Fig. 4a). In contrast, contribution of carid shrimps and teleosts became greater with increasing body size of *A. japonicum* (Fig. 4a). When the dietary data were examined by season, seasonal differences in dietary compositions were found in the diets of *A. japonicum* (Fig. 4b). Dietary compositions of *A. japonicum* in winter and spring comprised mainly copepods and carid shrimps (Fig. 4b). During summer, however, carids (40.3%) were the most important dietary component, followed by crabs (13.4%) and teleosts (11.6%). Carid shrimps and teleosts were important in autumn diets, collectively contributing 70.5% to the overall dietary volume (Fig. 4b).

PERMANOVA tests revealed that the dietary composition significantly differed between length classes (pseudo-F=8.396, df=1, $p=0.001$) and among seasons (pseudo-F=2.914, df=3, $p=0.025$). There was also a significant interaction between factors of size and season (pseudo-F=3.207, df=3, $p=0.005$). The results of two-way crossed ANOSIM tests also showed that the dietary compositions of *A. japonicum* were significantly different with length class (global-R=0.884, $p=0.001$) and season (global-R=0.548, $p=0.002$). Pairwise ANOSIM tests revealed that pairwise seasonal comparisons between cold season (winter and spring) and warm season (summer and autumn) were significant, but not significant between summer and autumn (global-R=0.291, $p=0.163$) and between winter and spring (global-R=0.021, $p=0.394$).

The unconstrained ordination plot using the first two principal coordinates axis show a clear separation of samples along the 1st and 2nd axes, which explained 48.4 and 30.1% of the variation within samples, respectively (Fig. 5). Samples of large length class were distributed on the upper right of the plot, while samples of small length class spread out on the plot, with the exception of upper right region. In PCO plot, copepods, amphipods and euphausiids were driving the differences on the small length class, whereas carid shrimps and teleosts were characterised by the large length class (Fig. 5). In terms of season, the points of winter and spring showed a clear

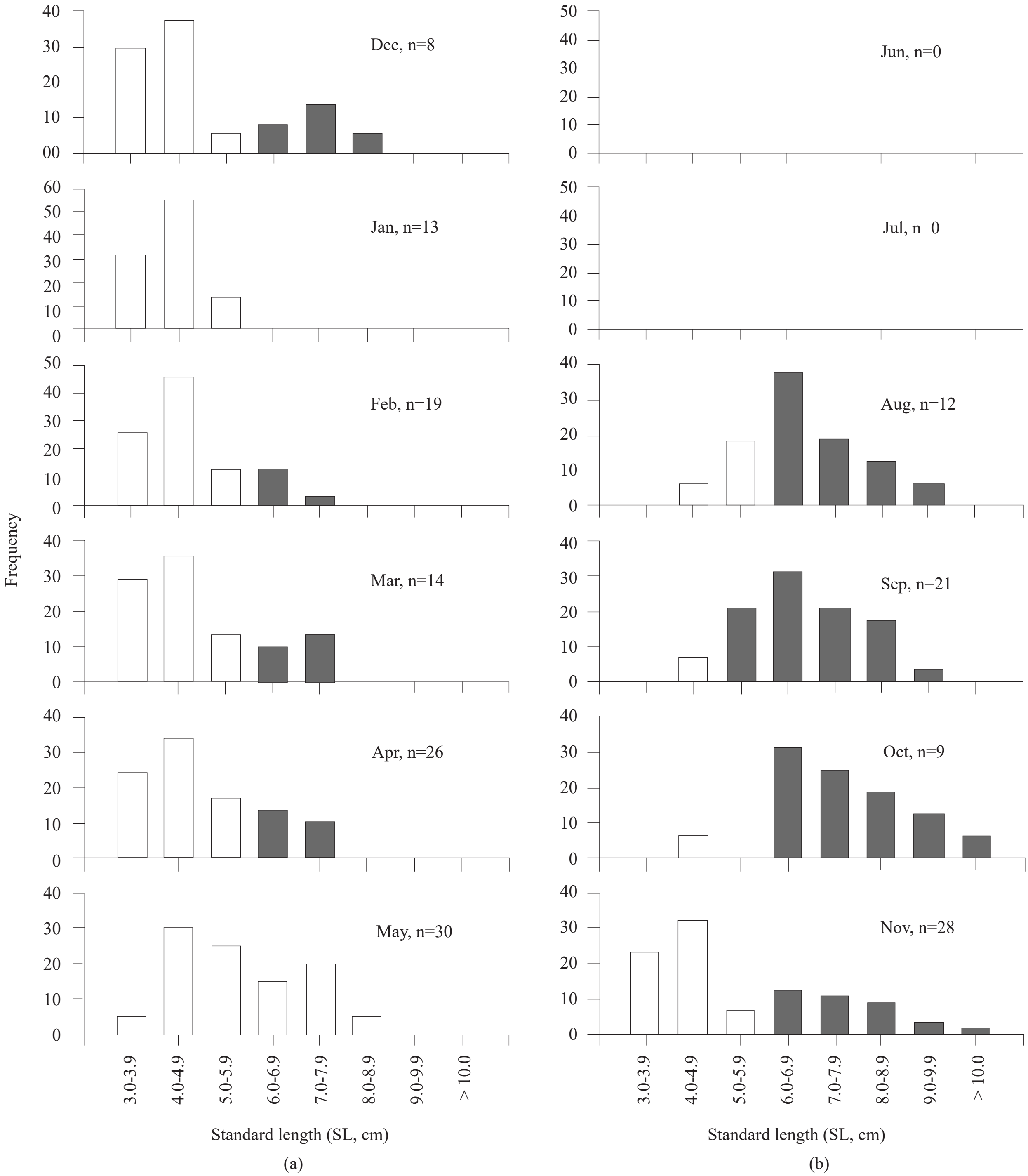

Fig. 2. Monthly variations in size frequency of *Acropoma japonicum* during (a) cold and (b) warm seasons. White bars = small length class, Grey bars = large length class

separation from those of summer and autumn along the first axis (Fig. 5). Copepods and chaetognaths highly correlated with winter and spring samples, while various prey taxa showed positive correlations with summer and autumn (Fig. 5).

Discussion

Based on the %IRI values, the greatest contributors in the diets of *A. japonicum* were copepods and carid shrimps, with the majority being pelagic or benthopelagic foods thus suggesting foraging in water column. The

Table 1. Percentage frequency of occurrence (%F), number (%N), dry weight (%W), and index of relative importance (%IRI) of prey items in the diets of *Acropoma japonicum* inhabiting south-eastern waters of Korea

Taxa	Prey items	%F	%N	%W	%IRI
Crustacea					
Copepoda*	Total	39.7	71.8	14.6	50.8
	Acartia	13.7	22.5	4.4	
	Calanus	30.1	46.6	9.1	
	Centropages	1.4	0.2	0.1	
	Corycaeus	1.4	0.4	0.1	
	Euchaeta	2.7	0.4	0.2	
	Nudinula	1.4	0.4	0.2	
	Paracalanus	2.7	1.4	0.5	
Ostracoda*	Unidentified	1.4	0.2	0.1	<0.1
Mysidacea*	Unidentified	2.7	0.4	0.8	<0.1
Euphausiacea*	Unidentified	20.5	7.2	12.5	6.0
Amphipoda*	Total	12.3	3.5	2.1	1.0
	Hyperidae	9.6	2.3	1.7	
	Gammeridae	2.7	1.2	0.4	
Decapoda					
Caridea*	Total	45.2	12.9	39.6	35.2
	Eualus spathulirostris	1.4	0.2	2.8	
	Leptochela sydniensis	27.4	9.8	25.9	
	Unidentified	20.5	2.9	11.0	
Brachyura*	Megalopa larvae	1.4	0.4	0.9	<0.1
Chaetognatha*	*Sagitta* spp.	4.1	0.8	1.6	0.1
Teleostei*	Total	15.1	2.7	27.6	6.8
	Myctophidae	11.0	2.2	25.0	
	Unidentified	4.1	0.6	2.6	

*Indicates prey taxa for multivariate analyses

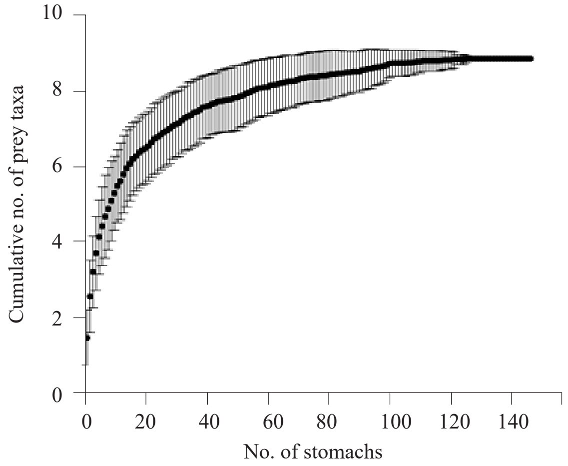

Fig. 3. Cumulative prey curves (prey taxa per stomach; ±SD) for *Acropoma japonicum* from the south-eastern waters of Korea

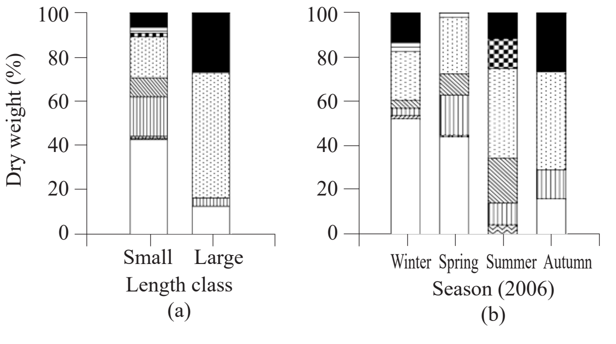

Fig. 4. Ontogenetic (a) and seasonal (b) variations in dietary compositions of *Acropoma japonicum* in the south-eastern waters of Korea

importance of these prey items was also found in the diets of *A. japonicum* in Japanese waters (Hamaoka *et al*., 2010). However, there was also region-specific differences in food resources between Korean and Japanese waters. In the Uwa Sea of Japan, teleosts (mostly gobies) formed major components in the diets of *A. japonicum*, followed by penaeid shrimps, while carid shrimps and copepods were more abundant in the diets of the species in Korean waters. Generally, fish target the most abundant available prey, which is indicative of the benthopelagic faunistic composition.

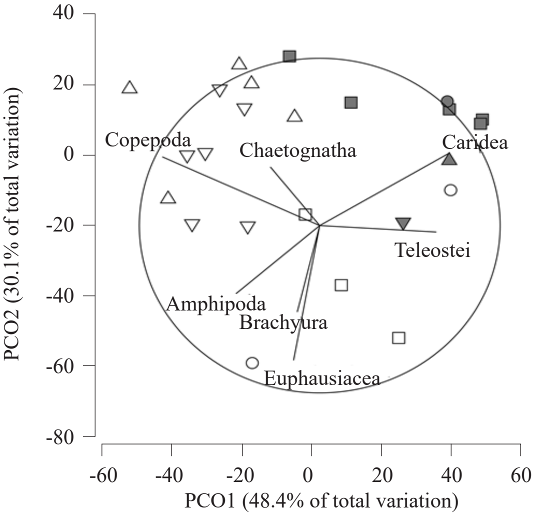

Fig. 5. Principal coordinate (PCO) analysis using an agglomerative ordination method based on dietary compositions across different length classes (open symbol = small length class, grey symbol = large length class) and seasons (triangle = winter, inverted triangle = spring, square = summer, circle = autumn) in the south-eastern waters of Korea. The vector represents Pearson correlation and the circle shows a correlation of 1

Although a high diversity of decapods was evident in our study area (Huh *et al*., 2010), *A. japonicum* usually consumed pasiphaeid shrimps *i.e., Leptochela sydniensis*. These prey items were frequently consumed by co-occurring pelagic fishes including *Coilia nasus* (Baeck *et al*., 2011), *Clupea pallasii pallasii* and juvenile *Trichiurus lepturus* (Choo, 2007) and also other fishes elsewhere such as *Chelidonichthys spinosus* from the Jeju Island (Kim *et al*., 2011) and the sardine *Sardinops sagax* and barracouta *Thyrsites atun* from southern Australia (Bulman *et al*., 2011). Pasiphaeid shrimps are a family of mesopelagic decapods from shelf and offshore environments (Poore, 2004) and thus predation on pasiphaeid shrimps indicate pelagic feeding behaviours of predatory fishes. However, many sympatric benthic fishes in the study area such as *Amblychaeturichthys* gobies (Huh *et al*., 2016) and fivespot flounder (*Pseudorhombus pentophthalmus*; Park and Huh, 2017), fed on crangonid shrimps which were the most dominant benthic shrimps in the study area (Huh *et al*., 2010). Although fish target the most abundant locally available prey and such behaviour may be influenced by the catch success rate and/or the probability of encountering prey (Persson and Diehl, 1990), *A. japonicum* specialised on pasiphaeid shrimps. This feeding strategy of *A. japonicum* likely reduces potential competition for available prey resources among co-occurring fish species in the study area.

Both PERMANOVA and ANOSIM revealed significant size-related difference in the diets of *A. japonicum.* Ontogenetic dietary change of *A. japonicum* mainly included shift from copepods to carid shrimps. Such an increase in the contribution of carid shrimps and teleosts may be partly explained by an increase in actual mouth size as *A. japonicum* grew (data not shown), thus increasing the capture efficiency of larger and more active prey (Scharf *et al*., 2000). Among fishes of the Family Acropomatidae, the relatively large-sized *Doederleinia berycoides* also showed distinct ontogenetic dietary changes from crustaceans to fishes, as body size increased (Huh *et al*., 2011). Size-related changes from small crustaceans (*e.g.* copepods) to larger shrimps and/or euphausiids are a general trend in the diets of small pelagic and/or benthopelagic fishes (Kock *et al*., 2000; Choo, 2007; Baeck *et al*., 2011). Such ontogenetic dietary changes may be related to maximize energy acquisition (Gerking, 1994), *i.e.* larger fish prefer bigger prey because they contain more energy and exploit their increased mobility to catch such prey (Stoner and Livingston, 1984).

Seasonal changes in feeding habits are associated with changes in food availability caused by environmental factors and physiological variation (Wootton, 1990). Although *A. japonicum* principally consumed copepods and carid shrimps, marked difference was observed in the diets among seasons. These differences were particularly evident between cold (13.6-14.7°C) and warm season (16.0-26.5°C; Park, 2010), with copepods being more in the former season, while carid shrimps more in the latter season. This could be probably due to differences in size distributions between seasons, because PERMANOVA showed that diet compositions of *A. japonicum* significantly interacted with size and season. Since mean size in cold season was significantly lower than that of warm season, the seasonal differences in diets strongly attributed the different size composition between cold and warm seasons. However, due to the lack of information on seasonal abundance of prey items in this study, the reasons behind the abundance of copepods and carid shrimps in the diet of *A. japonicum* during cold and warm season remain unclear.

In conclusion, this study offers important insights into the dietary habits of *A. japonicum* that are abundant in the south-eastern waters of Korea. Stomach contents indicated that they consumed mainly pelagic (*e.g.* copepods and euphausiids) and benthopelagic (*e.g.* carid shrimps) crustaceans, independent of size or season. Copepods were consumed by smaller individuals and during cold season, while carid shrimps were abundant in the diets of larger fishes and during warm season. Nonetheless, a lack of samples covering all possible size ranges imposed limitations on describing absolute diet of the species throughout its entire life history. Additional studies on the trophic ecology of *A. japonicum* are essential to understand prey-predator relationships in benthic ecosystems of the eastern Korean Sea. Results from this study would contribute to the understanding of *A. japonicum* dietary habits, and serve as an important baseline for future food web analyses for various fishes in the region.

Acknowledgments

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