Iranian Journal of Fisheries Sciences 22(2) 352-367 2023
DOI: 10.22092/ijfs.2023.129084

Research Article

Feeding habits of chub mackerel, *Scomber japonicus* (Houttuyn, 1782) in the South Sea of Korea

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Received: October 2022 Accepted: February 2023

Abstract

This study analyzed the stomach contents of Chub mackerel, *Scomber japonicus*, collected from purse seine and set net fisheries samples in the South Sea of Korea in March 2020 to February 2022 for juvenile, mature, and older fish, which are useful to identify ecosystem functions and study food competition, interspecific feeding relationships, and the food web. The size of *S. japonicus* samples ranged from 5.5 to 46.6 cm in fork length. *S. japonicus* were a carnivore that feed mainly on euphausiids and pisces. The estimated average trophic level of *S. japonicus* ranged from 3.65±0.64 to 4.00±0.78. Examination of the feeding habits according to ontogenic feeding patterns of *S. japonicus* revealed that the mean weight of prey (*mW*/*ST*) continuously increased. There were differences in the composition of the stomach contents of *S. japonicus* by the sampling period and size class, and also the interaction between them. *S. japonicus* were specialized feeders with pisces and euphausiids as their dominant prey.

Keywords: *Scomber japonicus*, South Sea of Korea, Feeding habits, Opportunistic feeder

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Introduction

The chub mackerel, *Scomber japonicus* (Houttuyn, 1782) belong to the family Scombridae and is a pelagic fish that inhabits depths of 0–300 m in temperate and tropical waters. *S. japonicus* is distributed in Korea, Japan, the East China Sea, and the eastern Pacific Ocean (Collette and Nauen, 1983). Its distribution in the coastal waters of Korea and the northwest Pacific Ocean is divided into the Tsushima Current stock and the Pacific stock according to the habitat range, migration route, and spawning site location (Shiraishi *et al*., 2008). *S. japonicus* that occurs in the coastal waters of Korea is classified as the Tsushima Current stock, which inhabits the East China Sea, and the western waters of Kyushu and Honshu in Japan (Kim *et al*., 2020). The South Sea plays an important role as spawning and nursery grounds for *S. japonicus* and is a high-density recruitment area for fishery resources (Kim *et al*., 2019) and major fishing grounds for the large purse seine fishery (Lee *et al*., 2012). *S. japonicus* comprises the highest proportion of fish caught by the purse seine fishery near the coast of Korea, accounting for about 18% of Korea's marine fish catch (Lee and Kim, 2011). The number of *S. japonicus* caught accounts for about 87% of domestic production in frequency and about 61% of Korea's large purse seine fishery industry. Therefore, Korea has been implementing a total allowable catch system since 1999 to manage *S. japonicus* resource. Following the Enforcement Decree of the Fisheries Resources Management Act in 2016, a ban period was implemented between April and June along with prohibition of catching fish of ≤ 21.0 cm TL. The large purse seine fishery industry implemented additional non-fishing periods closure from March 14 to April 14. However, the large purse seine fishery and *S. japonicus* catches continue to decline annually (KOSIS, 2022), and the *S. japonicus* fishing grounds in the South Sea of Korea, which are directly affected by climate change, are also continuously changing (Lee *et al*., 2012).

Research conducted *S. japonicus* ecology in south Korea has included the development of eggs, larvae, and juveniles (Kim *et al.*, 2008), the distribution of fish eggs and larvae (Lee *et al*., 2006; Lee *et al*., 2016), the buoyancy and vertical distribution of eggs (Jung *et al*., 2013), maturation and spawning (Cha *et al*., 2002; Kim *et al.*, 2020), first annulus formation and age and growth (Choi *et al*., 2000; Kang *et al*., 2015; Jung *et al.*, 2021), and feeding habits (Cha *et al*., 2004; Yoon *et al.*, 2008; Seong *et al*., 2021).

Resource ecological research on mackerel, as a major fishery resource, is continuously being conducted depending on factors that change the biological characteristics of the fishery, such as the changing marine environment and the development of fishing technology. However, feeding ecology is directly affected by prey items, which change according to physical, chemical, and biological factors. Therefore, it is necessary to understand the biological and ecological aspects of a target fishery resource through continuous monitoring, and the interspecific feeding relationships to describe ecosystem function, food competition, and the food web. Most fish change their ecological status and prey items to use energy more efficiently as they grow (Huh *et al*., 2008). As these changes can cause fluctuations in the fishery resource, it is necessary to understand the order of the ecosystem by researching size groups and managing the fishery resource appropriately for each size group (Kim *et al*., 2021).

This study analyzed the stomach contents of *S. japonicus* samples collected from juvenile, mature, and older fish in the South Sea of Korea for 2 years, from March 2020 to February 2022. We identified the main prey items, ecological status, and feeding strategy, the difference in prey item composition according to growth, and the feeding characteristics according to the sampling year and size class of *S. japonicus*.

Materials and methods

S. japonicus juvenile samples used in this study was collected from set net and large purse seine fisheries from March 2020 to February 2022 in the 98, 222, 223, 224, 232, and 233 trenches in the South Sea of Korea (Fig. 1).

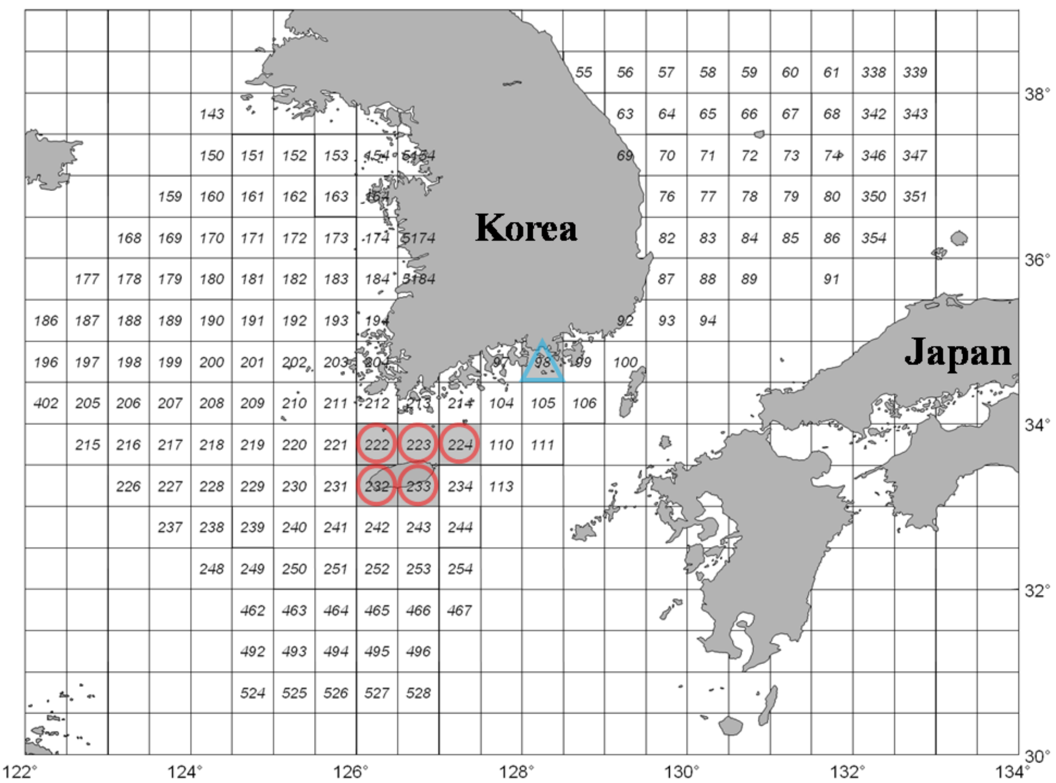

Figure 1: A map showing the trench where *Scomber japonicus* were caught in the South Sea of Korea (■,○=Large purse seine, ∆=Set net).

For the comparison of the diet composition, the results were divided into Group A, denoting the sampling period from March 2020 to February 2021 and Group B, denoting the sampling period from March 2021 to February 2022. Immediately after capture, all specimens were packed in ice and taken to the laboratory where fork length (FL) and wet weight were measured to the nearest centimeter (cm) and gram (g), respectively. All specimens were fixed in 10% formalin solution immediately after removing the stomach. Stomach contents were identified to the lowest taxonomic level possible under a dissecting microscope. The wet weight (g) of each prey item was determined.

Diet was quantified based on frequency of occurrence (%*F*) and wet weight percentage (%*W*), which were calculated using the following equations (Hyslop, 1980).

$$\%F = A_i/N \times 100$$

$$\%W = W_i/W_{total} \times 100$$

Where A_i is the number of fish preying on species *i*, *N* is the total number of fish examined (excluding individuals with empty stomachs), W_i is the wet weight of prey species *i*, and W_{total} is the total wet weight of prey. Then the ranking index (*RI*) was calculated for each prey type, as follows:

$RI = \%F \times \%W$ and expressed as a percentage (%*RI*)

$$\%RI = \frac{RI_i}{\sum_{i=1}^{n} RI} \times 100$$

The trophic level for any consumer species i is (Pauly *et al*., 1998; Pauly and Palomares, 2000):

$$TROPH_i = 1 + \sum_{j=1}^{G} DC_{ij} TROPH_j$$

Where $TROPH_j$ is the fractional trophic level of prey *j*, CD_{ij} represents the fraction of *j* in the diet of *i* and *G* is the total number of prey species.

The TROPH and standard errors (SE) of *S. japonicus* in the study area were calculated using TrophLab (Pauly and Palomares, 2000); a standalone Microsoft Access routine for estimating trophic levels (www.fishbase.org).

Size-related dietary changes were examined by dividing *S. japonicus* specimens into three size classes: <20.0 cm, 20.0-30.0 cm, ≥30.0 cm. Because gravimetric data are considered to be the most accurate representation of the relative importance of prey taxa, especially when prey items of different sizes are ingested (Hyslop, 1980), subsequence analyses were performed using the gravimetric data for each prey taxon. To examine the dietary differences of *S. japonicus* by size class and group (i.e. the sampling period), dietary data was randomly sorted into subgroup that included between three and five individuals, depending on the sample size of that group. Such random grouping of gravimetric data was advantageous to reduce the number of prey items in the samples with zero values, thus increasing the effectiveness of multivariate analysis (White *et al*., 2004; Marshall *et al*., 2008). The matrix was then subjected to a series of two-way PERMANOVAs to identify any significant effects of group in two levels (i.e. two sampling periods), size class in three levels, as well as their interactions.

The mean weight of prey items per stomach (*mW/ST*) was used to characterize size related changes in the diet via one-way analysis of variance (ANOVA).

To assess the feeding strategy of *S. japonicus*, we used the graphical analysis method proposed by Amundsen *et al*. (1996) (Fig. 2). This method allows prey importance (dominant-rare), predator feeding strategy (specialization-generalization), and trophic niche breadth (wide-narrow) to be analyzed by a two-dimensional representation of prey-specific abundance and frequency of occurrence. In mathematical terms, the prey-specific abundance is calculated as:

$$P_i = \left(\frac{\sum S_i}{\sum S_{ti}}\right) \times 100$$

Where P_i is the prey-specific abundance of prey i, S_i is the number of prey i in each fish stomach, and S_{ti} is the total number of prey in predators that contain prey i.

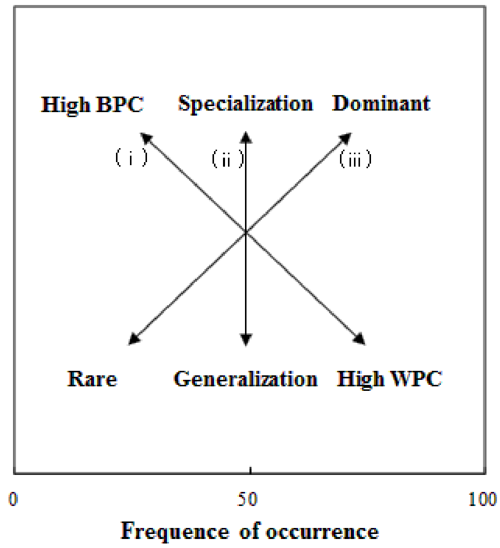

Figure 2: Explanatory diagram for interpretation of niche-width contribution (axis I, within-phenotypic component (WPC) or between-phenotypic component (BPC)) of the study population, feeding strategy (axis ii), and prey importance (Axis iii).

Results

Length-frequency distribution

During the sampling period from March 2020 to February 2021 (Group A), 380 *S. japonicus* were collected with the length range of 7.7-41.4 cm FL and average length (±SD) of 26.9±7.5 cm (Fig. 3). During the sampling period from March 2021 to February 2022 (Group B), 423 *S. japonicus* were collected and the length ranged from 5.9 to 46.6 cm FL with an average of 27.7±8.8 cm FL.

Diet composition and trophic level

Among 380 *S. japonicus* from Group A, percentage of empty stomach was 19.5%. A total of 306 *S. japonicus* stomachs contained 13 identifiable prey taxa with 9 prey species. Fishes accounted for the most diet based on %*IRI* (52.1%). Within fishes, *Engraulis japonicus* was the most common fish prey, consisting of 20.8% by weight, and occurring in 10.8% of all stomachs examined. Euphausiacea was second in importance, comprising 47.5% by *IRI*. Amphipods, copepods and Ascidiacea were infrequently consumed, composing ≤0.2% by *IRI* in the diets. In addition, the nutritional level of *S. japonicus* for Group A was 3.65±0.64. Among 423 *S. japonicus* from Group B, percentage of empty stomach was 11.6%. A total of 374 *S. japonicus* stomachs contained 14 identifiable prey taxa with at least 17 prey species (Table 1). Fishes were the most important prey item for *S. japonicus*, comprising 91.4% of the index of relative importance. Among them, *Engraulis japonicus* was the dominant taxon, making up 25.9% of occurrences and 45.8% of the weight. Euphausiacea was second in importance, comprising 5.6% by *IRI*. Shrimps and amphipods were infrequently consumed, composing of ≤1.2% by *IRI* in the diets of *S. japonicus*. In addition, the trophic level of Group B *S. japonicus* was 4.00±0.78.

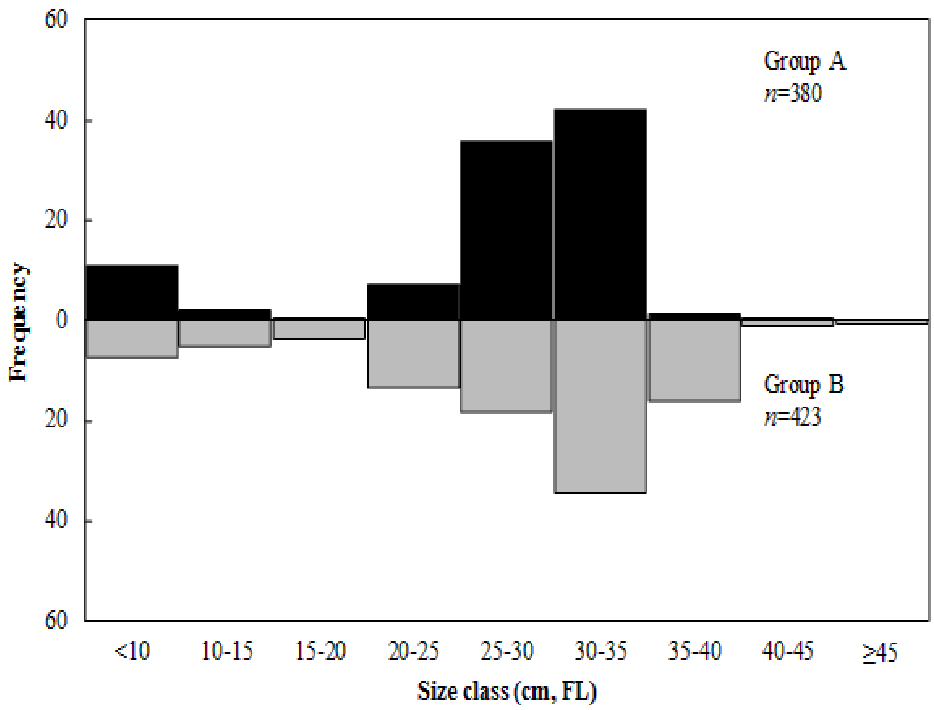

Figure 3: Length frequency distribution of *S. japonicus* collected in the South Sea of Korea. Group A indicates the sampling period from March 2020 to February 2021 and Group B, showing the sampling period from March 2021 to February 2022.

Table 1: Composition of the stomach contents of *S. japonicus* by frequency of occurrence (%F), weight (%W) and ranking index (%RI) in the South Sea of Korea for two periods: from March 2020 to February 2021 (Group A) and from March 2021 to February 2022 Group B).

Group	**A**				**B**			
Trophic level	**3.65±0.64**				**4.00+0.78**			
Prey organism	***%F***	***%W***	***RI***	***%RI***	***%F***	***%W***	***RI***	***%RI***
Amphipoda	**14.7**	**0.6**	**9.4**	**0.2**	**10.7**	**3.0**	**31.7**	**0.6**
Caprella sp.					0.5	0.1		
Gammaridae					0.8	+		
Hyperiidae	7.5	0.2			3.2	2.1		
Parathemisto japonica	2.3	0.1						
Parathemisto sp.	4.9	0.3			4.3	0.3		
Unidentified Amphipoda					2.1	0.5		
Brachyura	**1.0**	**0.1**	**0.1**	**+**	**1.3**	**0.1**	**0.1**	**+**
Charybdis bimaculata	0.3	0.1						
Unidentified Brachyura	0.7	+			1.3	0.1		
Copepoda	**9.8**	**0.7**	**6.5**	**0.1**	**0.5**	**+**	**+**	**+**
Calanus sp.	0.3	+						
Unidentified Copepoda	9.5	0.6			0.5	+		
Cumacea	**0.3**	**+**	**+**	**+**	**0.3**	**+**	**+**	**+**
Euphausiacea	**36.6**	**60.8**	**2,226.8**	**47.5**	**16.3**	**17.3**	**282.4**	**5.6**
Euphausia spp.	36.6	60.8			16.3	17.3		
Isopoda					**0.3**	**+**	**+**	**+**
Macrura	**2.0**	**0.1**	**0.2**	**+**	**15.5**	**3.8**	**59.7**	**1.2**
Acetes japonicus					0.3	+		
Leptochela gracilis	0.7	+			0.8	0.1		
Leptochela sydniensis					0.5	0.1		
Palaemon gravieri					1.3	0.4		
Solenocera melantho					0.3	0.1		
Unidentified Macrura	1.3	0.1			13.1	3.1		
Mysidacea					**1.1**	**0.2**	**0.3**	**+**
Stomatopoda					**1.9**	**0.2**	**0.4**	**+**
Oratosquilla oratoria					0.5	+		
Squillidae					1.3	0.2		
Ascidiacea	**4.6**	**1.0**	**4.6**	**0.1**	**8.0**	**2.0**	**15.9**	**0.3**
Salpidae	4.6	1.0			8.0	2.0		
Bivalvia	**0.3**	**0.1**	**+**	**+**	**0.3**	**+**	**+**	**+**
Cephalopoda	**1.3**	**0.1**	**0.1**	**+**	**7.5**	**5.6**	**42.0**	**0.8**
Euprymna morsei	0.3	+			0.8	0.1		
Loligo beka					0.5	0.4		
Loligo sp.					0.5	0.9		
Sepiola birostrata					1.1	0.3		
Todarodes pacificus					0.5	0.7		
Watasenia scintillans	0.3	+						
Unidentified Cephalopoda	0.7	+			4.0	3.1		
Chaetognatha	**1.0**	**+**	**+**	**+**	**1.9**	**0.5**	**1.0**	**+**
Sagitta sp.	1.0	+			1.9	0.5		
Gastropoda	**0.3**	**+**	**+**	**+**				

Table 1 (continued):

Monogenea	**3.3**	+	+	+				
Pisces	**67.0**	**36.4**	**2,441.9**	**52.1**	**68.4**	**67.2**	**4,601.0**	**91.4**
Benthosema pterotum	1.0	0.3						
Bregmaceros japonicus	0.7	0.2			0.5	0.5		
Carangidae	0.3	0.2						
Champsodon snyderi					1.1	0.3		
Conger myriaster					0.3	0.1		
Engraulidae					19.0	9.7		
Engraulis japonicus	10.8	20.8			25.9	45.8		
Maurolicus muelleri					1.6	0.4		
Scomber japonicus					0.5	+		
Spratelloides gracilis	14.1	2.5						
Synodontidae					0.8	0.1		
Trichiurus japonicus					0.5	0.1		
Unidentified Pisces	**41.2**	**12.5**			**18.4**	**10.2**		
Total		**100.0**	**4,689.6**	**100.0**		**100.0**	**5,034.4**	**100.0**

+: less than 0.1%

Diet composition by size-class and sampling period

The diet of small (FL<20.0 cm) and medium sized (FL=20.0-30.0 cm) *S. japonicus* from Group A (Group AI and Group AII, respectively) consumed mainly fishes, which made up 99.8 and 76.2% of the diet in %*W*, respectively. But, the large size (FL≥30.0 cm) of *S. japonicus* from the same group (Group AIII) fed mainly on Euphausiacea, representing 79.7% of the diet in %*W*. In general, for *S. japonicus* of Group A, the proportion of fish prey was decreased as body size increased, whereas the consumption of Euphausiacea increased gradually. Small sized *S. japonicus* from group B (Group BI) consumed mainly fishes, which made up 72.7% of the diet in %*W* (Fig. 4).

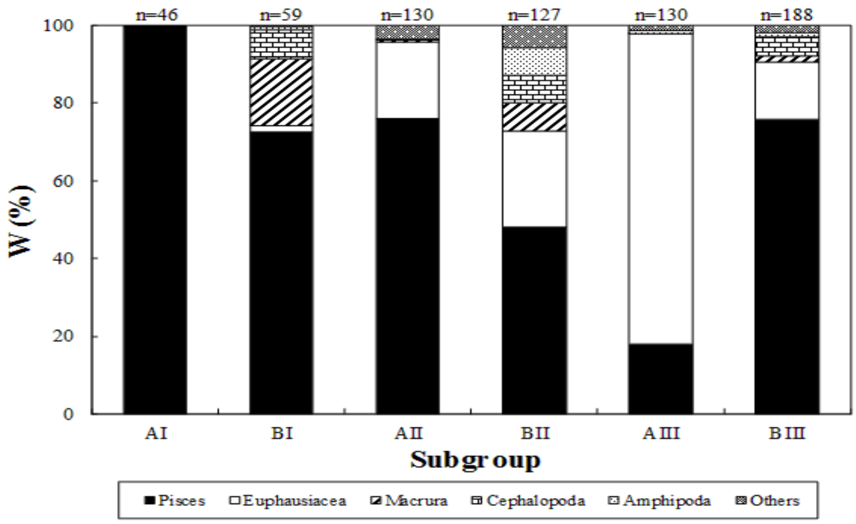

Figure 4: Ontogenetic changes in the diet composition of *S. japonicus* in South Sea based on weight (%W) by size class and group (AI: <20.0 cm of Group A, AII: 20.0-30.0 cm of Group A, AIII: ≥30.0 cm of Group A, BI: <20.0 cm of Group B, BII: 20.0-30.0 cm of Group B, BIII: ≥30.0 cm of Group B).

The diet of medium sized fish (Group BII) was composed mainly of fish, which made up 48.2% of the diet in %*W*. And large size *S. japonicus* (Group BIII) fed mainly on fish, which represented 75.9% of the diet in %*W*. *S. japonicus* of Group B showed that fishes were the most important prey in all sizes.

Examination of average weight of prey for the two sampling periods increased with size class (Fig. 5). Also, One-way ANOVA showed a significant difference in terms of the average prey weight per stomach by size class for two groups (Group A: DF=2,436, p<0.05; Group B: Df=2,504, p<0.05).

The two-way PERMANOVA demonstrated that the dietary compositions of *S. japonicus* differed significantly with group and size class, with significant interactions between two factors (p<0.05) (Table 2).

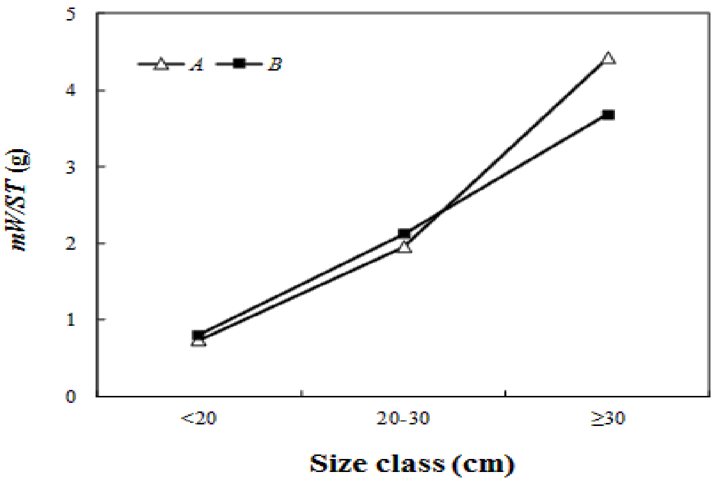

Figure 5: Variation of mean weight of prey per stomach (*mW/ST*) of *S. japonicus* by size class among the two groups (Group A, from March 2020 to February 2021 and B, from March 2021 to February 2022) in the South Sea of Korea.

Feeding strategy

The relative prey importance of *S. japonicus* is graphically represented in Figure 6, where prey-specific abundance (P_i) is plotted against the frequency of occurrence (F_i). Graphical analysis of the diet composition based on the weight showed that the P_i-F_i plot explains a mixed feeding strategy for *S. japonicus* from Group A: a specialization for fishes and a generalization for other different prey items. Fishes is located in the upper right and Euphausiacea in upper center of the diagram, and the diets constituted the important prey items composing of 65.3% and 86.8% by P_i and 67.0% and 36.6% by F_i of the stomach contents, respectively. However, other food items (crabs, copepods, amphipods, gastropods, etc.) were rare or unimportant prey items, with low values of P_i (less than 63.8%) and F_i (less than 14.7%). For Group B, fishes were the important prey taxa, due to high values F_i (68.4%) and P_i (85.3%). Other prey taxa were located towards the lower or upper left axis of the diagram in regions of low prey importance relative to the population sampled.

Table 2: Sum of Squares (SS), Mean squares (MS), pseudo-F ratios and Significance levels (P) for a series of PERMANOVA tests, comparison of the stomach contents for group, size class and interactions between group and size class.

Source	df	SS	MS	Pseudo-F	P
Group	1	9294.2	9294.2	7.034	0.001
Size class	2	28897.0	14449.0	10.934	0.001
Group × Size class	2	21312.0	10656.0	8.064	0.001

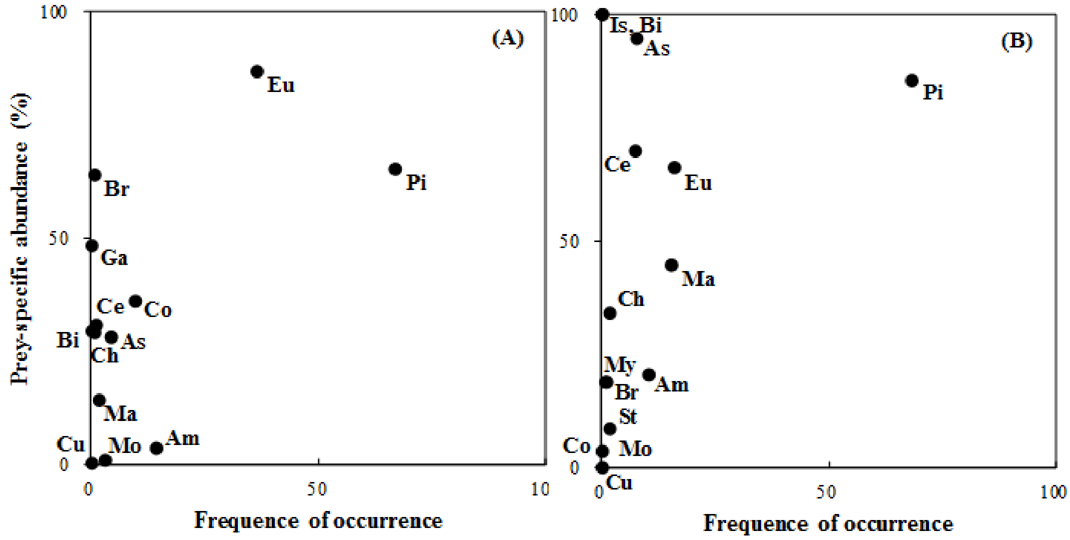

Figure 6: Graphical representation of feeding pattern of *S. japonicus* in the South Sea of Korea. Am, Amphipoda; As, Ascidiancea; Bi, Bivalvia; Br, Brachyura; Ce, Cephalopoda; Ch, Chaetognatha; Co, Copepoda; Cu, Cumacea; Eu, Euphausiacea; Ga, Gastropoda; Is, Isopoda; Ma, Macrura; Mo, Monogenea; My, Mysidacea; Pi, Pisces; St, Stomatopoda (Group A, from March 2020 to February 2021, and Group B, from March 2021 to February 2022).

Discussion

The main prey of *S. japonicus* during the two sampling periods was *E. japonicus* at fish species level. *E. japonicus* is an important nutritional stage within the food web that connects the top predators, as well as zooplankton and phytoplankton, such as diatoms, copepods, tintinnids, and euphausiids (Kim *et al.*, 2013; Kim *et al.*, 2017). Euphausiacea is an ecologically important group that connects the food chain between top predators, such as fish and mammals, and primary producers, such as phytoplankton (Greene *et al.*, 1988). In the South Sea, *E. japonicus* and Euphausiacea are clustered, and they are the main foodstuffs favored by many fish, including pelagic and benthic fish (Baeck and Huh., 2003; Jeong *et al.*, 2016; Kim *et al.*, 2021).

Studies on *S. japonicus* feeding ecology (Cha *et al.*, 2004; Yoon *et al.*, 2008; Seong *et al.*, 2021), also showed that *E. japonicus* is a popular prey item among fish. In addition to *E. japonicus*, Amphipoda, crustacean larvae, and

Salpidae were detected as main prey items. These prey species have one thing in common: they form high-density populations. Therefore, *S. japonicus* is a carnivorous fish that feeds on fish, crustaceans, and Salpidae (Seong *et al*., 2021). The reason for the difference in main prey items in two sampling periods of this study was that *S. japonicus* is believed to feed primarily on prey that appears abundantly in the environment. In particular, the zooplankton Euphausiacea undergoes a diurnal vertical migration, in which they travel toward the sea bottom during the day and rise at night (Gang and Kim, 2005). Due to these characteristics, it is also expected that the feeding strategy of *S. japonicus* changes according to temporal factors, such as collection time and depth. A future feeding ecology study should consider various factors, such as collection depth and time. The trophic level of aquatic consumers can take a value between 2.0 for herbivorous/detritivores to 5.0 for piscivorous/carnivorous organisms (Pauly *et al*., 1998; Pauly and Palomares, 2000). In this study, the nutritional level of Group A (From March 2020 to February 2021) *S. japonicus* was 3.65±0.64, whereas that of Group B (From March 2021 to February 2022) *S. japonicus* was 4.00±0.78. Therefore, the nutritional level of *S. japonicus* averaged at 3.65±0.64 to 4.00±0.78. In the previous study (Cha *et al*., 2004; Yoon *et al*., 2008; Seong *et al*., 2021), the trophic levels were 3.73±0.69, 3.79±0.33, and 3.92, respectively, which is similar to our study. The average nutritional level of organisms in the South Sea is 3.46±0.004 (Zhang and Lee, 2004). Therefore, *S. japonicus* is an intermediate nutritional organism that connects zooplankton, such as Euphausiacea, with small fish, such as *E. japonicus*, and top predators in Korea's South Sea, such as *Coryphaena hippurus* (Jeong *et al*., 2017) and *Isurus oxyrinchus* (Huh *et al*., 2010), that feed on *S. japonicus*.

The ecological status and prey items of most fish change as they grow (Kim *et al*., 2021). In this study, the ontogenetic change of Group A *S. japonicus* from fish to Euphausiacea was observed. Group B *S. japonicus* prey was dominated by fish of all sizes. In general, as fish grow, they feed on larger prey items to maximize energy efficiency, rather than preying on smaller prey items several times (Wainwright and Richard, 1995). However, Group A *S. japonicus* converted from fish to Euphausiacea, so its ecological status decreased. Given these results, *S. japonicus* feed mainly on animals that live abundantly in their habitat to minimize energy used for foraging and to increase the likelihood of capturing food (Persson and Diehl, 1990). *S. japonicus* also do not show dramatic changes in ecological status or prey as they grow. Therefore, *S. japonicus* try to reduce competition for prey food with other predators using the same prey source, which promotes efficient growth. As a result of analyzing the difference in prey feeding characteristics, the average weight of the prey items per individual in Groups A and B *S. japonicus* increased. Therefore, *S. japonicus* eats a sufficient amount of prey that is abundant in the environment, without considering the size of the prey and the number of times it is eaten. Significant differences were observed between groups, size classes, and the interaction between the group and size class. The reason is that *S. japonicus* is an opportunistic feeder that mainly feeds on prey items that occur abundantly in their habitats, such as zooplankton and small fish. Therefore, this result is useful as basic data to identify prey items in the stomach contents of *S. japonicus* and to understand interspecific feeding relationships and the food web structure.

In this study, Group A *S. japonicus* was a specialist feeder that mainly feeds on fish and Euphausiacea. Group B *S. japonicus* were specialist feeders that mainly feed on fish. Thus, *S. japonicus* predominantly feeds on fish and Euphausiacea that are abundant in the South Sea of Korea, but due to its opportunistic feeding behavior, it may show differences in prey species when prey species are temporarily abundant or when the dominant prey species change due to various factors.

The water temperature continues to rise in the South Sea, which is directly affected by climate change, and *S. japonicus* fishing grounds are continually changing (Lee *et al*., 2012). Nevertheless, the results of this study were similar to those of studies conducted in 2004, 2008, and 2021. This is because *E. japonicus*, which are both eurythermal and euryhalinous are abundant in the South Sea and remain a major prey source (Kim *et al*., 2013). However, continued increases in water temperatures may affect the distribution of *S. japonicus* stocks by changing the distribution of *E. japonicus* stocks, which are the main prey source, or by introducing new prey competition. So, it is necessary to monitor continuously *S. japonicus* feeding ecology and nutritional stage. The results of this study are basic data to understand the feeding habits of *S. japonicus* and will be useful to identify ecosystem functions and study food competition, interspecific feeding relationships, and the food web.

Acknowledgements

This research was a part of the project titled ‘Research center for fishery resource management based on the information and communication technology’ (2022, grant number 20180384), funded by the Ministry of Oceans and Fisheries, Korea. The English in this document has been checked by at least two professional editors, both native speakers of English. For a certificate, please see: http://www.textcheck.com/certificate/FmQvNv

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