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Research Article

Feeding habits of the marbled flounder *Pseudopleuronectes yokohamae* (Günther, 1877) in the coastal waters off Pohang, East Sea of Korea

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Keywords

Pseudopleuronectes yokohamae,
East Sea of Korea,
Feeding habits,
Trophic level

Abstract

The diet composition of the marbled flounder *Pseudopleuronectes yokohamae* was examined using 975 specimens collected from January to December 2022 in the coastal waters off Pohang, East Sea of Korea. The range of total length was 14.4–47.6 cm. Polychaetes were the most important prey item, accounting for 91.9% of the index of relative importance, with the Lumbrineridae family being the most dominant, followed by Ampharetidae and Terebellidae. The trophic level of *P. yokohamae* was 3.08. Polychaetes showed no significant differences in dietary composition among size classes (<25.0 cm, 25.0–30.0 cm, 30.0–35.0 cm, and ≥35.0 cm), although the mean prey weight per stomach differed significantly with size. Polychaetes were the dominant prey item across all seasons. Both the mean prey weight per stomach and mean number of prey items per stomach varied significantly by season. A two-way PERMANOVA revealed that both size class and season had significant effects on dietary composition (p>0.05). To assess the nutritional status of individuals, the condition factor was calculated. It was lowest in March and highest in November. Therefore, increase in feeding activity and prey intake during spring is likely associated with post-spawning energy recovery.

Article info

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Introduction

The marbled flounder *Pseudopleuronectes yokohamae*, belonging to the family Pleuronectidae within the order Pleuronectiformes, is a coastal benthic fish species distributed from the East China Sea to southern Hokkaido, including the coastal waters of Korea (NIFS, 2014). Moreover, *P. yokohamae* is the most dominant pleuronectid species inhabiting the coastal waters off Pohang in the East Sea of Korea, migrating to nearshore areas shallower than 40 m during its spawning season between December and February (Hong *et al.,* 2008; Kim *et al*., 2016; Tomiyama *et al.,* 2021).

Owing to its high commercial value as a seafood resource, *P. yokohamae* has been subject to resource conservation measures in Korea, including the establishment of a closed fishing season from December 1 to January 31 and minimum legal catch size (Huh *et al*., 2012; Kim *et al*., 2016). Although the catch of *P. yokohamae* is aggregated under pleuronectid fishes in Korean fisheries statistics, making it difficult to determine species-specific catch data, the annual average catch of pleuronectid fishes, including *P. yokohamae*, in Gyeongsangbuk-do Province was 4,344 tons in 2011, declined to 2,772 tons in 2016, and subsequently increased to 5,254 tons in 2024 (KOSIS, 2025). Previous studies have shown that *P. yokohamae* reaches 50% of its population maturity size (50% maturity size) at approximately three years of age (Kim *et al*., 2016; Yang *et al*., 2017). Given this relatively long maturation period, fishing activities are expected to have a considerable impact on the population dynamics of *P. yokohamae*. Therefore, biological studies of the species are essential for effective monitoring and sustainable management.

Previous studies on the feeding habits of *P. yokohamae* have been conducted in various regions, including the central Yellow Sea (Park *et al*., 2016; Roh *et al*., 2022) and Gwangyang Bay (Kwak and Huh, 2003) and Tongyeong in the South Sea (Huh *et al*., 2012) in Korea, as well as in the Seto Inland Sea (Hata *et al*., 2016), Sendai Bay (Takahashi *et al*., 2018), and Tokyo Bay (Lee *et al*., 2019) in Japan. However, to date, no studies have investigated the feeding habits of *P. yokohamae* inhabiting the coastal waters off Pohang in the East Sea, despite existing research on its reproductive biology and growth (Kim *et al*., 2016; Yang *et al*., 2017).

As feeding habits can vary by habitat and environmental conditions, the analysis of stomach contents is fundamental to understanding the ecological role of a species in different regions (Zhang, 2006; Park and Gwak, 2009; Kim *et al*., 2022). Because *P. yokohamae* is known to occur year-round in the coastal waters off Pohang (Hong *et al*., 2008), and resource enhancement programs such as juvenile releases are actively underway, it is crucial to investigate its prey composition to support successful resource enhancement efforts.

Therefore, the objective of this study was to analyze the stomach content composition of *P. yokohamae* inhabiting the coastal waters off Pohang in the East Sea of Korea, identify its primary prey items, and assess variations of prey composition by size and season. The findings provide essential ecological information for the ecosystem-based management of *P. yokohamae*.

Materials and methods

Sample collection and stomach content analysis

Specimens of *P. yokohamae* used in this study were collected monthly from January to December 2022 by gillnet fisheries in the coastal waters off Pohang, East Sea of Korea. Each gill net was 600 meters in length with a mesh size of less than 20 cm. The nets were soaked for approximately three days and deployed more than once per month until the target sample size was obtained. After capture, the total length (TL, cm) and body weight (BW, g) of each specimen were measured at the South Sea Fisheries Research Institute, Korea National Institute of Fisheries Science (NIFS). Subsequently, the stomachs were excised, preserved in 10% neutral formalin, and transported to the Marine Animal Resources Laboratory at Gyeongsang National University for analysis.

Stomach contents were analyzed under a dissection microscope (LEICA 12; LEICA, Wetzlar, Germany), and prey items were identified to the lowest possible taxonomic level. The wet weight of each prey item was measured to the nearest 0.001 g using a precision analytical balance (ME204TE/00; Mettler Toledo, Greifensee, Switzerland).

The stomach content analysis results were expressed as the frequency of occurrence (%*F*), numerical proportion (%*N*), and weight proportion (%*W*), calculated according to the following formulas:

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

$$\%N = N_i/N_{total} \times 100$$

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

Where, A_i is the number of fish containing prey item i, N is the total number of fish with nonempty stomachs, N_i is the number of prey item i, N_{total} is the total number of prey items, W_i is the wet weight of prey item i, and W_{total} is the total wet weight of all prey items.

The index of relative importance (*IRI*) for each prey category was calculated following the method described by Pinkas *et al*. (1971):

$$IRI = \%F \times (\%N + \%W)$$

The *IRI* was then standardized to a percentage (%*IRI*) as:

$$\%IRI = \frac{IRI_I}{\sum_{i=1}^{n} IRI} \times 100$$

Trophic level estimation

The trophic level (TL_k) of *P. yokohamae*, indicating its ecological position, was estimated using TrophLab (Pauly *et al*., 2000), based on the following formula:

$$TL_k = 1 + \sum_{j}^{n} |P_j \times TL_j|$$

Where, P_j is the relative importance (%*IRI*) of the prey category j and TL_j is the trophic level of the prey item j. The trophic levels of the prey taxa were referenced from Pauly *et al*. (1998), Cortés (1999), and Ebert and Bizzarro (2007).

Size and seasonal grouping

To examine size-related differences in diet, specimens with nonempty stomachs were categorized into four size classes: <25.0 cm, 25.0–30.0 cm, 30.0–35.0 cm, and ≥35.0 cm. For seasonal comparisons, samples were grouped into spring (March–May; n =

73), summer (June–August; *n* = 62), autumn (September–November; *n* = 70), and winter (December–February; *n*=42).

To examine the dietary differences of *P. yokohamae* by size class and season, the data were grouped into subgroups consisting of 3 to 5 individuals for each size class and season. Since the number of individuals in the largest size class was small, the 30.0–35.0 cm and ≥35.0 cm groups were combined into a single ≥30.0 cm category for analysis. The resulting matrix was then subjected to two-way PERMANOVA to identify significant effects of three size classes (<25.0 cm, 25.0–30.0 cm, and ≥30.0 cm) and four seasons.

For each size class and season, the mean number of prey items per stomach (*mN*/*ST*) and the mean prey weight per stomach (*mW*/*ST*) were calculated. Statistical differences were analyzed using one-way analysis of variance (ANOVA) performed with Microsoft Excel 365.

Condition factor

To assess the nutritional condition of *P. yokohamae* before and after the spawning season, the monthly condition factor (CF) was calculated using the following formula:

$$CF = BW(g)/TL(cm)^3 \times 10^2$$

Where, BW is the body weight (g) and TL is the total length (cm).

Results

Total length distribution

In total, 975 specimens of *P. yokohamae* were collected during the study period, exhibiting a total length (TL) range of 14.4–47.6 cm (Fig. 1). The size class of 20.0–25.0 cm accounted for the highest proportion, representing 40.9% of the total collected specimens.

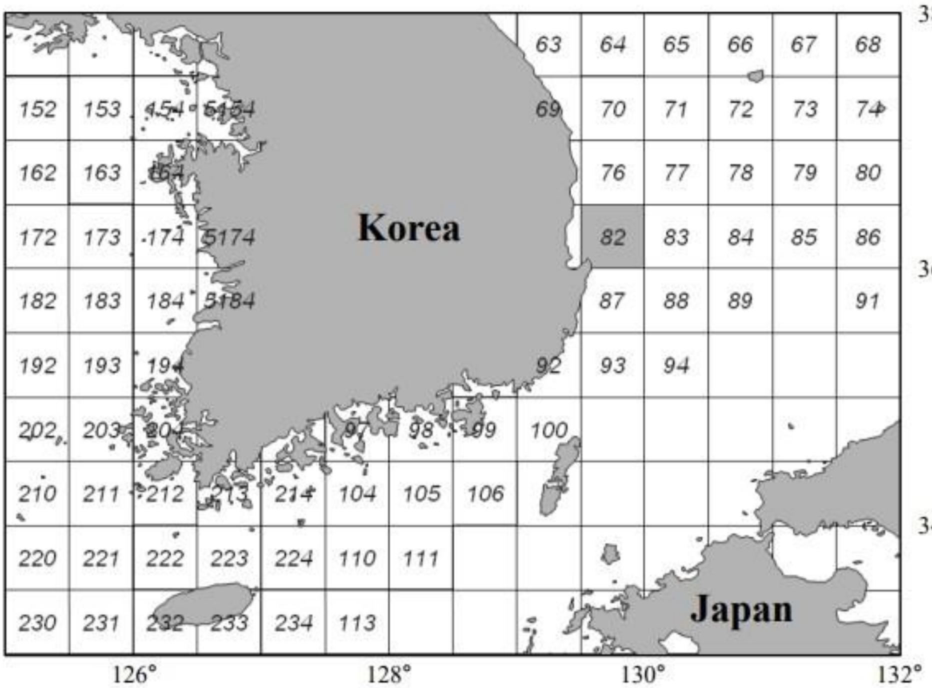

Figure 1: Location of sampling area in the coastal waters off Pohang, East Sea of Korea.

Stomach content composition and trophic level

The stomach contents of *P. yokohamae* were analyzed (Table 1). Of the 975 specimens examined, 728 individuals had empty stomachs, yielding an empty stomach rate of 74.7%. Of the 247 individuals with prey, polychaetes were the predominant prey item, with a frequency of occurrence of 77.7%, numerical proportion of 50.1%, and weight proportion of 61.6%. The relative importance index (%*IRI*) of polychaetas was 91.9%.

Table 1: Composition of the stomach contents of *P. yokohamae* collected from January to December 2022 in the coastal waters off Pohang, East Sea of Korea, showing frequency of occurrence (%*F*), number (%*N*), weight (%*W*), and index of relative importance (%*IRI*).

Prey organism		%*F*	% *N*	% *W*	%*IRI*
Amphipoda		**28.3**	**12.2**	**2.5**	**4.4**
	Ampelisca sp.	9.3	2.6	0.3	
	Byblis sp.	10.5	4.7	0.4	
	Caprellidae	4.0	1.8	1.4	
	Melita sp.	6.5	1.1	0.2	
	Themisto sp.	0.4	+	+	
	Unidentified Amphipoda	13.4	2.0	0.2	
Brachyura		**3.6**	**0.4**	**0.5**	+
Crustacea		**1.6**	**0.1**	+	+
Cumacea		**0.4**	**0.1**	+	+
Euphausiacea		**2.8**	**29.4**	**17.7**	**1.4**
	Euphausia spp.	2.8	29.4	17.7	
Isopoda		**1.2**	**0.1**	+	+
Macrura		**1.6**	**0.1**	**0.3**	+
	Alpheidae	0.4	+	+	
	Unidentified Macrura	1.2	0.1	0.3	
Pycnogonida		**1.6**	**0.2**	+	+
Stomatopoda		**1.2**	**0.2**	**0.3**	+
Tanaidacea		**1.6**	**0.2**	+	+
Anthozoa		**13.4**	**1.5**	**4.3**	**0.8**
Aplysiidae		**4.0**	**0.4**	**4.6**	**0.2**
Asteroidea		**0.4**	+	+	+
Bivalvia		**3.6**	**0.3**	**1.0**	+
Desmospongia		**0.4**	**0.1**	**1.0**	+
Gastropoda		**1.6**	**0.1**	**0.1**	+
Hydrozoa		**3.6**	**0.3**	**0.3**	+
Ophiuroidea		**19.0**	**1.7**	**3.0**	**1.0**
Ostracoda		**1.6**	**0.2**	+	+
Polychaeta		**77.7**	**50.1**	**61.6**	**91.9**
	Ampharetidae	14.2	7.4	3.4	
	Amage sp.	1.6	0.2	0.1	
	Aphroditidae	0.8	0.1	1.1	
	Cirratulidae	0.8	0.1	0.2	
	Cirratulus sp.	1.2	0.1	0.1	
	Eunicidae	9.7	3.0	3.0	
	Glyceridae	5.7	1.0	0.7	
	Goniada sp.	0.8	0.2	0.2	

Table 1 (continued):

	Prey organism	%*F*	% *N*	% *W*	%*IRI*
	Lumbrineridae	19.4	7.1	3.3	
	Nereididae	6.9	1.3	5.2	
	Ophioglycera sp.	0.4	0.1	+	
	Orbiniidae	0.4	+	0.1	
	Syllidae	1.2	0.1	0.1	
	Terebellidae	10.5	3.4	4.3	
	Unidentified Polychaeta	64.8	26.1	39.6	
Polyplacophora		**0.4**	+	+	+
	Chitonidae	0.4	+	+	
Sipunculida		**3.6**	**0.3**	**2.6**	**0.1**
Eggs		**1.6**	**1.6**	+	+
Seaweeds		**2.0**	**0.2**	+	+
Vinyls		**0.4**	+	+	+
	Total		**100.0**	**100.0**	**100.0**

Among the polychaetes, the Lumbrineridae family was the most dominant, followed by Ampharetidae and Terebellidae. Amphipods (Amphipoda) were the second most important prey group, showing a %*IRI* of 4.4%, based on a frequency of occurrence of 28.3%, numerical proportion of 12.2%, and weight proportion of 2.5%. Other prey items such as euphausiids (Euphausiacea), brittle stars (Ophiuroidea), and anthozoans (Anthozoa) were also found, but each accounted for less than 1.4% of the total %*IRI*.

The trophic level of *P. yokohamae* inhabiting the coastal waters off Pohang was estimated to be 3.08.

Ontogenetic changes in diet composition

To assess ontogenetic changes in the diet, the specimens were categorized into four size classes (Fig. 2). In all size classes, polychaetes were identified as the primary prey group (PERMANOVA, $p>0.05$).

Mean number and weight of prey items per stomach by size class

The mean number of prey items per stomach (*mN*/*ST*) and the mean prey weight per stomach (*mW*/*ST*) for each size class were analyzed (Fig. 3). The *mN*/*ST* values were 3.74 (±0.50), 2.91 (±0.26), 9.52 (±4.41), and 2.61 (±0.67) for the <25.0 cm, 25.0–30.0 cm, 30.0–35.0 cm, and ≥35.0 cm size classes, respectively, showing no statistically significant differences (one-way ANOVA, $p>0.05$).

The *mW*/*ST* values were 0.15 (±0.02), 0.21 (±0.03), 0.44 (±0.15), and 0.24 (±0.10) g for the <25.0 cm, 25.0–30.0 cm, 30.0–35.0 cm, and ≥35.0 cm size classes, respectively. The mean prey weight increased up to the 30.0–35.0 cm class and then decreased, indicating a statistically significant difference among size classes (one-way ANOVA, $p<0.05$).

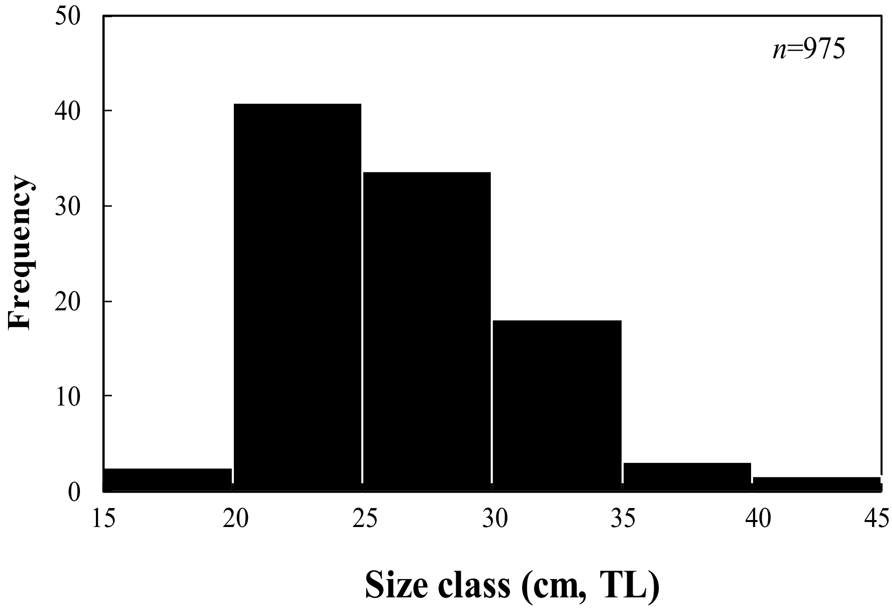

Figure 2: Total length frequency distribution of *P. yokohamae* collected from January to December 2022 in the coastal waters off Pohang, East Sea of Korea.

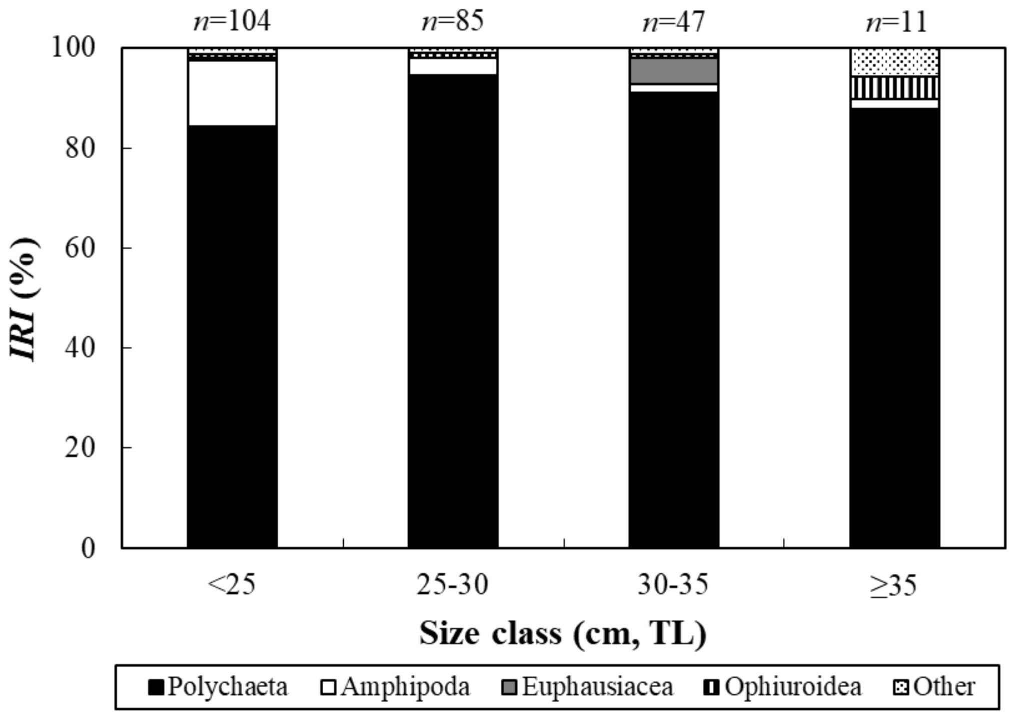

Figure 3: Ontogenetic changes in the composition of stomach contents by the index of relative importance (%IRI) of *P. yokohamae* collected from January to December 2022 in the coastal waters off Pohang, East Sea of Korea.

Seasonal changes in diet composition

Seasonal variations in diet composition were analyzed by dividing the specimens into spring, summer, autumn, and winter groups (Fig. 4). In all seasons, the polychaetes were the predominant prey group. The %*IRI* of the polychaetes was highest in autumn (94.7%) and lowest in winter (82.5%) (PERMANOVA, $p>0.05$).

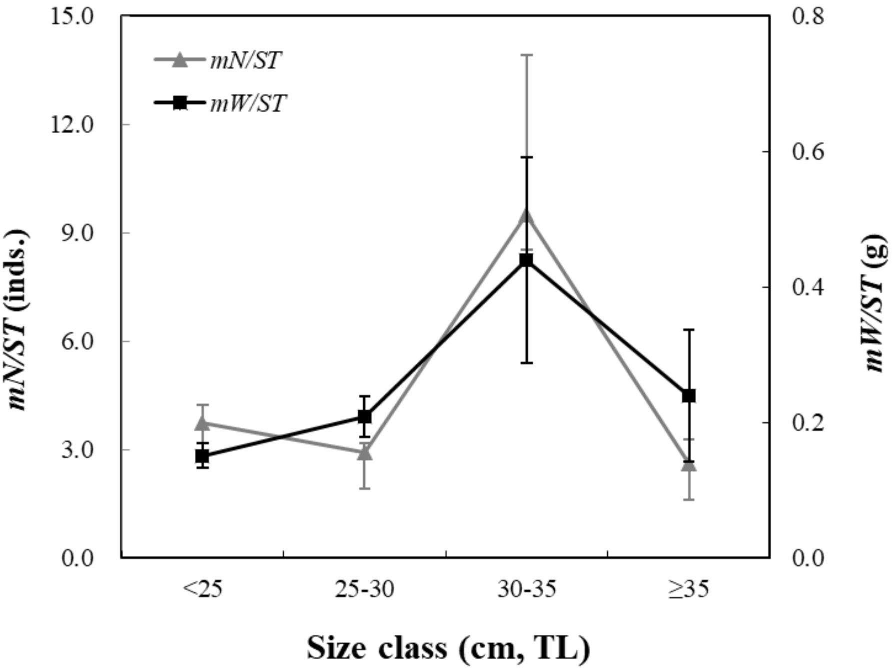

Figure 4: Variations in the mean (± standard error) number of prey items per stomach (*mN*/*ST*) and the prey weight per stomach (*mW*/*ST*) among the size classes of *P. yokohamae* collected from January to December 2022 in the coastal waters off Pohang, East Sea of Korea (<25.0 cm, *n* = 104; 25.0–30.0 cm, *n* = 85; ≥30.0 cm, *n* = 58).

Mean number and weight of prey items per stomach by season

Seasonal differences in the mean number and weight of prey items per stomach were examined (Fig. 5). The *mN*/*ST* values were 9.99 (±4.21), 3.63 (±0.43), 2.78 (±0.35), and 2.59 (±0.33) for spring, summer, autumn, and winter, respectively, showing significant seasonal variation (one-way ANOVA, $p<0.05$).

The *mW*/*ST* values were 0.54 (±0.15) g, 0.13 (±0.02) g, 0.14 (±0.02) g, and 0.18 (±0.03) g for spring, summer, autumn, and winter, respectively, also showing significant seasonal differences (one-way ANOVA, $p<0.05$).

Monthly changes in the condition factor

The monthly variation in the condition factor (CF) of *P. yokohamae* was analyzed (Fig. 6). The CF was lowest in March (mean: 1.22), increased to 1.30 in April, and then gradually increased to reach the highest mean value of 1.52 in November (Fig. 7).

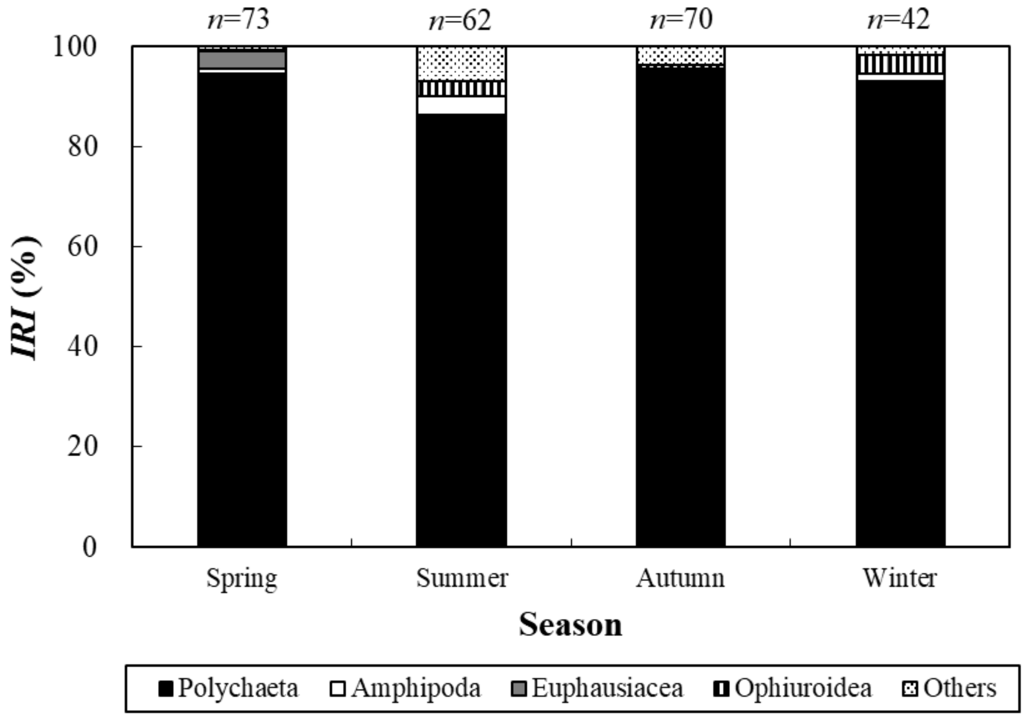

Figure 5: Seasonal variations in the composition of stomach contents by the index of relative importance (%*IRI*) of *P. yokohamae* collected from January to December 2022 in the coastal waters off Pohang, East Sea of Korea.

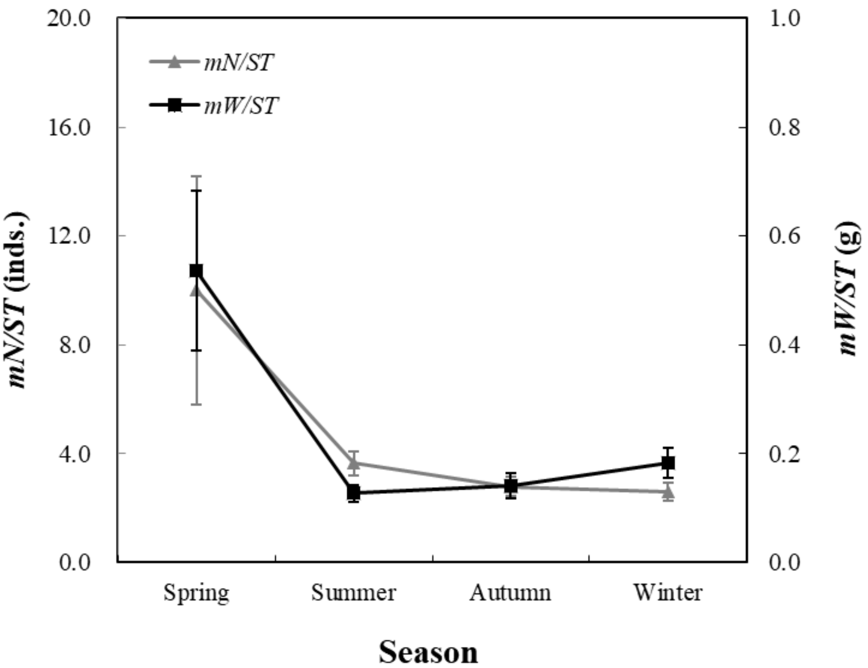

Figure 6: Seasonal variations in the mean (± standard error) number of prey items per stomach (*mN*/*ST*) and the prey weight per stomach (*mW*/*ST*) of *P. yokohamae* collected from January to December 2022 in the coastal waters off Pohang, East Sea of Korea (Spring, *n* = 73; Summer, *n* = 62; Autumn, *n* = 70; Winter, *n* = 42).

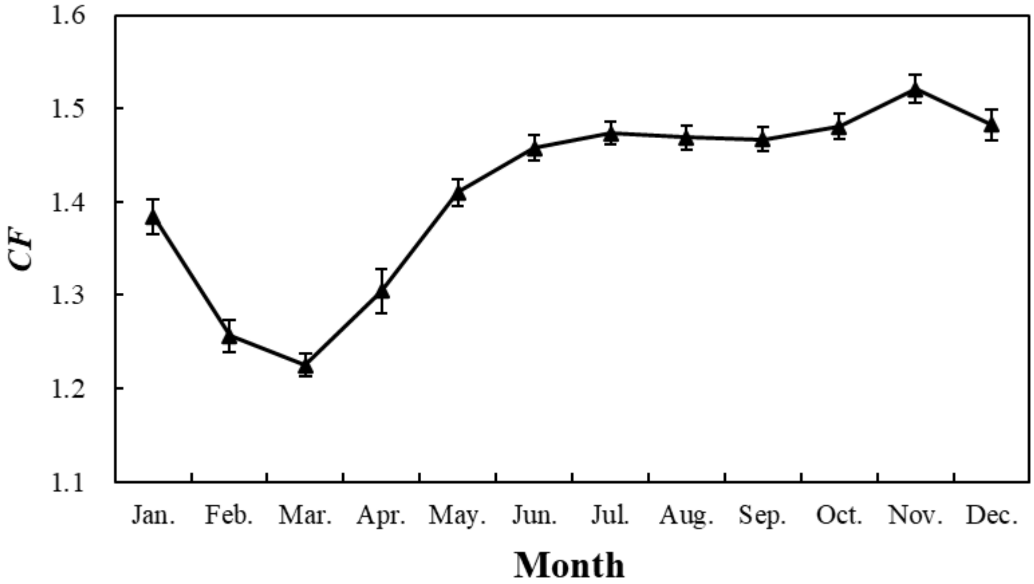

Figure 7: Monthly changes in the mean (± standard error) value of the condition factor (CF) for *P. yokohamae* collected from January to December 2022 in the coastal waters off Pohang, East Sea of Korea.

Discussion

In this study, *P. yokohamae* exhibited a high empty stomach rate, with approximately three-quarters of individuals showing no stomach contents. High empty stomach rates in fish have been attributed to digestion during capture or transportation, piscivorous feeding habits, or a mismatch between feeding and capture times (Huh *et al*., 2006; Choi *et al*., 2019). Given that the specimens were captured using gillnets, it is likely that digestion occurred either within the fishing gear or during transportation, resulting in the observed high empty stomach rate.

The present results indicate that polychaetes are the most important prey group for *P. yokohamae*. Polychaetes, being less mobile, are considered good indicators of environmental changes and habitat characteristics. They primarily feed on organic matter in sediments or the water column and play a key role in energy transfer to higher trophic levels (Koo *et al*., 2008; Lee *et al*., 2022). Moreover, previous studies have reported that *P. yokohamae* inhabiting the central Yellow Sea, South Sea of Korea, and the Seto Inland Sea and Sendai Bay of Japan primarily feed on polychaetes (Kwak and Huh, 2003; Hata *et al*., 2016; Park *et al*., 2016; Takahashi *et al*., 2018; Roh *et al*., 2022). However, in the coastal waters off Tongyeong, *P. yokohamae* primarily consumed bivalves, likely reflecting the dense distribution of bivalve aquaculture farms in that region (Huh *et al*., 2012; Roh *et al*., 2022). These findings suggest that the main prey of *P. yokohamae* may vary depending on local environmental conditions. Nonetheless, the dominance of polychaetes observed in this study is consistent with most previous research (Shin and Koh, 1992; Kim *et al*., 2022; Lee *et al*., 2023).

Among polychaetes, members of the Lumbrineridae family were the most dominant. Shin and Koh (1992) and Han *et al*. (2015) reported that lumbrinerid polychaetes are abundant in the coastal waters off Pohang. Moreover, members of the Lumbrineridae family are recognized as indicator species for polluted environments, suggesting that their high abundance in this region may be associated with environmental degradation due to port facilities and wastewater inflow (Lee *et al*., 2003; Lee *et al*., 2023). Consequently, *P. yokohamae* is characterized as an opportunistic benthophagous carnivore primarily feeding on the abundant lumbrinerid polychaetes within its habitat.

The trophic level of *P. yokohamae* in this study was estimated at 3.08. In comparison, previous studies reported higher trophic levels for *P. yokohamae*, 3.33 in the Yellow Sea and 3.14 in Gwangyang Bay in the South Sea (Kwak and Huh, 2003; Roh *et al*., 2022). This difference likely reflects the dominance of polychaetes (91.9% of %*IRI*) in the present study, whereas a greater diversity of prey such as gastropods, fish, and amphipods was reported in previous studies, leading to higher trophic levels. Thus, *P. yokohamae* in the coastal waters off Pohang functions as a key intermediary in the local food web, primarily consuming low-trophic benthic organisms such as polychaetes and serving as prey for higher predators such as Pacific cod (*Gadus macrocephalus*) and Black edged sculpin (*Gymnocanthus herzensteini*) (Yoon *et al*., 2012; Yang *et al*., 2013).

Regarding ontogenetic changes, *P. yokohamae* across all size classes primarily consumed polychaetes, and no evident dietary shift was observed with growth. However, *P. yokohamae* exhibited a dietary shift from amphipods to polychaetes at a body length of 4.0 cm in Gwangyang Bay (Kwak and Huh, 2003) and at 8.0 cm in the Seto Inland Sea (Hata *et al*., 2016). In the Yellow Sea, the importance of polychaetes decreased while that of gastropods increased with growth (Roh *et al*., 2022). Because the specimens collected in the present study ranged from 14.4 to 47.6 cm in TL, smaller individuals (<14.0 cm) were not sampled. Juvenile *P. yokohamae* (≤10.0 cm) typically inhabits shallow seagrass beds or estuarine areas and migrate offshore as they grow (Kwak and Huh, 2003; Able *et al*., 2005), which may explain the absence of smaller individuals in this study. Therefore, it is presumed that dietary shifts occur at sizes below 10.0 cm, as suggested by the findings of Kwak and Huh (2003) and Hata *et al.* (2016), with juveniles feeding more heavily on small invertebrates such as amphipods.

Analysis of the mean number and weight of prey items per stomach by size class revealed that although the mean number of prey items per stomach did not differ significantly, the mean prey weight showed statistically significant differences among size classes. Previous studies have reported varying patterns: *P. yokohamae* from Tongyeong exhibited significant differences in both mean prey number and weight with growth (Huh *et al*., 2012), whereas individuals from the Yellow Sea exhibited significant differences in mean prey weight but not in prey number, consistent with the present study findings (Roh *et al*., 2022). Such regional differences are likely attributable to variations in dominant prey types, with bivalves dominating in Tongyeong and polychaetes in the Yellow Sea and Pohang.

Seasonal analysis indicated that polychaetes were the predominant prey across all seasons. Given their significant pollution in the coastal waters of Pohang, polychaetes, including lumbrinerids, which are known as pollution indicator species, are abundant year-round (Lee *et al*., 2003; Lee *et al*., 2023). The high abundance of polychaetes, coupled with limited escape ability compared to more mobile prey such as fish or cephalopods, suggests that *P. yokohamae* adopts an optimal foraging strategy with a high success rate.

Seasonal variations were also observed in the mean number and weight of prey items per stomach, with the highest values recorded in spring. The CF of *P. yokohamae* was lowest in March and increased thereafter until June. Considering that the spawning season for *P. yokohamae* in the East Sea occurs from December to February (Kim *et al*., 2016), the observed increase in feeding activity and prey intake during spring is likely associated with post-spawning energy recovery (Bond, 1979; Balanov *et al*., 2006; Baeck *et al*., 2010). The results of this study are expected to serve as fundamental data for research on the stock structure of *P. yokohamae*, as well as studies on interspecific and intraspecific food competition and food web dynamics.

Conclusion

The coastal waters off Pohang in the East Sea are continuously affected by the inflow of industrial effluents and domestic wastewater from nearby industrial complexes (Lee *et al*., 2003; Lee *et al*., 2023). Due to the bay-shaped geography of the region, these pollutants tend to accumulate in the benthic environment rather than being discharged outward. In this study, the marbled flounder (*P. yokohamae*) was found to feed primarily on benthic prey organisms. These findings suggest that future changes in the benthic environment may directly affect the feeding ecology of *P. yokohamae*. In particular, the accumulation of pollutants and shifts in benthic community composition could alter the diet composition and feeding patterns of this species. This study may serve as fundamental data for ecological restoration and resource management efforts such as juvenile release programs and sea forest creation aimed at enhancing the stocks of *P. yokohamae*. In such efforts, the importance of ensuring a stable food supply and improving benthic habitat conditions should be emphasized. Moreover, the results provide valuable baseline information not only for understanding the stock structure of *P. yokohamae*, but also for future studies on interspecific and intraspecific food competition and food web dynamics.

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