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Resource Use among Six Commercial Fish Species from the South-Eastern Gill Net Fisheries, Korea

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Abstract: Dietary habits and inter-specific differences in resource use among six commercial fish species, *Chelidonichthys spinosus*, *Cleisthenes pinetorum*, *Glyptocephalus stelleri*, *Hexagrammos otakii*, *Lophius litulon*, and *Sebastes schlegelii*, collected from the southern coast of the East Sea, Korea, were analyzed using stomach content and stable isotope analyses. Teleosts were the main prey items for *C. pinetorum* and *L. litulon*, while both crabs and teleosts contributed to the diets of *C. spinosus* and *S. schlegelii*. *Glyptocephalus stelleri* mainly consumed polychaetes and carid shrimps, and *H. otakii* mostly ingested crabs. The composition of prey items was significantly different in the diets of the six fish species. Further, carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) stable isotope values were significantly different among the six species, indicating different trophic positions. *L. litulon*, *C. pinetorum*, and *S. schlegelii* had narrow niches, whereas *C. spinosus*, *G. stelleri*, and *H. otakii* had relatively wider niches. This study demonstrated differences in patterns of food resource use among the six fish species that were categorized into two patterns of resource use according to their main prey items: diet diversity, trophic niche width, and trophic position. These results could contribute to the understanding of trophic relationships among fish species inhabiting the East Sea, Korea.

Keywords: demersal fish; stomach contents; stable isotopes; diet diversity; trophic niche; East Sea



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1. Introduction

Fish are secondary and/or tertiary consumers in marine ecosystems and often play an essential role as prey for higher trophic level predators [1,2]. Dietary studies and trophic dynamics are crucial for understanding the trophic positions of fishes and the trophic pathways of food resources that are utilized by fishes. Stomach content and stable isotope analyses are generally used to identify the trophic ecology of individual fishes and a group of fishes [3–5].

A stomach content analysis (SCA) allows the identification of high-resolution prey items that are directly fed upon by fish. Since this method provides taxonomic information on specific prey items, it can provide information on prey compositions that cooccur with predatory fishes and the extent of prey choices for certain prey items [6]. A number of studies have described the features of fish feeding ecology using SCA [5,7–9]. However, this method has a limitation in describing long-term and/or continuous prey selection of fishes, because the information reflects very short-term dietary choices of prey items that were ingested only a few hours ago when the fish are sampled [4,10]. This limitation could be supplemented with the stable isotope analysis (SIA), which can provide time-integrated information on feeding habits regarding prey items assimilated by consumers, thus providing long-term diet choices and food pathways [3]. Stable isotope analyses have been widely used to determine food sources, trophic positions, and trophic niche widths of marine organisms. A trophic

niche width calculated by a range of stable isotope values can offer diverse information on feeding types in consumer diets [11]. Although the trophic niche width caused by stable isotope values can be easily obtained, it is impossible to determine what prey items make up that trophic niche width. Therefore, combining the analyses of stomach contents and stable isotopes improves the interpretation of dietary studies of fishes and supplements taxonomical data with trophic niche information [12–14].

Several studies on the feeding habits of fish assemblages have been conducted, and their diet compositions have shown a significant degree of resource discrimination among cooccurring species [15–18]. Only a few studies on food resource use among cooccurring fish species have been conducted in the East Sea off the Korean coast [8], while most studies on the utilization of prey resources have been conducted by a single fish species. In addition, relatively few numbers of studies have been conducted on the trophic ecology of fish using both stomach content and stable isotope analyses globally [13,19,20]. The lack of such research using integrated methods was due to the difficulty of interpreting the results caused by the different temporal resolutions of the two methodologies [4].

This study demonstrated the food resource uses of six fish species, *Chelidonichthys spinosus* (McClelland, 1844), *Lophius litulon* (Jordan, 1902), *Glyptocephalus stelleri* (Schmidt, 1904), *Cleisthenes pinetorum* Jordan & Starks, 1904, *Hexagrammos otakii* Jordan & Starks, 1895, and *Sebastes schlegelii* Hilgendorf, 1880, which were dominant in terms of abundance during the study period. These species usually inhabit the near-bottom areas of coastal water. Among the six species, *S. schlegelii* and *H. otakii* usually inhabit rocky bottom areas at relatively shallow depths (~30 m), whereas *C. spinosus*, *G. stelleri*, *C. pinetorum*, and *L. litulon* inhabit relatively deeper waters (normally sandy and/or muddy bottoms) than the former two species [21,22]. In our survey of demersal fish assemblage, they were the most dominant in terms of abundance during warm seasons when the period coincided with intensive fishing seasons for flounders and rockfishes. In addition, the six species have been commonly caught as commercial target species of gillnet fisheries in the study area as well as adjacent coastal waters [23–25].

Consequently, the dietary habits of six commercial fish species in the East Sea, Korea, were assessed in this study. Research on the food utilizations of commercially important fish species inhabiting similar areas is an important approach in terms of ecological and fisheries aspects, because it can explain the mechanisms of ecological relationships such as food competition and/or partitioning among them [4]. Therefore, our objectives were to investigate the resource use patterns of *C. spinosus*, *L. litulon*, *G. stelleri*, *C. pinetorum*, *H. otakii*, and *S. schlegelii* using stomach content and stable isotope analyses. Therefore, this study provided comprehensive analyses of feeding habits of six common fish species using both SCA and SIA methods; this approach could contribute to the understanding of trophic relationships among fish species living in the East Sea, Korea.

2. Materials and Methods

2.1. Sampling

The sampling area was located in the southern part of the eastern Korean coast (35°30' N–35°93' N, 129°51' E; Figure 1). To cover the entire study area, sampling was conducted in three sites at depths between 30 and 50 m. Fish samples were collected during Korean late spring and early summer (between May and July 2016) using a bottom gill net (3 m in height, 66 mm inner mesh, and 606 mm outer mesh). The net was set near the bottom of each site and hauled after 24 h. This study investigated the diets of six fish species caught during the warm season, because the catches of the species were higher during the season when the water temperature had begun to increase in Southeastern Korean waters. Immediately after capture, the fish samples were packed with ice and transported to the laboratory for stomach content and stable isotope analyses. The total length (TL) and wet body weight of individual fish were measured to the nearest millimeter and gram, respectively. Stomachs were removed from each specimen, and the contents were preserved in 5% (*v/v*) formalin for 24 h and then transferred to 70% (*v/v*) isopropanol

until the stomach contents were analyzed. In addition, white dorsal muscle tissues from each specimen were excised and stored in a deep freezer until stable isotope analyses were conducted.

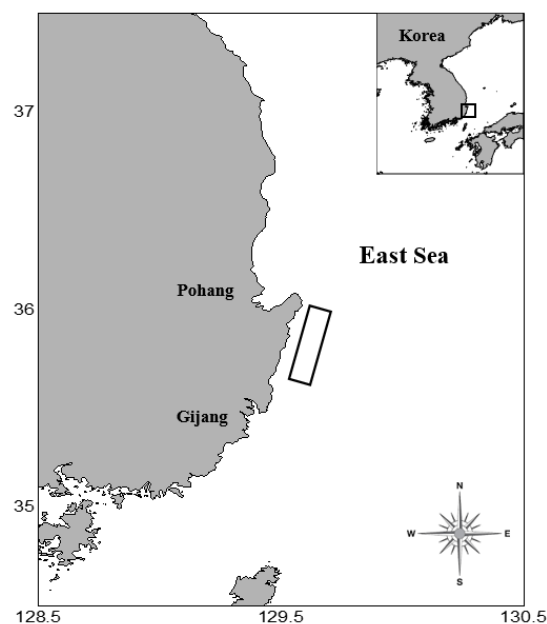


Figure 1. Location of the study area (within boxed area) in the southeastern waters off East Sea, Korea.

2.2. Stomach Content Analyses

The six target fish species were subjected to stomach contents analysis by extracting the stomachs (between esophagus and intestine), and the contents were examined under a stereomicroscope. Prey items were identified as accurately as possible to the species and then categorized into functional prey groups (generally at class or order levels). Diets were quantified by frequency of occurrence ($\%F = 100 \times A_i \times N^{-1}$), a numerical percentage ($\%N = 100 \times N_i \times N_T^{-1}$), and mass percentage for each specimen's diet ($\%M = 100 \times M_i \times M_T^{-1}$), where A_i is the number of fish preying on prey item I , N is the total number of fish examined (excluding those with empty stomachs), N_i (M_i) is the number (mass) of prey individuals i , and N_T (M_T) is the total number (mass) of prey individuals in the diets of individual fish (Table S1). Dietary data of six species were subjected using mass percentage data of the functional prey group for multivariate analyses, because gravimetric data produce stable and accurate diet descriptions and are considered to most accurately represent the relative importance of prey items, especially when prey items of different sizes are ingested [26,27]. In addition, ecological analyses using a taxonomic level higher group than the species level are less affected by environmental variables in the determination of prey compositions and can lead to visualizing the results of prey compositions more effectively [28]. Consequently, the mass percentage of prey items in the diets of the six fish species was square root-transformed to avoid any tendency of the main dietary components to be exclusively dominant, and a Bray–Curtis similarity matrix was constructed. The matrix was then subjected to permutational multivariate analysis of variance (PERMANOVA) and posterior pairwise analysis to evaluate differences in the diet compositions between fish species. Similarity of percentages (SIMPER) was used to calculate the contributions of prey items to the differences in the samples. A canonical analysis of principal coordinates (CAP) was used to identify the relationship between different prey items and fish species. Statistical analyses were performed using the software PRIMER v7 + add-on module [29].

Diet diversity was calculated for each fish species based on numerical dietary data using the Shannon–Wiener diversity index (H') [30].

2.3. Stable Isotope Analyses

SIA was performed on a randomly selected subset of samples. Prior to stable isotope analyses, each muscle was freeze-dried for 24 h at -80°C and ground into a powder using a mortar and pestle. The ground samples weighing approximately 0.001–0.002 g were packed into tin capsules, and the ratios of carbon and nitrogen stable isotopes were analyzed using an isotope mass spectrometer (Finnigan Delta C XL mass spectrometer) at the stable isotope laboratory of the University of Alaska, Fairbanks, AK, USA. The results are expressed in notation relative to the standards Pee Dee Belemnite and atmospheric N_2 for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, respectively, according to the equation $X (\text{‰}) = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000$, where X is ^{13}C or ^{15}N , and R is the mass ratio of the heavy-to-light stable isotopes $^{13}\text{C}/^{12}\text{C}$ or $^{15}\text{N}/^{14}\text{N}$ for either the sample or standard, respectively [27,31]. ANOVA was conducted to evaluate the differences in the mean stable isotope values ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) between fish species. Tukey's honest significant difference (HSD) test was used for post hoc comparisons following the ANOVA. To determine the trophic niche area of fish species, the convex hull total area (TA), standard ellipse area (SEA), and corrected standard ellipse area (SEAc) were calculated using carbon and nitrogen stable isotope values from each sample [32]. The TA is highly sensitive and exponentially increases according to the number of samples, while the SEA accurately represents the trophic niche. In addition, because a conventional SEA can be underestimated for a small sample size, SEAc can be used to avoid bias caused by small sample sizes and show each trophic niche width of six fish species [32]. Consequently, a more robust SEAc was used for estimating and comparing isotopic niche widths [33]. This process was performed using the Stable Isotope Bayesian Ellipses in the R (SIBER) package (software R version 4.2.1).

2.4. Trophic Position

Dietary composition data were used to estimate the trophic position with the aid of TrophLab software (June 2000 version, [34,35]). This software yields a trophic level (or TROPH value) that reflects the position of the organism within the food web, which largely defines the aquatic ecosystem. To estimate the trophic position of fish by prey item, it is necessary to consider both the dietary composition and trophic levels of their food item(s). A dietary trophic position (i.e., TROPH) of fish species is estimated to be $\text{TROPH}_i = 1 + \sum \text{DC}_{ij} \times \text{TROPH}_j$, where DC_{ij} is the proportion of prey "j" in the diet of predator "i", and TROPH_j is the trophic level of prey "j". The standard error (SE) of each TROPH value was estimated using the weight contribution and trophic level of each prey item in the diet. In terms of stable nitrogen isotopes, $\delta^{15}\text{N}$ values provide an indication of the trophic position of consumers [36]. Thus, the trophic position (TP) was calculated as follows: $\text{TP} = 1 + [(\delta^{15}\text{N}_{\text{sample}} - \delta^{15}\text{N}_{\text{baseline}})/3.4]$, where 1 represents the trophic position of primary consumers, 3.3 was used for the ^{15}N baseline, which is the average ^{15}N value of the primary prey source for the coastal marine ecosystem in the eastern waters off Korea [37], and 3.4 indicates an increment in $\delta^{15}\text{N}$ per 1.0 trophic level.

3. Results

3.1. Trend in Dietary Composition

The ranges of body lengths of six fish species were 15.6–31.0 cm in total length (TL) for *C. spinosus*, 15.6–31.2 cm TL for *C. pinetorum*, 19.1–28.7 cm TL for *G. stelleri*, 22.4–38.7 cm TL for *H. otakii*, 31.7–39.2 cm TL for *L. litulon*, and 16.7–31.8 cm TL for *S. schlegelii*. A total of 213 stomachs from six common fish species were analyzed. At least 17 taxa (functional prey groups) of prey items were identified from the stomachs of the six fish species (Table 1). In the stomach contents of *C. spinosus*, crabs accounted for the highest dietary contribution, comprising 41.68% of the mass percentage (%M), followed by teleosts (32.91%) and carid shrimps (21.56%). The *L. litulon* diet contained mostly teleosts, accounting for 85.53% by mass percentage, whereas cephalopods and carid shrimps had relatively low dietary contributions (less than 10% in %M). Similarly, *C. pinetorum* mainly consumed teleostes (64.34%) and cephalopods (20.22%), followed by carid shrimps (15.43%). The main prey items of *G. stelleri*

were polychaetes and carid shrimps, accounting for 37.31% and 30.80% of the mass dietary contributions, respectively. Crabs and carid shrimps comprised the main dietary contents of *H. otakii*, accounting for 51.56% and 20.00% of the diet, respectively. Teleosts (42.86%) were the primary prey items of *S. schlegelii*, followed by crabs and crinoids. Diet diversity was the highest in *C. spinosus* ($H' = 2.782$) and the lowest in *L. litulon* ($H' = 1.282$).

Table 1. Number of stomachs analyzed, percentage of empty stomachs, diet diversity, and mass contributions of prey organisms in the diets of six demersal fish species along the southeastern coast of East Sea, Korea (Species codes: CS, *Chelidonichthys spinosus*; LL, *Lophius litulon*; GS, *Glyptocephalus stelleri*; CP, *Cleisthenes pinetorum*; HO, *Hexagrammos otakii*; and SS, *Sebastes schlegelii*).

Taxa	CS	LL	GS	CP	HO	SS
Number of stomachs analyzed	62	62	26	28	10	25
Empty stomachs (%)	33.3	41.9	19.2	50.0	50.0	68.0
Diversity (H')	2.782	1.282	2.432	1.885	1.834	1.567
MACRO ALGAE *	0.10				0.36	
POLYCHAETA	0.34		37.31		13.08	
MOLLUSCA						
Bivalvia	1.03		11.28			
Cephalopoda	0.06	5.28		15.43	15.00	
CRUSTACEA						
Malacostraca						
Euphausiacea	0.03					
Stomatopoda	0.05					
Mysidacea	0.03					
Amphipoda	0.13		3.79			
Cumacea			0.04			
Decapoda unidentified	0.77					
Caridea	21.56	9.19	30.80	20.22	20.00	
Brachyura	41.68		0.29		51.56	28.57
Thoracica	1.31					
ECHINODERMATA						
Crinoidea						
CHORDATA						28.57
Ascidiacea						
Teleostei	32.91		8.07			
Unidentified material		85.53		64.34		42.86
Debris			8.42			

Note: * Almost Chlorophyta, Rhodophyta, Phaeophyceae.

The PERMANOVA test with unrestricted permutations of raw data revealed that the overall diet compositions of the six fish species were significantly different ($p < 0.05$, Pseudo-F = 11.974). Among the 15 pairwise comparisons of dietary compositions of the six fish species after PERMANOVA, 10 were significantly different ($p < 0.05$), whereas no significant differences were found for 5 pairwise comparisons (i.e., *C. spinosus* vs. *H. otakii*, *C. spinosus* vs. *S. schlegelii*, *C. pinetorum* vs. *L. litulon*, *C. pinetorum* vs. *S. schlegelii*, and *H. otakii* vs. *S. schlegelii*).

Bray–Curtis dissimilarity was the highest between *G. stelleri* and *S. schlegelii* (99.66%), whereas it was the lowest between *L. litulon* and *S. schlegelii* (48.59%). Based on SIMPER analysis, teleosts were the main prey group that contributed to the differences observed between two piscivores (*C. pinetorum* and *L. litulon*) and other species among most of all the species (Table 2). The dietary composition of *C. spinosus* was different from that of other fish species based on the greater abundance of crabs.

Table 2. Summary of results from the similarity of percentages (SIMPER) pairwise tests for differences among the dietary compositions of the six species. The values above the diagonal line indicate the dissimilarity percentages between the six species, and prey categories beneath the diagonal line are the top three dietary items that contribute the dietary differences between species (Species codes: CS, *Chelidonichthys spinosus*; LL, *Lophius litulon*; GS, *Glyptocephalus stelleri*; CP, *Cleisthenes pinetorum*; HO, *Hexagrammos otakii*; and SS, *Sebastes schlegelii*).

	CS	LL	GS	CP	HO	SS
CS	-	75.06	90.21	77.72	71.01	68.72
LL	Teleostei Brachyura Caridea	-	96.26	49.61	97.05	48.59
GS	Brachyura Caridea Polychaeta	Teleostei Polychaeta Caridea	-	90.09	86.83	99.66
CP	Teleostei Brachyura Caridea	Teleostei Caridea Cephalopoda	Teleostei Caridea Polychaeta	-	92.14	67.88
HO	Brachyura Caridea Teleostei	Teleostei Brachyura Caridea	Brachyura Polychaeta Caridea	Teleostei Brachyura Caridea	-	76.97
SS	Teleostei Brachyura Caridea	Teleostei Brachyura Caridea	Teleostei Brachyura Polychaeta	Teleostei Brachyura Caridea	Teleostei Brachyura Caridea	-

A canonical analysis of the principal coordinates further showed factors that indicated group separation among the six fish species. Teleosts were key in separating *C. pinetorum* and *L. litulon* from other species, whereas strong contributions of polychaetes and crabs were observed in the dietary samples of *G. stelleri* and *C. spinosus*, respectively. Consequently, the six fish species could be classified into three groups: the first group included piscivorous *C. pinetorum*, *L. litulon*, and *S. schlegelii*; the second group included *G. stelleri*, which primarily consumed polychaetes; and the last group contained *C. spinosus* and *H. otakii*, which mainly ingested crabs (Figure 2).

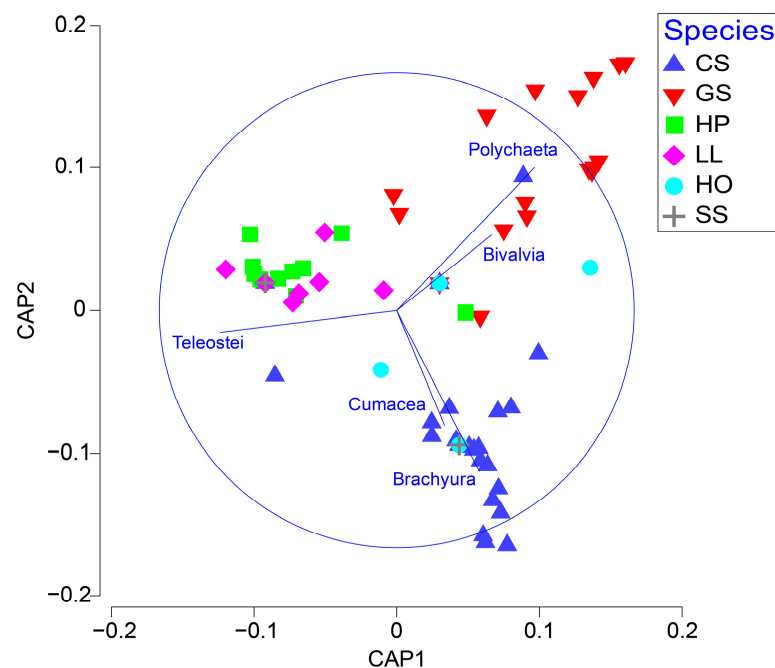


Figure 2. Canonical analysis of principal coordinates (CAP) showing the distribution of six fish species in a multivariate space. This graph indicated that the six fish species had distinct prey items associated with them (Species codes: CS, *Chelidonichthys spinosus*; LL, *Lophius litulon*; GS, *Glyptocephalus stelleri*; CP, *Cleisthenes pinetorum*; HO, *Hexagrammos otakii*; and SS, *Sebastes schlegelii*).

3.2. Stable Isotope Values

A total of 66 white muscle tissues (16 for *C. pinetorum*, 10 for *C. spinosus*, 13 for *G. stelleri*, 5 for *H. otakii*, 10 for *L. litulon*, and 12 for *S. schlegelii*) were analyzed. The range of $\delta^{13}\text{C}$ was from -19.529‰ to -16.015‰ , and $\delta^{15}\text{N}$ ranged from 10.670‰ to 13.381‰ . The highest mean $\delta^{13}\text{C}$ (-16.936‰) and $\delta^{15}\text{N}$ (12.895‰) values were observed in the muscle tissue of *H. otakii*, whereas the lowest mean values (-18.218‰ in $\delta^{13}\text{C}$ and 11.737‰ in $\delta^{15}\text{N}$) were observed in *C. pinetorum* (Figure 3). There were significant differences in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values between the six fish species (ANOVA, $p < 0.05$, F-value = 2.434 for $\delta^{13}\text{C}$ and 3.625 for $\delta^{15}\text{N}$). Tukey's post hoc tests indicated that the mean $\delta^{13}\text{C}$ value of *H. otakii* was higher than those of *C. pinetorum*, *L. litulon*, and *S. schlegelii*, whereas the mean $\delta^{15}\text{N}$ value of *C. pinetorum* was lower than those of *H. otakii*, *L. litulon*, and *S. schlegelii* (Tukey's HSD test, $p < 0.05$). The highest SEAc was shown in *G. stelleri*, whereas *C. pinetorum* had the lowest value. There were two patterns of SEAc values for the six species: *C. spinosus*, *G. stelleri*, and *H. otakii* showed relatively higher values, whereas *L. litulon*, *C. pinetorum*, and *S. schlegelii* showed lower values (ANOVA, $p < 0.05$) (Figure 3; Table 3). The trophic niche areas of the former species were also higher than those of the latter (Figure 4).

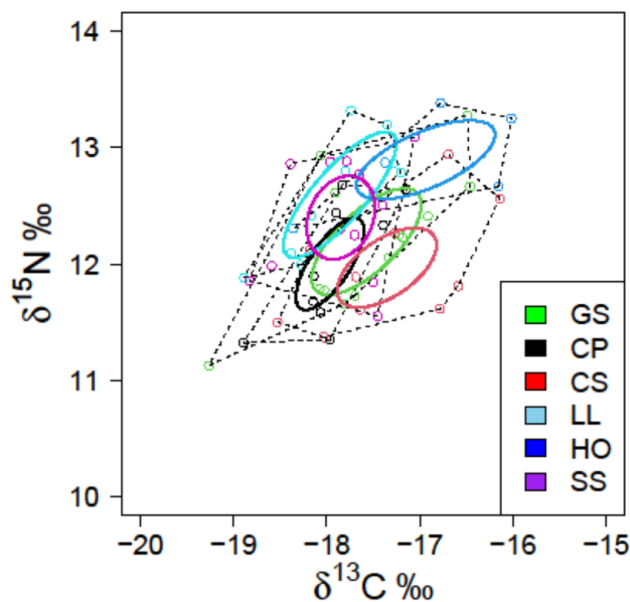


Figure 3. Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) stable isotope compositions for six fish species. The solid and dotted lines indicate corrected standard ellipse areas (SEAc) and convex hull total areas (TA) based on their stable isotope values, respectively (Species codes: CS, *Chelidonichthys spinosus*; LL, *Lophius litulon*; GS, *Glyptocephalus stelleri*; CP, *Cleisthenes pinetorum*; HO, *Hexagrammos otakii*; and SS, *Sebastes schlegelii*).

Table 3. Standard ellipse area (SEA) and corrected standard ellipse area (SEAc) values of six fish species in the study area (Species codes: CS, *Chelidonichthys spinosus*; LL, *Lophius litulon*; GS, *Glyptocephalus stelleri*; CP, *Cleisthenes pinetorum*; HO, *Hexagrammos otakii*; and SS, *Sebastes schlegelii*).

	CS	LL	GS	CP	HO	SS
SEA	1.016	0.524	1.019	0.507	1.015	0.807
SEAc	1.109	0.589	1.147	0.571	1.353	0.887

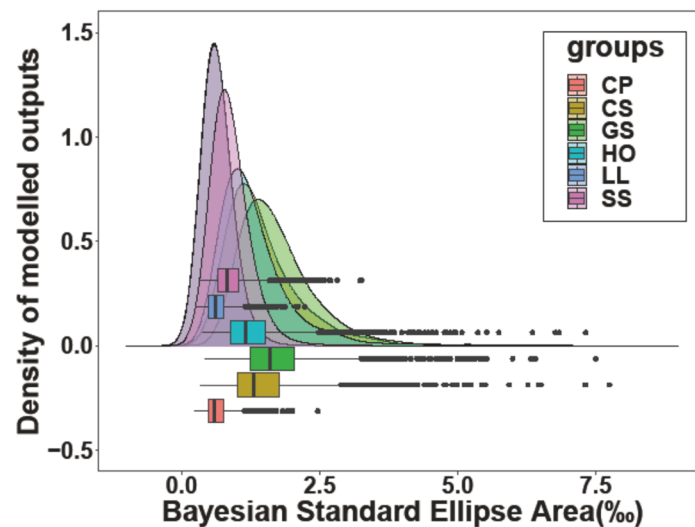


Figure 4. Bayesian standard ellipse areas showing the trophic niche for six fish species (Species codes: CS, *Chelidonichthys spinosus*; LL, *Lophius litulon*; GS, *Glyptocephalus stelleri*; CP, *Cleisthenes pinetorum*; HO, *Hexagrammos otakii*; and SS, *Sebastes schlegelii*).

3.3. Trophic Position

The trophic levels (TROPHs) estimated by stomach content analyses ranged from 3.38 to 4.08, while the values calculated from $\delta^{15}\text{N}$ ranged from 3.55 to 3.82. The mean TROPH values for *C. pinetorum*, *G. stelleri*, *H. otakii*, and *L. litulon* were higher than those for the nitrogen ($\delta^{15}\text{N}$) stable isotope (ANOVA, $p < 0.05$), whereas the opposite trends were evident for *C. spinosus* and *S. schlegelii* (ANOVA, $p > 0.05$). In addition, the species with the largest difference in trophic level, calculated by both dietary composition and nitrogen ($\delta^{15}\text{N}$) stable isotope value, was *L. litulon*, located away from the 1:1 line, whereas the smallest gap was observed in *S. schlegelii* (Figure 5).

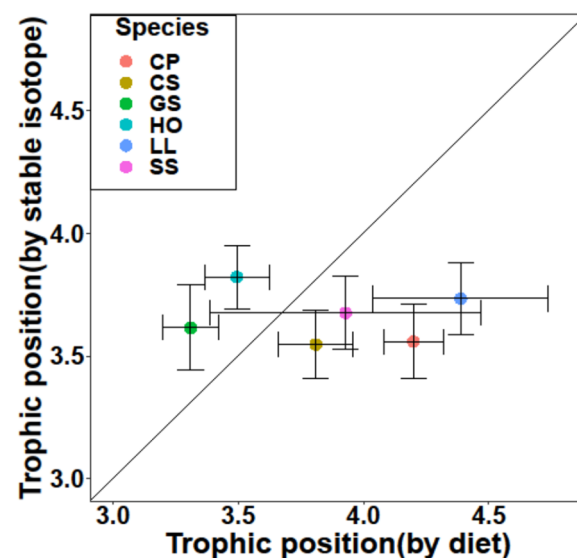


Figure 5. Comparison of the mean trophic position (\pm SD) estimates of the species included in this study, calculated using dietary and $\delta^{15}\text{N}$ methods.

4. Discussion

This study demonstrated the food resource uses of six fish species, *C. pinetorum*, *C. spinosus*, *G. stelleri*, *H. otakii*, *L. litulon*, and *S. schlegelii*, which were dominant in terms of abundance during the study period. These species usually inhabit the near-bottom areas of coastal waters. Among the six species, *S. schlegelii* and *H. otakii* usually inhabit rocky bottom

areas at relatively shallow depths (~30 m), whereas *C. spinosus*, *G. stelleri*, *C. pinetorum*, and *L. litulon* inhabit relatively deeper waters (normally sandy and/or muddy bottoms) compared to the former two species [21,22]. In our survey of demersal fish assemblage, they were the most common fish species and mainly caught during warm seasons when the period coincided with intensive fishing seasons for flounders and rockfishes. In addition, the six species have been commonly caught in the study area, as well as adjacent coastal waters [23–25]. Consequently, this study provided comprehensive analyses of feeding habits of six common fish species using both the SCA and SIA methods.

The results of the dietary analyses for the six species were comparable with those of previous studies undertaken at a larger scale in Korea and adjacent countries. For example, *C. spinosus* in this study primarily consumed decapod crustaceans (both crabs and carid shrimps) and teleosts secondarily. Similarly, *C. spinosus* inhabiting the southeastern coast of Korea and around Jeju Island collectively showed high contributions of decapods, including prawns, carid shrimps, and crabs, in the diets [38,39]. The diets of *L. litulon* in the southern part of the eastern Korean Sea, including the current study area, contained a high proportion of teleosts [40] and is thus regarded as a piscivorous fish. Broad-scale dietary studies of *G. stelleri* in the East Sea have shown that the species generally feeds on polychaetes, mollusks, and amphipods [41,42], which was similar to the present results. Several dietary studies of *S. schlegelii* have shown results consistent with those of the present study, consuming mainly teleosts and decapod crustaceans secondarily [43–46]. There are slightly different trends in prey choices between the current and previous studies for *C. pinetorum* and *H. otakii* [45–48]. Such differences might be attributed to regional differences in the available prey items and/or relatively small sample numbers to describe the feeding habits of *C. pinetorum* and *H. otakii* in this study. Nonetheless, some species such as *H. otakii* and *S. schlegelii* have shown considerably small sample sizes due to low catches and relatively high ratio of empty stomach, which seems not to have resulted in describing true dietary habits. Therefore, further studies are needed for those fish species.

Diet diversity showed distinct trends of diverse resource use among the six fish species, with higher values for *C. spinosus*, *G. stelleri*, and *H. otakii* and lower values for *L. litulon*, *C. pinetorum*, and *S. schlegelii*. These results are consistent with the dietary analyses of six species—that is, a higher diet diversity was characteristic of benthic invertebrate feeders (the former three species), while a lower diet diversity was shown in the diets of piscivores (the latter three species) (see Table 2). Based on the results of dietary dissimilarities, overall, the diets of the six fish species did not highly overlap (Table 2 and Figure 2). Prey choices of fish species are determined by the extent of accessibility for available prey resources and/or the ability of predators to select specific prey items according to the feeding strategy that maximizes the net energy gain [49–51]. For instance, among demersal fish species inhabiting the southern continental shelf of the East Sea, four benthic invertebrate feeders showed relatively higher dietary diversity and niche breadth, whereas these values were lower for piscivores and/or decapod feeders, indicating a more diversified diet for the former four fish species [8].

The resource uses of the six fish species were further assessed using stable isotope analyses, which is a complementary method for determining the trophic ecology of fish with the SCA. Stable isotopes can represent trophic sources accumulated in the body of a predator over several months [52]. Generally, fractionations of carbon and nitrogen isotopes are enriched by about <1‰ and 3–4‰ per trophic level, respectively [36,53–56]. Thus, a food source could be inferred from the $\delta^{13}\text{C}$ values, whereas $\delta^{15}\text{N}$ values are used as a predictor of the relative trophic position [36,56]. The $\delta^{13}\text{C}$ values for the six fish species in this study ranged from -19.529‰ to -16.015‰ , while those of $\delta^{15}\text{N}$ were between 10.670‰ and 13.381‰ . According to Kang et al. [37], the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of POM in offshore sites were $-22.1 \pm 1.3\text{‰}$ and $4.3 \pm 0.7\text{‰}$, and those of epilithic microalgae were $-18.8 \pm 1.8\text{‰}$ and $6.6 \pm 1.1\text{‰}$ in the eastern Korean peninsula, respectively. Therefore, the six fish species in this study appeared to be associated with benthic food webs, and they were positioned between secondary and tertiary predators.

The trophic niches described by SEAc for *C. spinosus*, *G. stelleri*, and *H. otakii* were relatively higher than those of the other species, indicating a wider Bayesian SEA. The results of higher SEAc may reflect diverse resource uses among the available food resources, which partially corresponds with the results of the diet diversity [57]. For example, the species that showed a wider trophic niche, including *C. spinosus*, *G. stelleri*, and *H. otakii*, showed a relatively high diet diversity based on the results of the SCA. The range of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in a consumer generally indicates the diversity of trophic resources and positions [58]. In addition, by comparing the results of diet diversity and SEAc results, there can be two types of resource uses, one with a wider trophic niche width and higher diet diversity and the other with a narrow trophic niche width and lower diet diversity.

In terms of trophic levels estimated by both the SCA and SIA, four fish species, *C. pinetorum*, *G. stelleri*, *H. otakii*, and *L. litulon*, showed significant differences between the two results, with consistently higher TROPH values than isotopic trophic levels. These dissimilarities often occur because of the different temporal resolutions of the two methods. Since SCA identifies the prey that are recently consumed and diverse species and SIA provides assimilated information of prey items for fish species, difference between the trophic levels estimated based on the analyses can generally occur [59–62].

In this study, differences in resource uses were observed among the six fish species based on the SCA and SIA. There were two types of resource uses for the six fish species: one included three fish species (*C. spinosus*, *G. stelleri*, and *H. otakii*) showing a higher consumption of benthic decapods and/or polychaetes, high diet diversity, and wider trophic niche widths, whereas the other three piscivores showed a relatively lower diet diversity and narrow trophic niche widths. Several studies have described the trophic ecology of fish species using both the SCA and SIA. For example, the three herbivorous Mediterranean fishes showed different trophic positions, especially in terms of the $\delta^{15}\text{N}$ values, but also indicated differences in prey choices among the taxa of benthic algae [62]. In the fish assemblage from the Western English Channel, although the SIA results reflected a high overlap of trophic niches among fish species, the SCA results indicated that their respective prey items were distinctly segregated [63]. The SCA and SIA did not always produce similar results due to different temporal resolutions [4], but the current study showed consistent trends of resource uses among the six species based on the two analyses. If the available food resources in the habitats are continuously maintained and the patterns of prey choice of the fish species are constant, the SCA and SIA will yield similar results in describing fish dietary habitats. Nevertheless, because the assimilation time of stable isotopes in the fish body is still unclear [64], there has been a limitation in understanding whether prey consumption in a short period of time accurately reflects the fish body due to the accumulation of stable isotopes over a long period.

In conclusion, we analyzed the prey resource utilization of six fish species usually caught in the East Sea off the southern Korean coast by using both the SCA and SIA. The results from this study effectively demonstrated the feeding relationships among the six fish species cooccurring in the study area. In addition, the SCA and SIA methodologies provided the extent of the resource uses for different prey resources among six fish species. Although the lack of sample numbers in this study limits our ability to describe the absolute diets of these species, analyses of the dietary habits and trophic ecology among these fish species are necessary to understand the biological relationships of benthic ecosystems in the southeastern waters of Korea. Overall, our results contribute to the understanding of trophic relationships among fish species inhabiting the East Sea, Korea.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/w15061146/s1>: Table S1: Frequency of occurrence (F) and numerical (N) and mass (M) percentages of prey organisms in the diets of six demersal fish species in the southeastern coast of East Sea, Korea (Species codes: CS, *Chelidonichthys spinosus*; LL, *Lophius litulon*; GS, *Glyptocephalus stelleri*; CP, *Cleisthenes pinetorum*; HO, *Hexagrammos otakii*; and SS, *Sebastes schlegelii*).

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