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# Comparative Analysis of Fish Community Structure between Eelgrass (*Zostera marina* L.) Beds and an Adjacent Unvegetated Area in Southern Korea

**Jeong Bae Kim, Jung Hwa Ryu[1] and Jin Koo Kim[2]***
*Environment Research Division, South Sea Fisheries Research Institute, NFRDI, Yeosu 556-823, Korea*
[1]*RyuJungHwa Marine Research Institute, 444-10, Gaya 3-dong, Busan 614-803, Korea*
[2]*Department of Marine Biology, Pukyong National University, 599-1, Daeyeon 3-dong, Nam-gu, Busan 608-737, Korea*

Fish community structure between eelgrass beds and an adjacent unvegetated area was investigated. Fishes were collected monthly from two eelgrass beds (Gamak and Yeoja Bays) and one adjacent unvegetated area in the southern sea of Korea between February 2006 and February 2007. The number of species for the Gamak and Yeoja Bays were 33, 28, respectively, while 28 species were identified from the unvegetated area. *Leiognathus nuchalis* was dominant in both Gamak and Yeoja Bays, while *Engraulis japonicus* was dominant in the unvegetated area. Cluster analysis conducted on total number of individuals for each species produced 3 groups; group A (appeared only in winter regardless of eelgrass), group B (appeared in eelgrass beds during all seasons except winter) and group C (appeared in the unvegetated area during all seasons except winter). The most important differentiating species between eelgrass beds and the unvegetated area were *Lateolabrax japonicus, L. nuchalis, Takifugu niphobles* and *Pholis nebulosa.* Based on the results of this study we can assume that eelgrass beds function as a nursery ground for young fishes from spring to fall, but not in winter.

Key words: Fish community, Population structure, Eelgrass, *Zostera marina*, *Lateolabrax japonicus*

## Introduction

*Zostera marina*, a perennial eelgrass species known as a marine seed plant, can be found on temperate and tropical coasts (den Hartog, 1970) and is regarded either as a food source for fish and shellfish, or a spawning/nursery ground for a number of fish species (Deegan et al., 2002; Kwak et al., 2003, 2004). Several studies have looked at the ecological importance of eelgrass, such as in relation to seasonal variation of fishes in eelgrass beds or seagrasses (Baeck et al., 2005; Huh and Kwak, 1997; Kim and Gwak, 2006; Lee and Lee, 2003; Lee et al., 2003; 2005; 2007) or nocturnal and diurnal differences of fish species composition in eelgrass beds (Huh and Kwak, 1997). Huh and Kwak (1998) have stated that young *Lateolabrax japonicus* appeared in eelgrass beds all year around and appeared to prefer small shrimp or fish, rather than the smooth skeleton shrimp *caprella*. More recently, Kwak et al. (2006) compared fish species composition between an eelgrass bed and an adjacent unvegetated area for the first time, showing that fish species were apparently more diverse in the eelgrass bed than the unvegetated area. There is still a paucity of data in this field, and as Kwak et al. (2006) suggested, detailed future studies are needed to look at food selectivity of fishes and defense mechanisms from predators in eelgrass beds.

Although numerous studies have aimed to understand ecosystem variations in eelgrass beds, the effects of eelgrass beds on fish community structure remains poorly understood. There is a need for more detailed comparative data in order to better clarify the function of eelgrass beds, specifically looking at physical and biological environmental conditions in different habitats.

*Corresponding author: taengko@pknu.ac.kr

In order to contribute to this knowledge-base, this study aimed to compare fish species composition and environmental characteristics in two different eelgrass beds and one unvegetated area as a control.

## Materials and Methods

### Sampling

This study was conducted in three regions; two adjacent eelgrass beds (Baekildo, Yeoja Bay; Wonpori, Gamak Bay) and one unvegetated area which was regarded as a control (Gongjeongri, Yeoja Bay). Specimens were collected once a month from February 2006 to February 2007, except in May, June and July of 2006 when collection was conducted twice monthly (Fig. 1), using a dragnet (length, 15m; left and right width, 3m; middle width, 15m; mesh size, 7.0 mm) three times in each sampling time and region (Fig. 2). Collected fishes were fixed in 10% formalin or 70% alcohol on the ship and then identified according to Kim et al. (2005) and Nakabo (2002). The two eelgrass beds were very shallow, 2-3 meters in depth, while the control unvegetated area was relatively deeper at 5-6 meters depth. The tidal range was on average 2.02 m, while tidal movement was 26-36 cm/sec. during sunrise and 26-51 cm/sec. during sunset (MOMAF, 2007). Water temperature, salinity and dissolved oxygen levels of the two study sites were measured monthly. Utilizing SCUBA, *Zostera marina* was also collected monthly using a square-shaped sphere to measure number of leaves per shoot, shoot height and width and length of leaves.

### Data analysis

To understand fish community structure, we calculated species richness (*d*, Margalef, 1963), species diversity index (*H'*, Shannon and Weaver, 1948), species evenness index (*J'*, Pielou, 1966) and species dominance index (λ, Simpson, 1949) using total number of individuals for each species.

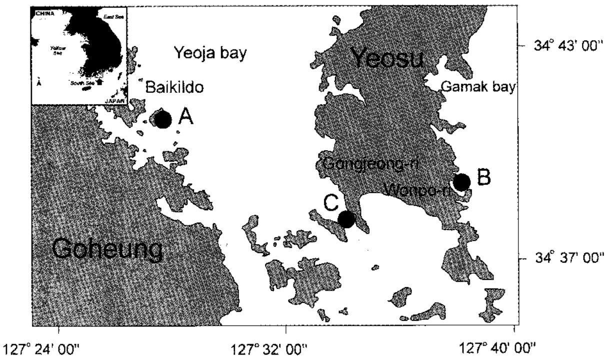


Fig. 1. Map showing the studying area. Baikildo (A) in Yeoja Bay and Wonpori (B) in Gamak Bay represent eelgrass beds and Gongjeongri (C) represents the unvegetated area.

$$D = \frac{S-1}{\log(N)}$$

$$H' = -\sum_{i=1}^{s}(pi)(\ln pi) \qquad pi = \frac{ni}{(N)}$$

$$J' = \frac{H'}{H'_{max}} = \frac{H'}{\ln S}$$

$$\lambda = \Sigma\left(\frac{ni}{N}\right)^2$$

where *pi* is the proportion of abundance of species *i* in a community were species individual number proportions are $p_1$, $p_2$, $p_3$,..., $p_n$, *S* is the number of species found and *N* is the total number of individuals.

For cluster analysis, we calculated the Bray-Curtis index of similarity and then constructed a dendrogram by UPGMA (Unweighted Pair Group Average Arithmetic) (Zar, 1999). All data were converted to fourth root to avoid bias in similarity analysis. We performed SIMPER in order to analyze species contribution in a community for each region resulting from community analysis (Clarke and Warwick, 2001).

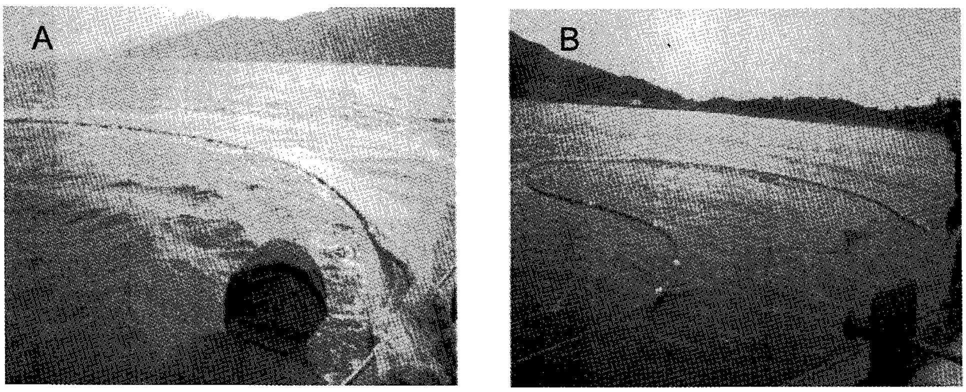


Fig. 2. Photographs showing sampling method, developing dragnet (A), towing dragnet (B).

$$S = 100\left\{1 - \frac{\Sigma_{j=1}^{n} |yij - ylj|}{\Sigma_{j=1}^{n} |yij + ylj|}\right\}$$

$$\delta = 100 - S$$

$$\delta_{ij}(i) = \frac{|yij - yik|}{\Sigma_{i=1}^{p}(yij + yik)}$$

where $y_{ij}$ is the entry in the *i*th row and *j*th column of the data matrix, i.e. the abundance for the *i*th species in the *j*sample. Similiarly, $y_{ik}$ is the count for the *i*th species in the *k*th sample. *S* is the Bray-Curtis similarity and $\delta$ is the dissimilarity between samples.

For all the above statistical analysis, we used PRIMER version 5.0. Furthermore, we carried out paired t-test and student *t*-test using SPSS version 12.0 to determine the effects of environmental factors, changes in growth of *Z. marina*, and comparative differences in fish community structure.

## Results

### Environmental condition

Water temperature at Gamak Bay and Yeoja Bay exhibited obvious seasonal variations (Fig. 3A). There was no significant difference in water temperature (minimum-maximum); 6.50 (February)-28.00°C (August) in Gamak Bay and 6.30 (February)-27.50°C (August) in Yeoja Bay (paired *t*-test, p>0.05). Salinity was slightly higher at Gamak Bay than Yeoja Bay, and salinity of the latter was strongly affected by rainfall (Fig. 3B). There was no statistical difference in salinity (minimum-maximum); 26.18 (July)-33.80 psu (February) in Gamak Bay and 22.02 (August)-33.90 psu (March) in Yeoja Bay (paired *t*-test, p> 0.05). There was no significant difference in dissolved oxygen (minimum-maximum); 5.90 (June)-11.06 mg/L (April) in Gamak Bay and 6.22 (June)-12.39 mg/L (January) in Yeoja Bay (Fig. 3C) (paired *t*-test, p>0.05).

*Zostera marina* was present during the entire study period. Number of its leaves per shoot [mimimum-maximum (average±SE)] was 4.8-6.7 (5.7±0.2) in Gamak Bay and 4.6-6.7 (5.4±0.2) in Yeoja Bay (Fig. 4A), showing significant difference (paired *t*-test, p< 0.05). Shoot height was least during winter, and greatest in early summer. Shoot height was 64.3-143.0 (92.7.9±3.1) cm in Gamak Bay and 63.3-137.3 (87.3±3.5) cm in Yeoja Bay (Fig. 4B), showing no significant difference (paired *t*-test, p>0.05). The width of leaves was 9.8-12.5 (10.8±0.3) mm in Gamak Bay and 7.5-10.5 (8.5±0.2) mm in Yeoja Bay (Fig. 4C), with statistical difference (paired *t*-test, p< 0.01). Length of leaves was 47.2-113.2 (73.0±3.2) cm in Gamak Bay and 48.9-49.7 (69.5±2.8) cm in Yeoja Bay (Fig. 4D), with no significant difference between the two eelgrass beds (paired *t*-test, p>0.05).

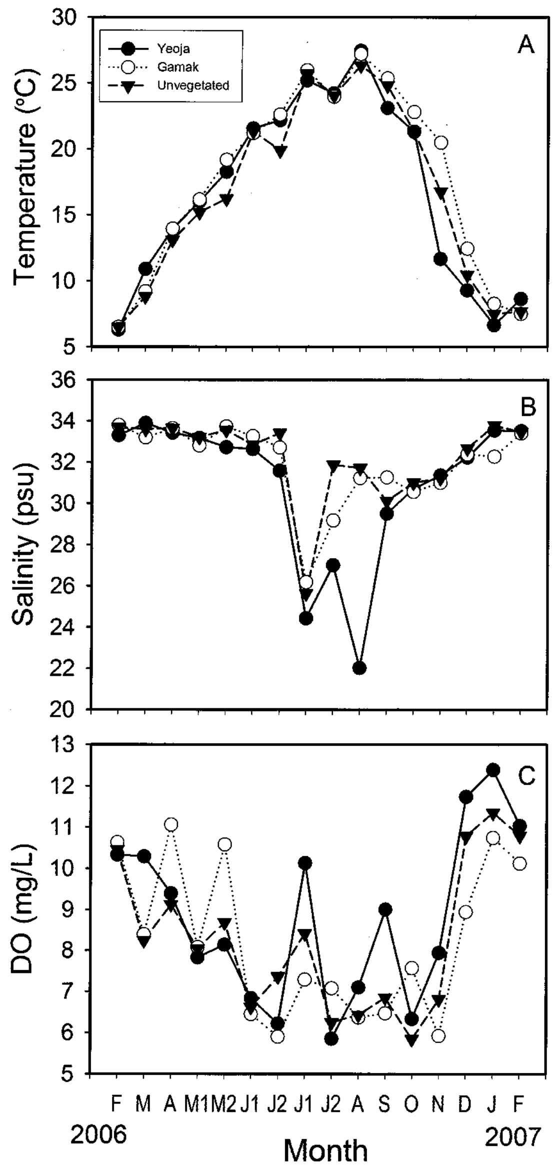


Fig. 3. Monthly variation of water temperature (A), salinity (B) and dissolved oxygen (C) levels in the two eelgrass beds.

### Fish species composition

The number of total individual species on sampling days ranged between 8-316 (average=102) in Gamak Bay, 3-245 (average=90) in Yeoja Bay and 0-2125 (average=158) in the unvegetated area (Fig. 5A). Although more individuals were sighted in the unvegetated area there was no significant difference among regions (paired *t*-test, p>0.05).

A total number of 33 fish species belonging to 23

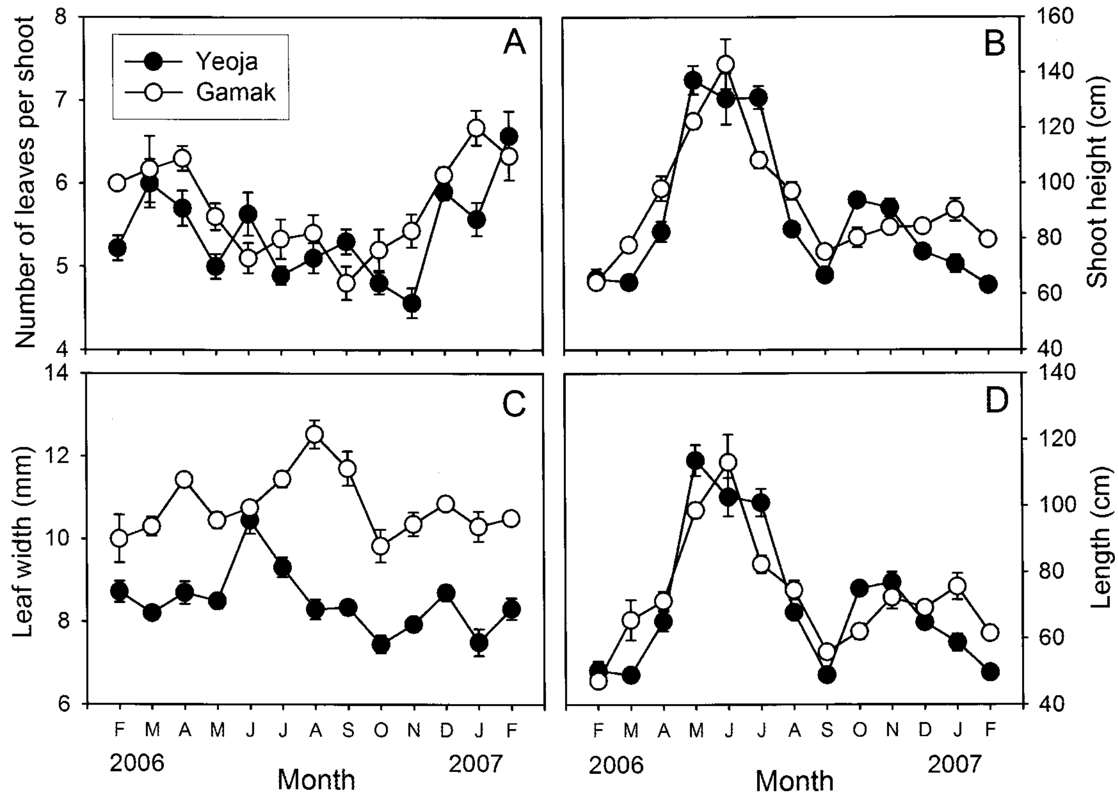


Fig. 4. Monthly variation of the number of leaves per shoot (A), shoot height (B), leaf width (C), leaf length (D) from the two eelgrass beds.

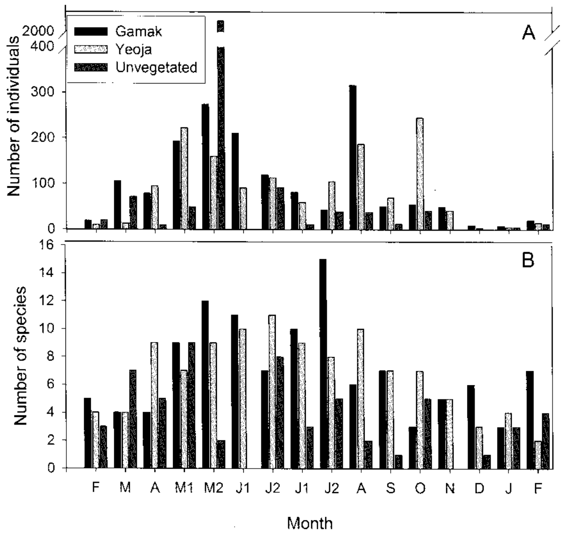


Fig. 5. Monthly variation of the number of individuals (A) and number of species (B) of fishes from the two eelgrass beds and the unvegetated area.

families under 8 orders were identified from Gamak Bay, 28 species belonging to 19 families under 8 orders from Yeoja Bay, and 28 species belonging to 19 families under 8 orders from the unvegetated area (Fig. 5B). The number of individuals in the two eelgrass beds differed significantly to the unvegetated area (paired *t*-test, $p<0.05$), but there was no significant difference between the two eelgrass beds (paired *t*-test, $p>0.05$). Among them, *L. nuchalis* (n=387, 23.77%), *L. japonicus* (182, 21.68%) and *Pholis nebulosa* (297, 18.24%) were dominant in Gamak Bay (Appendix I). Similarly, in Gamak Bay, *L. nuchalis* (32422.63%) was the most dominant species, followed by *L. japonicus* (291, 20.32%), *Thryssa adelae* (258, 18.02%) and *P. nebulosa* (137, 9.57%) in Yeoja Bay (Appendix II). In the unvegetated area, *Engraulis japonicus* (2,238, 88.67%) was the most dominant species, showing a clear difference compared to the two eelgrass beds. Young *L. japonicus* were found in Gamak Bay from April to December, and from April to July in Yeoja Bay (Appendix III).

Species richness was 0.50-3.75 in Gamak Bay, 0.38-2.12 in Yeoja Bay and 0.13-2.06 in the unvegetated habitat (Fig. 6A). There was no significant difference between Gamak and Yeoja Bays in species richness (paired *t*-test, $p>0.05$), however, the two eelgrass beds differed significantly compared to the unvegetated area (paired *t*-test, $p<0.05$). Species evenness was 0.11-0.97 in Gamak Bay, 0.43-0.96 in Yeoja Bay and 0.11-0.86 in the unvegetated area (Fig.

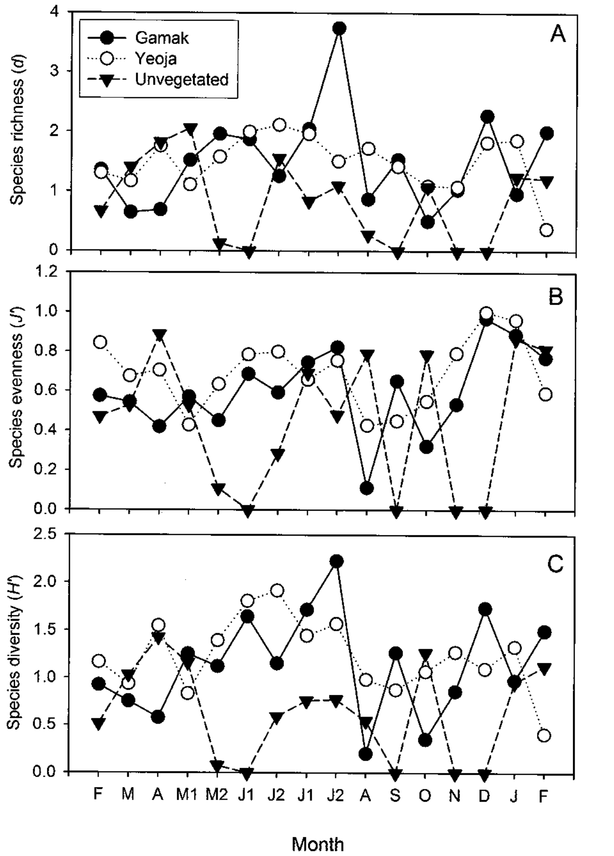


Fig. 6. Monthly variation of species richness (A), evenness (B) and diversity (C) of fishes from the two eelgrass beds and the unvegetated area.

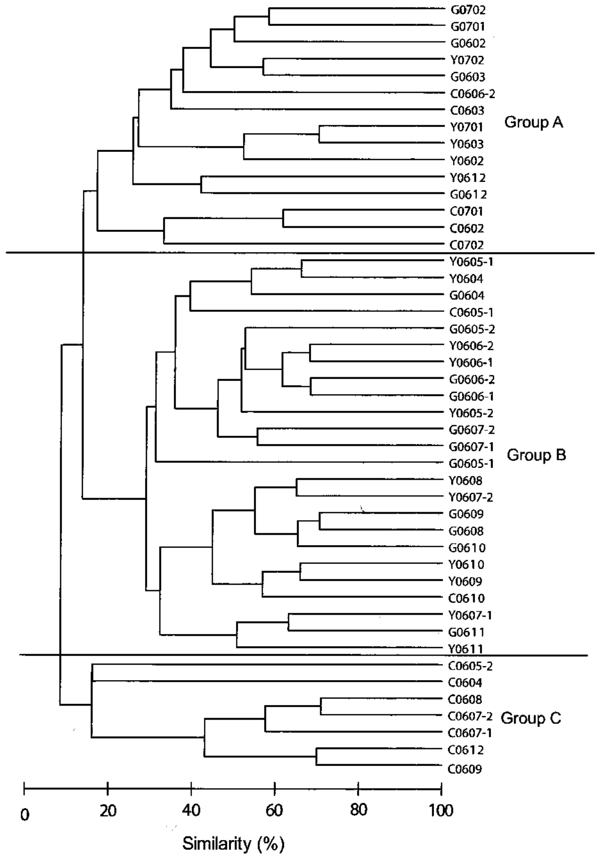


Fig. 7. Dendrogram illustrating relationship among sampling time and region based on the number of individuals collected from the three regions between February, 2006 and February, 2007. Y, G and C indicate Yeoja, Gamak and unvegetated area, respectively.

6B); the values in two eelgrass beds showed no significant difference (paired *t*-test, p>0.05), while those in Yeoja Bay differed significantly compared to the unvegetated area (paired *t*-test, p<0.05). Species diversity index was 0.20-2.24 in Gamak Bay, 0.41-1.92 in Yeoja Bay and 0.08-1.43 in the unvegetated area (Fig. 6C); There was no significant difference in species diversity between Gamak and Yeoja Bay (paired *t*-test, p>0.05), however, the two eelgrass beds differed significantly compared to the unvegetated area (paired *t*-test, p<0.05).

**Community structure**

Cluster analysis based on the number of individuals for each species yielded 3 groups; group A (appeared only in winter regardless of eelgrass), group B (appeared in eelgrass beds during all seasons except winter) and group C (appeared in the unvegetated area during all seasons except winter) (Fig. 7).

In group A, contribution was highest in *P. nebulosa* (63.2%), followed by *Hexagrammos otakii* at 16.0%. However, in group B, contribution was highest in *L. japonicus* (35.3%), followed by *L. nuchalis* at 24.6%. In group C, the highest contribution was by *E. japonicus* at 49.1% followed by *Hyporhampus sajori* at 43.0% (Table 1).

The top differentiating species between groups A and B was *L. nuchalis* (20.5%), which appeared throughout the year in eelgrass beds, but relatively less so in winter. This was followed by *L. japonicus* (18.0%) and *Takifugu niphobles* (8.7%) which were observed during all seasons, except winter, while *P. nebulosa* (13.1%) was observed during all seasons but less so in winter (Table 2).

The top differentiating species between groups A and C was *E. japonicus* (27.9%), followed by *P. nebulosa* (16.1%), *H. sajori* (12.0%) and *H. otakii* (9.7%) which showed relatively higher contribution in discriminating between these two groups (Table 2).

Species showing the highest contribution towards differentiation between groups B and C was *L. nuchalis* (17.8%), followed by *L. japonicus* (15.7%), *P. nebulosa* (8.7%), and *T. niphobles* (7.2%) (Table 2).

Table 1. Levels of contributions to average similarity of each group

| Group | Species name | Average individual | Contribution (%) | Cum. Contribution (%) |
|---|---|---|---|---|
| A | *Pholis nebulosa* | 9 | 63.2 | 63.2 |
| | *Hexagrammos otakii* | 6 | 16.0 | 79.3 |
| B | *Lateolabrax japonicus* | 29 | 35.3 | 35.3 |
| | *Leiognathus nuchalis* | 32 | 24.6 | 59.9 |
| | *Takifugu niphobles* | 7 | 11.5 | 71.4 |
| | *Pholis nebulosa* | 14 | 11.4 | 82.8 |
| C | *Engraulis japonicus* | 203 | 49.1 | 49.1 |
| | *Hyporhampus sajori* | 3 | 43.0 | 92.1 |

Table 2. Levels of contributions to average dissimilarity between group A and B (dissimilarity = 86.27), group A and C (dissimilarity = 94.21), group B and C (average dissimilarity = 84.95)

| Group | Species name | Average individual | | | Contribution (%) |
|---|---|---|---|---|---|
| | | Group A | Group B | Group C | |
| A and B | *Leiognathus nuchalis* | 0 | 32 | 2 | 20.5 |
| | *Lateolabrax japonicus* | 0 | 29 | 0 | 18 |
| | *Pholis nebulosa* | 9 | 14 | 0 | 13.1 |
| | *Takifugu niphobles* | 0 | 7 | 0 | 8.7 |
| | *Acanthogobius* sp. | 0 | 9 | 0 | 6.5 |
| A and C | *Engraulis japonicus* | 0 | 10 | 203 | 27.9 |
| | *Pholis nebulosa* | 9 | 14 | 0 | 16.1 |
| | *Hyporhampus sajori* | 0 | 2 | 3 | 12 |
| | *Hexagrammos otakii* | 6 | 0 | 0 | 9.72 |
| | *Clupea pallasii* | 0 | 2 | 6 | 5.2 |
| B and C | *Engraulis japonicus* | 0 | 10 | 203 | 19.9 |
| | *Leiognathus nuchalis* | 0 | 32 | 2 | 17.8 |
| | *Lateolabrax japonicus* | 0 | 29 | 0 | 15.7 |
| | *Pholis nebulosa* | 9 | 14 | 0 | 8.7 |
| | *Takifugu niphobles* | 0 | 7 | 0 | 7.2 |

## Discussion

A total of 45 species were collected using a dragnet from the three identified regions, of which 33, 28, and 28 species were identified in Gamak Bay, Yeoja Bay, and the unvegetated area, respectively. Huh and Kwak (1997) identified 57 species in eelgrass beds of Gwangyang Bay, which is more diverse than our results. This difference may be due to the use of different fishing gear (dragnet vs. bottom trawl net). Kim and Gwak (2006) identified 34 species in eelgrass beds of Geojedo utilizing a surf net , while 33 species were identified by Baeck et al., (2005) in Jindong Bay using a beam trawl. These results are smaller than ours, which was assumed due to differrent sampling efforts (16 vs. 14 times).

Cluster analysis was based on fish species composition divided into 3 groups; group A (appeared in winter regardless of eelgrass), group B (appeared in eelgrass bed except winter) and group C (appeared in unvegetated area except winter). This community structure characteristic may be associated with differrent water temperature (student *t*-test, $p<0.01$), salinity (student *t*-test, $p<0.05$) and dissolved oxygen (student *t*-test, $p<0.01$) levels. For example, in temperate areas, it has been shown that water temperature has an effect on community structure (Huh et al., 1997; Lee et al., 2000), which was confirmed in this study. Kim and Gwak (2006) have stated that eelgrass beds function as shelter and nursery grounds. However, our result revealed that eelgrass bed may not be working as a shelter and/or nursery grounds in winter.

With the exception of winter, *L. nuchalis* (average 32 individuals), *L. japonicus* (29), *E. japonicus* (10), *T. niphobles* (7) and *Syngnathus schlegeli* (2) were dominant in eelgrass beds all year around, while *E. japonicus* (203), *H. sajori* (3) and *L. nuchalis* (2) were dominant in the unvegetated area, resulting in clear differences between group B and C.

Comparing environmental factors in the two eelgrass beds, salinity was maintained over 30 psu until June but suddenly decreased from July. This was due to 333 mm of precipitation in July, which was the maximum amount in that year (KMA, 2009). Thereafter, salinity rapidly recovered to average levels in Gamak Bay, while low salinity of up to 22 psu lasted in Yeoja Bay until August. In addition, there were significant differences in width and the number of leaves of *Z. marina* between the two eelgrass beds. Despite these environmental differences, there was no difference in community structure between the two eelgrass beds.

Our results showed that the number of young *L. japonicus* peaked in May (16°C), being consistent with previous findings by Han et al. (2001), who stated that young *L. japonicus* prefer to live in water temperatures of between 14-16°C. Subsequently, young *L. japonicus* has a tendency to decrease in number from June (more than 20°C), suggesting that they may have migrated into deeper areas with growth. Regarding the appearance of young *L. japonicus* in an eelgrass bed, Huh and Kwak (1998) insisted that its high occurrence rate may be attributable to large amount of prey such as crustaceans. In addition, Huh and Kwak (1997) reported that *L. nuchalis*, abundant in eelgrass beds, feed mainly on copepods and crab larvae. In conclusion, eelgrass beds provide some species (e.g., *L. japonicus*, *L. nuchalis*, *P. nebulosa*, *T. niphobles*, *S. schlegeli* and *Tridentiger trigonocephalus*) with food source throughout the year, probably except in winter. We suggest that eelgrass beds should be protected and promoted for coastal ecosystem restoration.

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Appendix I. The abundance of species at each month in Gamak Bay (unit : inds./3 hauls)

| Year | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 07 | 07 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | F | M | A | M1 | M2 | J1 | J2 | J1 | J2 | A | S | O | N | D | J | F | Sum | % |
| Scientific name | | | | | | | | | | | | | | | | | | |
| Congridae sp. | 0 | 0 | 0 | 107 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 108 | 6.6 |
| *Engraulis japonicus* | 0 | 0 | 0 | 0 | 29 | 51 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 82 | 5.0 |
| *Thryssa adelae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.1 |
| *Clupea pallasii* | 0 | 0 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 1.2 |
| *Konosirus punctatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 0.2 |
| *Mugil cephalus* | 0 | 22 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 26 | 1.6 |
| *Strongylura nastomella* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.1 |
| *Hyporhampus sajori* | 0 | 0 | 0 | 4 | 1 | 0 | 1 | 16 | 3 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 28 | 1.7 |
| *Aulichthys japonicus* | 1 | 2 | 0 | 0 | 2 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 2 | 17 | 1.0 |
| *Hippocampus* sp. | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.1 |
| *Syngnathus schlegeli* | 0 | 0 | 3 | 7 | 3 | 4 | 0 | 4 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 26 | 1.6 |
| *Syngnathus* sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.1 |
| *Macrohamphosus scolopax* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.1 |
| *Sebastes thompsoni* | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0.4 |
| *Sebastes schlegelii* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.1 |
| *Platycephalus indicus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 4 | 0.3 |
| *Hexagrammos agrammus* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.1 |
| *Hexagrammos otakii* | 0 | 4 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 0.4 |
| *Pseudoblennius cottoides* | 2 | 0 | 0 | 0 | 2 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 10 | 0.6 |
| *Lateolabrax japonicus* | 0 | 0 | 9 | 50 | 18 | 17 | 12 | 27 | 16 | 8 | 15 | 4 | 4 | 2 | 0 | 0 | 182 | 21.7 |
| *Lateolabrax maculatus* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0.2 |
| *Sillago japonica* | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.1 |
| *Leiognathus nuchalis* | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 1 | 0 | 304 | 26 | 49 | 0 | 0 | 0 | 0 | 387 | 23.8 |
| *Pagrus major* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.1 |
| *Acanthopagrus schlegelii* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.1 |
| *Upeneus japonicus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.1 |
| *Ditremma temmincki* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.1 |
| *Zoarchias uchidai* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.1 |
| *Pholis nebulosa* | 14 | 77 | 65 | 0 | 33 | 66 | 26 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 3 | 10 | 297 | 18.2 |
| *Acanthogobius flavimanus* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 8 | 0.5 |
| *Acanthogobius* sp. | 0 | 0 | 0 | 0 | 0 | 58 | 72 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 132 | 8.1 |
| *Tridentiger trigonocephalus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 1.3 |
| *Takifugu niphobles* | 0 | 0 | 0 | 1 | 4 | 4 | 3 | 12 | 3 | 1 | 4 | 1 | 37 | 0 | 0 | 4 | 74 | 4.6 |
| Sum | 19 | 105 | 78 | 193 | 103 | 211 | 119 | 81 | 42 | 316 | 50 | 54 | 49 | 9 | 8 | 20 | 1,457 | 100 |

Appendix II. The abundance of species at each month in Yeoja Bay (unit : inds./3 hauls)

| Year | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 07 | 07 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | F | M | A | M1 | M2 | J1 | J2 | J1 | J2 | A | S | O | N | D | J | F | Sum | % |
| Scientific name | | | | | | | | | | | | | | | | | | |
| Congridae sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.07 |
| *Engraulis japonicus* | 0 | 0 | 0 | 0 | 90 | 0 | 9 | 0 | 0 | 3 | 3 | 22 | 0 | 0 | 0 | 0 | 127 | 8.87 |
| *Thryssa adelae* | 0 | 0 | 0 | 6 | 14 | 0 | 9 | 0 | 32 | 128 | 1 | 68 | 0 | 0 | 0 | 0 | 258 | 18.02 |
| *Thryssa kammalensis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 3 | 0.21 |
| *Clupea pallasii* | 0 | 0 | 14 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 1.61 |
| *Sardinella zunasi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 7 | 0 | 0 | 0 | 0 | 15 | 1.05 |
| *Konosirus punctatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.07 |
| *Mugil cephalus* | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.21 |
| *Hyporhampus sajori* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 7 | 0.49 |
| *Syngnathus schlegeli* | 0 | 0 | 4 | 2 | 5 | 2 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 1.12 |
| *Sebastes thompsoni* | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.14 |
| *Platycephalus indicus* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 5 | 0.35 |
| *Hexagrammos agrammus* | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.14 |
| *Hexagrammos otakii* | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 5 | 0.35 |
| *Liparis tanakai* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.07 |
| *Lateolabrax japonicus* | 0 | 0 | 33 | 166 | 31 | 14 | 16 | 10 | 19 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 291 | 20.32 |
| *Sillago japonica* | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0.42 |
| *Leiognathus nuchalis* | 0 | 0 | 0 | 0 | 5 | 17 | 14 | 1 | 33 | 42 | 53 | 144 | 15 | 0 | 0 | 0 | 324 | 22.63 |
| *Acanthopagrus schlegelii* | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0.77 |
| *Oplegnathus fasciatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.07 |
| *Zoarchias uchidai* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.07 |
| *Pholis nebulosa* | 5 | 9 | 33 | 37 | 9 | 24 | 4 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 12 | 137 | 9.57 |
| *Acanthogobius flavimanus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 15 | 1.05 |
| *Acanthogobius* sp. | 0 | 0 | 0 | 0 | 0 | 23 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 67 | 4.68 |
| *Tridentiger trigonocephalus* | 3 | 2 | 1 | 0 | 2 | 4 | 4 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 2 | 0 | 22 | 1.54 |
| *Tridentiger* sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.07 |
| Gobiidae sp. | 0 | 1 | 6 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 11 | 0.77 |
| *Takifugu niphobles* | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 32 | 14 | 5 | 1 | 0 | 16 | 0 | 0 | 0 | 76 | 5.31 |
| Sum | 10 | 13 | 95 | 222 | 160 | 91 | 113 | 59 | 105 | 187 | 69 | 245 | 41 | 3 | 5 | 14 | 1,432 | 100 |

Appendix III. The abundance of species at each month in the unvegetated area (unit : inds./3 hauls)

| Year | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 06 | 07 | 07 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | F | M | A | M1 | M2 | J1 | J2 | J1 | J2 | A | S | O | N | D | J | F | Sum | % |
| Scientific name | | | | | | | | | | | | | | | | | | |
| Congridae sp. | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0.08 |
| *Engraulis japonicus* | 0 | 0 | 2 | 2 | 2,094 | 0 | 80 | 1 | 30 | 29 | 0 | 0 | 0 | 0 | 0 | 0 | 2,238 | 88.67 |
| *Thryssa adelae* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 5 | 0.2 |
| *Thryssa kammalensis* | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 8 | 0.32 |
| *Clupea pallasii* | 0 | 0 | 0 | 35 | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 66 | 2.61 |
| *Sardinella zunasi* | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 16 | 0.63 |
| *Mugil cephalus* | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.12 |
| *Hyporhampus sajori* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 8 | 6 | 9 | 12 | 0 | 0 | 1 | 0 | 0 | 37 | 1.47 |
| *Aulichthys japonicus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.04 |
| *Hippocampus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.04 |
| *Syngnathus schlegeli* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0.04 |
| *Sebastes inermis* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.08 |
| *Platycephalus indicus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.04 |
| *Hexagrammos agrammus* | 0 | 11 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0.55 |
| *Hexagrammos otakii* | 17 | 50 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 79 | 3.13 |
| *Pseudoblennius cottoides* | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.08 |
| *Pseudoblennius* sp. | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.08 |
| *Lateolabrax japonicus* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.04 |
| *Trachiurus japonicus* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.16 |
| *Leiognathus nuchalis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 0 | 0 | 0 | 19 | 0.75 |
| Stichaeidae sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0.16 |
| *Ernogrammus hexagrammus* | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.08 |
| *Zoarchias uchidai* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.04 |
| *Pholis nebulosa* | 0 | 3 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0.28 |
| *Ammodytes personatus* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.04 |
| *Tridentiger trigonocephalus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 2 | 0.08 |
| Gobiidae sp. | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 0.12 |
| *Takifugu niphobles* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.08 |
| Sum | 20 | 71 | 9 | 49 | 2,125 | 0 | 91 | 11 | 39 | 38 | 12 | 41 | 0 | 1 | 5 | 12 | 2,524 | 100 |