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# Diversity and Assemblage Structure of Marine Fish Species Collected by Set Net in Korean Peninsula During 2009–2013

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**Abstract** – Assemblage structure analysis was conducted based on seasonal fish species composition data collected four times a year during 2009–2013 from 10 stations around Korea (except the western coast of Korea) using set nets. A total of 154 fish species were identified, of which *Trachurus japonicus* (22.1%) was the most dominant, followed by *Konosirus punctatus* (9.2%) and *Scomber japonicus* (8.7%). Species richness was highest in Jumunjin (in the mid-eastern coast of Korea) and lowest in Gijang (in the east-southern coast of Korea), and species diversity was highest in Gangjeong (southern Jejudo Island) and lowest in Hanrim (northern Jejudo Island). Based on a Bray–Curtis similarity index value of 38%, the 10 stations were divided into three groups: group A comprised four stations in the eastern coast of Korea, group B comprised four stations in the east-southern coast of Korea and Jejudo Island, and group C comprised two stations in the west-southern coast of Korea. One-way analysis of similarities showed significant differences among groups (global R: 0.822, $p = 0.001$). The characteristics of the sea currents (e.g., Tsushima Warm Current, North Korea Cold Current) and water masses (e.g., Yellow Sea Bottom Cold Water) might have influenced this grouping.

**Keywords** – marine fish, diversity, assemblage structure, set net

## 1. Introduction

The Korean peninsula is surrounded by water on the west (Yellow Sea), south (East China Sea), and east (East Sea) (Fig. 1) and is subject to the effects of various sea currents and water masses (Kim 2009). The distinct environmental characteristics of each sea affect the fish species diversity, particularly as a result of paleoclimatic change and/or contemporary sea currents (Rebstock and Kang 2003; Jung et al. 2013; Kim et al. 2015, 2017; Bae et al. 2020). Of the three seas, the eastern and southern seas of Korea, including Jejudo Island, are dominated by the impacts of the Tsushima Warm Current, unlike the western sea of Korea (Seung 1992; Rebstock and Kang 2003). The eastern sea of Korea is very deep, with an average depth of 1,684 m and thermal fronts generated near Jukbyun, where the East Korea Warm Current (originating from the Tsushima Warm Current) encounters the North Korea Cold Current (Gong and Son 1982; Seung 1992). The eastern sea of Korea is home to a wide variety of fish species, including warm- and cold-water species and deep-sea species (Han et al. 2002; Ryu et al. 2005; Sohn et al. 2015). On the other hand, the southern sea of Korea is shallow, ranging from 100–200 m in depth, and is divided into the western and eastern channels. The western channel (namely Chu-ja channel) is affected by the Yellow Sea Bottom Cold Water, the Tsushima Warm Current, and freshwater influx, while the eastern channel (namely Korea Strait) is affected only by the Tsushima Warm Current and freshwater influx (Kim et al. 1999). Jejudo Island in the western channel of the southern sea of Korea is affected by a nexus of environmental factors such as the Tsushima Warm Current, China's coastal water mass, the Yellow Sea Bottom Cold Water, and the southern coastal water mass (Kim et al. 1999; Choi et al. 2008). Although many studies on seasonality and fish community structure related to global warming have been conducted (Kim 2009), all of those have been limited to a local area. Comprehensive and integrated research on the diversity and assemblage structure of fish over a wider area is needed for better understanding and precise predicting of marine ecosystem change.

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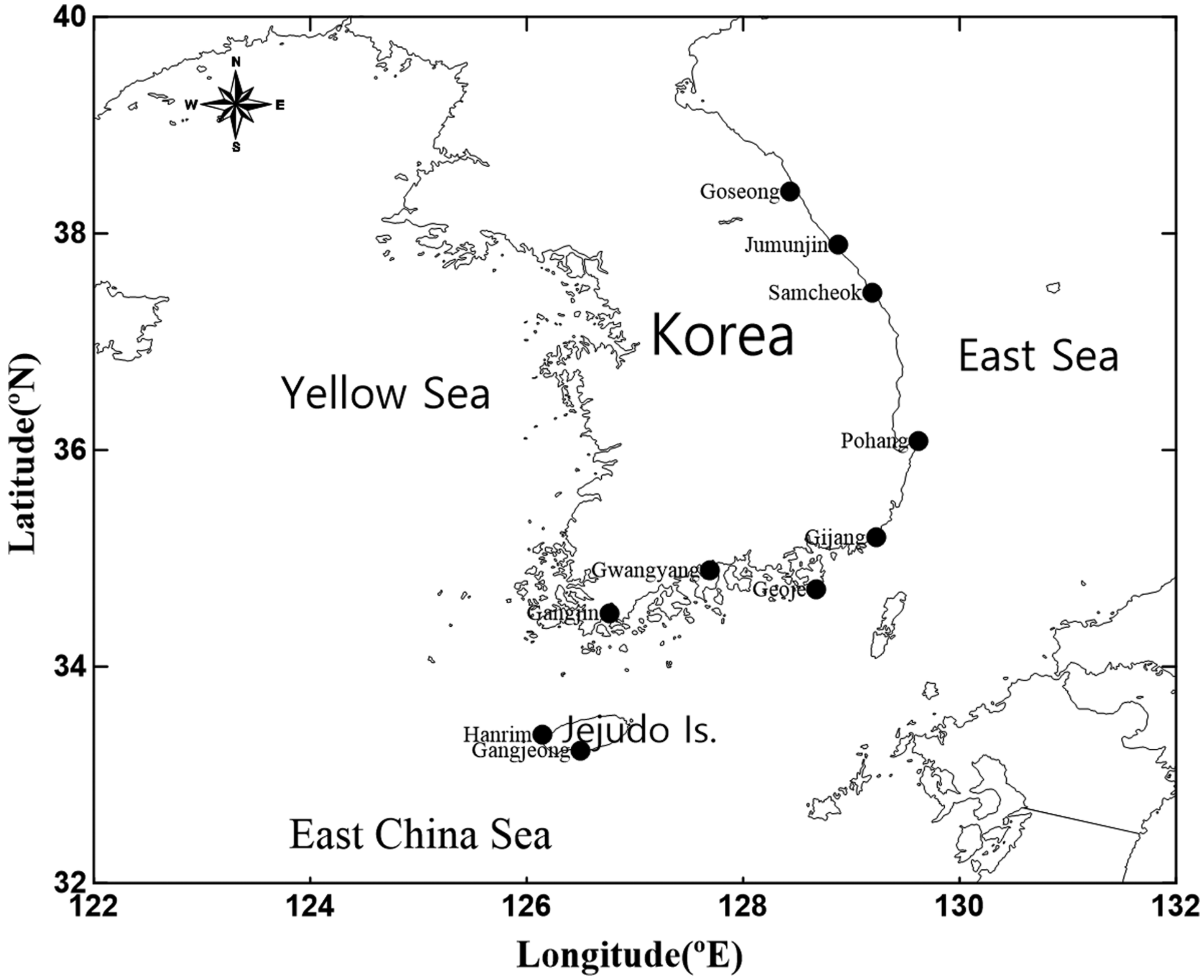


**Fig. 1.** Map showing the sampling sites (10 stations) in the waters around Korea

The set net technique employed in this survey comprises fishing gear that entices schools of fish into coastal waters and is significantly affected by surface water temperature, with stationary nets set at shallow depths of 10–40 m (Kim et al. 1999, 2009). Rising surface water temperatures have recently resulted in the frequent occurrence of subtropical species around Jejudo Island and in the eastern sea of Korea (Kim et al. 1999; Kim 2009; Jung et al. 2013), in turn leading to changes in the structure of the fisheries industry and in the diet of people. This study analyzed the species diversity and assemblage structure of marine fish using set nets on Jejudo Island, the southern coast of Korea, and the eastern coast of Korea to gain a better understanding of the shifts in marine fish distribution driven by various sea currents (e.g., Tsushima Warm Current) and water masses (e.g., Yellow Sea Bottom Cold Water), and assessed the implications of the findings for biogeographical barriers with regard to marine fish species.

## 2. Materials and Methods

The survey recorded fish species in the southern coast of Korea (SCK, 2009–2010), Jejudo Island (JJ, 2011), and the eastern coast of Korea (ECK, 2012–2013). Throughout the survey, fish species were seasonally collected (four times a year) from 10 stations (40 collections in total), including two stations on JJ (Gangjeong and Hanrim), four stations in the SCK (Gangjin, Gwangyang, Geojedo, and Gijang), and four stations in the ECK (Pohang, Samcheok, Jumunjin, and Goseong) (Fig. 1). The survey used set nets (net width 250 m, net length 800 m, mesh size 50 × 50 mm) at all stations. Because we could not find set nets to use in the western sea of Korea, the western coast of Korea was excluded here. The nets were installed and kept in place for ~24 h before hauling. All fish caught in the nets were collected. Larger catches were divided into several groups for transportation to the laboratory, where all the fish were identified and grouped according to species. Species identification and classification were carried out in accordance with Nakabo (2002), Kim et al. (2005), and Kim and Ryu (2017). Data concerning water temperature and salinity during the survey period were collected from the Marine Environment Information System (https://www.meis.go.kr/portal/main.do) for analysis. The Shannon–Wiener Diversity Index (Pielou 1977) was applied to delineate the ecological index. We also generated a dendrogram based on the Bray–Curtis similarity index and applied the unweighted pair-group method with the arithmetic mean technique, with data transformed to the fourth root, to evaluate the assemblage structure of each station (Zar 1999). To compare the subgroups, one-way analysis of similarities and similarity percentage analysis were used to identify the species contribution in a community for each region resulting from the community structure, a process that contributed to delineation of the subgroups (Clarke and Warwick 2001). These analyses were conducted using PRIMER 6.0 software.

## 3. Results

### Environmental variables

Seasonal water temperature records collected during the survey period revealed that the water temperature was highest in Gangjeong on Jejudo Island during the winter (February), with an average temperature of 14.9°C, and was lowest in Goseong in the mid-ECK, with an average temperature of 6.2°C. During the spring (May), the water temperature was highest in Gwangyang in the west-SCK, at 17.8°C, and lowest in Goseong in the mid-ECK, at 13.4°C. During the summer (August), water temperature was highest in Gijang in the east-SCK, at 27.8°C and lowest in Geojedo, close to Gijang in the east-SCK, at 23.8°C. During the autumn (November), the water temperature was highest in Gangjeong on southern JJ at 22.8°C and lowest in Pohang in the south-ECK at 14.1°C. These results indicate that the east-SCK tends to be warmer than the west-SCK, the southern coast of JJ is warmer than its northern coast of JJ, and the south-ECK is warmer than the mid-ECK (Fig. 2A).

In terms of seasonal salinity, in February, the recorded salinity was highest in Gangjeong and Harim on JJ, at 34.5 psu, and lowest in Gwangyang in the west-SCK, at 32.7 psu. In May, salinity was highest in Hanrim on northern JJ, at 34.4 psu, and lowest in Geojedo in the east-SCK, at 33.6 psu. In August, it was highest in Gijang in the east-SCK, at 33.7 psu, and lowest in Gwangyang in the west-SCK, at 26.5 psu. In November, Hanrim on northern JJ showed the highest salinity, at 34.3 psu, and Gangjin in the west-SCK the lowest salinity, at 31.9 psu (Fig. 2B).

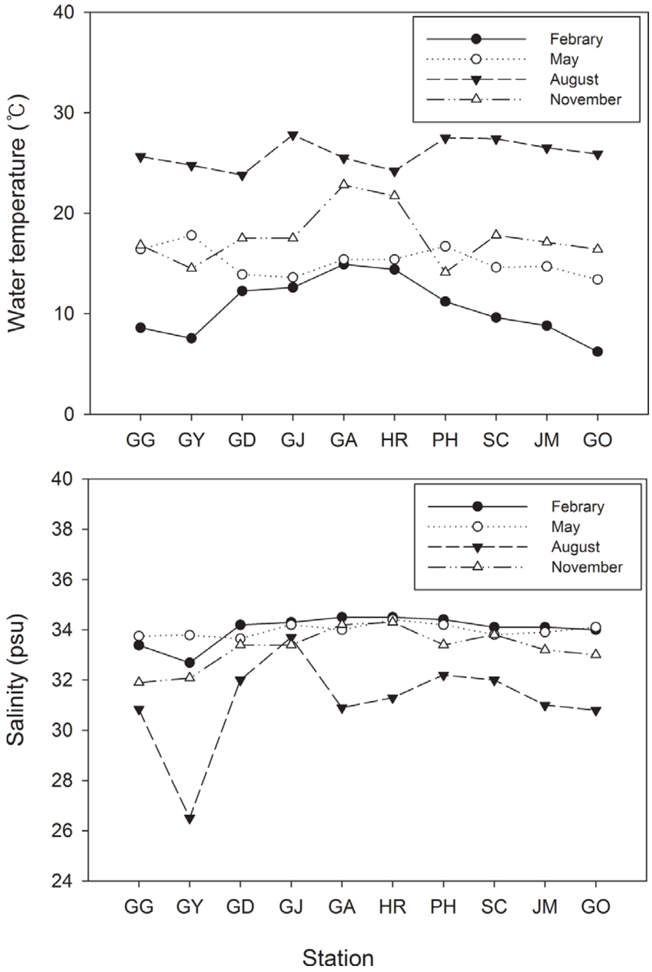


**Fig. 2.** The water temperature (A) and salinity (B) of the surface layer at the 10 sampling stations between 2009 and 2013. GG: Gangjin; GY: Gwangyang; GD: Geojedo; GJ: Gijang; GA: Gangjeong; HR: Hanrim; PH: Pohang; SC: Samcheok; JM: Jumunjin; GO: Goseong

### Species diversity

A total of 154 marine fish species were collected from 10 stations throughout JJ, SCK, and ECK using set nets from 2009 to 2013. Among those species, *Trachurus japonicus* (22.1%) was recorded as the most dominant, followed by *Konosirus punctatus* (9.2%) and *Scomber japonicus* (8.7%) (Table A1). In terms of individual stations, Jumunjin in the mid-ECK yielded the highest number of species (48 spp.), whereas Gijang in the east- SCK yielded the lowest (33 spp.). The average number of species across all stations was 40 (Fig.

3A). The highest (2,303 inds.) and lowest (292 inds.) numbers of individual fish were recorded in Jumunjin in the mid- ECK and Gangjeong on southern JJ (Fig. 3B). The Shannon–Wiener diversity index was calculated for each station and was highest (3.0) in Gangjeong on southern JJ and lowest (1.3) in Hanrim on northern JJ (Fig. 3C).

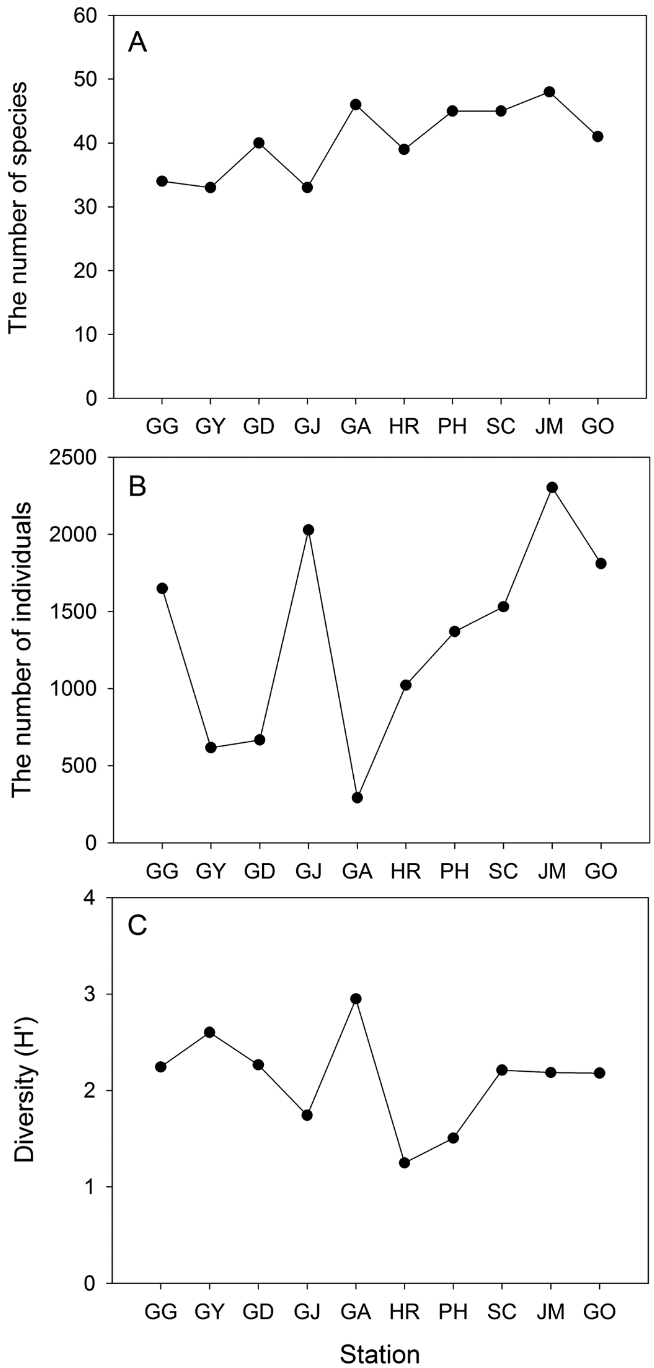


**Fig. 3.** The number of species (A), number of individuals (B), and diversity (C) between 2009 and 2013 at the 10 stations located in Korean waters. GG: Gangjin; GY: Gwangyang; GD: Geojedo; GJ: Gijang; GA: Gangjeong; HR: Hanrim; PH: Pohang; SC: Samcheok; JM: Jumunjin; GO: Goseong

**Assemblage structure**

The assemblage structure was analyzed based on the marine fish species composition collected at the 10 stations. Based on a Bray–Curtis similarity index value of 38%, the surveyed stations were divided into three groups (A, B and C): group A included the four stations (Pohang, Samcheok, Jumunjin, and Goseong) in the ECK, group B incorporated the two stations (Gijang and Geojedo) in the east-SCK and the two stations (Gangjeong and Hanrim) on JJ, and group C included the remaining two stations (Gangjin and Gwangyang) in the west-SCK (Fig. 4). One-way analysis of similarities revealed significant differences among groups A, B and C (global R: 0.822, p = 0.001). According to the similarity percentage analysis, groups A and B were distinguished by the presence (or dominance) of the species *Oncorhynchus masou masou, Konosirus punctatus*, and *Thamnaconus modestus*; groups B and C were distinguished by the presence (or dominance) of the species *Nuchequula nuchalis*, *Chelon haematocheilus*, and *Trachurus japonicus*; and groups A and C were distinguished by the presence (or dominance) of the species *N. nuchalis*, *T. modestus*, and *Scomber japonicus* (Table A2).

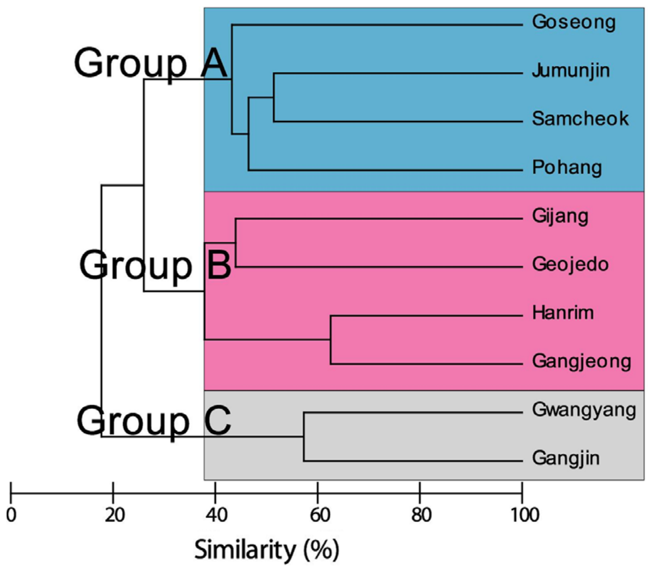


**Fig. 4.** Dendrogram showing the relationship among the 10 sampling stations based on the number of individuals of each species collected from Jejudo Island, southern coast and eastern coast of Korea between 2009 and 2013

## 4. Discussion

This study aimed to clarify the fish assemblage structure in the waters around the Korean peninsula by investigating seasonal variations in fish species collected for 5 years between 2009 and 2013 using set nets deployed around JJ, the SCK and the ECK, which are strongly affected by the Tsushima Warm Current. During the survey period, a total of 154 marine fish species were identified. The fish assemblage analysis revealed that the sampling stations were divided into three groups: 1) the ECK, 2) the east-SCK and JJ, and 3) the west-SCK. We assumed that the SCK formed two quite different fish assemblages (east and west, respectively), possibly due to the effects of different sea currents or water masses. Since two completely different currents (East Warm Current and the North Korea Cold Current) coexist in the ECK, such complex oceanographic characteristics would have separated the ECK from the other seas. Unlike our results, however, a community structure analysis based on demersal fish species using Danish seine fishery showed that the two clusters were formed north and south on the boundary of Jukbyun (Sohn et al. 2015). This may be due to differences between pelagic and benthic ecosystem in the ECK. The west-SCK is affected by coastal water influx from the Yellow Sea, whereas the east-SCK and JJ are strongly affected by the Tsushima Warm Current (Seung 1982; NFRDI 2010, 2011). Recent population genetics studies on *Konosirus punctatus*, *Hippocampus mohnikei* and *Takifugu niphobles* identified differences in the genetic composition between the east- and west-SCK (Myoung and Kim 2014; Han et al. 2019; Bae et al. 2020), which may be attributable to biogeographic barriers caused by different oceanic characteristics in the east- and west-SCK.

The most dominant species throughout the survey period was *Trachurus japonicus*, which was predominant in Geojedo and Gijang in the east-SCK, and Hanrim of JJ in May. In August, it was the dominant species found in Geojedo and Gijang in the east-SCK, Hanrim of JJ, and Pohang in the south-ECK, indicating that it moved northwards. In November, it was found predominantly in Geojedo in the east-SCK, Gangjeong and Hanrim of JJ, and Jumunjin in the mid-ECK, indicating that it moved further to the north. *T. japonicus* has three known populations (southern East China Sea, middle East China Sea, and northern Kyushu populations) (Yamada et al. 2007); the middle East China Sea population migrates north up to Eocheong-do Island in the Yellow Sea from May to June and then migrates south during the fall, and the northern Kyushu population migrates to JJ from May to June and moves further up to Gyeongsangbukdo Province from September to October before returning south in November (Lee 1970). In our study, we found that *T. japonicus* did not return south in November but moved further north to Gangwondo Province, indicating that the migratory range of *T. japonicus* was extended to the north. The result shows that the northern distribution limits of the warm-water fish species such as *T. japonicus* are gradually shifting north. Goseong of Gangwondo Province, the northernmost survey station in our study, showed frequent occurrences of warm-water fish species such as *K. punctatus*, *Zeus faber*, *Seriola quinqueradiata*, and *T. modestus* in 2013, which is significantly different from the results of a previous survey carried out in Goseong using set nets (Ryu et al. 2005), which reported 0 ind. of *K. punctatus*, 2 inds. of *Z. faber*, 22 inds. of *S. quinqueradiata*, and 1 ind. of *T. modestus*. During the present survey, a total of 41 fish species were identified in Goseong during four sampling times, which was slightly higher than the results of a previous study (36 species during four sampling times; Ryu et al. 2005). This was because of differences in the surface seawater temperature (SST); the average SST in the surveyed waters of our study was 15.5°C, 0.8°C higher than that in Ryu et al. (2005). Seawater temperature is the most crucial environmental factor affecting the ocean ecosystem. Many studies have shown evidence of fish species alternation (e.g., *Scomber japonicus* vs. *Sardinops melanostictus*, see Zhang et al. 2000; *Engraulis japonicus* vs. *S. melanostictus*, see Kim and Kang 2000) related to climatic regime shifts occurring in the late 1980s or early 1990s. In addition, abrupt change in the distributional area of fish (e.g., walleye pollock, Pacific cod, pointhead flounder and shotted halibut) was detected by comparing a geographical information system map based on fishing data between the 1980s and 1990s (Tian et al. 2008). According to long-term observations conducted in the English Channel (Hawkins et al. 2003), physical environmental changes lead to significant changes in the species composition of marine organisms. Those studies suggest long term monitoring researches are necessary for better understanding of marine ecosystem change so that more accurate predications can be made about such change.

In our study, 45 fish species were identified at the sampling station of Samcheok in the mid-ECK, which is significantly different from the results of Kang et al. (2014), who identified 38 species in Uljin (Hupo) and 25 species in Samcheok (Jangho) in the mid-ECK in 2006. Jukbyun, located on the boundary between Gyeongsangbukdo Province and Gangwando

Province, is where the East Korea Warm Current and the North Korea Cold Current meet (Choi et al. 2010), resulting in frequent occurrences of cold-water species in the north and warm-water species in the south (Kang et al. 2014). Kang et al. (2014) recorded a SST of 24.7°C in Uljin (Hupo) and 22.0°C in Samcheok (Jangho) in August, and this 2.7°C difference is remarkable considering the two sites are located only ~100 km apart. It should be noted that twice as many species were identified in Samcheok (Jangho) in our study as the number identified by Kang et al. (2014), which may be associated with an increase of up to 5.4°C in SST in this area (from 22.0°C in August 2006 to 27.4°C in August 2013).

The effects of global warming are evident in Korea's coastal and offshore waters, with recent abrupt increases in SST during the winter season and the higher catch of warm-water species, particularly in the East Sea (Rebstock and Kang 2003). From our study, it is evident that the extent of species composition change was relatively greater in the ECK than in the SCK due to the more rapid increase in SST. The East Korea Warm Current flowing north and North Korea Cold Current flowing south along the ECK meet and form a front zone near Jukbyun (Gong and Son 1982; Lee and Jeon 2005; Kang et al. 2014); however, it is assumed that the front zone has recently moved further north to Jumunjin due to the rising SST. This assumption is supported by the results of various recent population genetic studies (Kim et al. 2010; Hong et al. 2012; Kim et al. 2015, 2017; Jang et al. 2019; Bae et al. 2020). We believe that this study will improve our knowledge of the rapidly changing ocean ecosystem around the Korean peninsula due to global warming and will thus enable us to minimize damage to the fishery industry and reframe the country's aquaculture industry.

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## Appendix

**Table A1.** Species compositions of fish using a set net in 10 stations of Korea between 2009 and 2013

| Scientific name \ Station | GG | GY | GD | GJ | GA | HR | PH | SC | JM | GO | Sum | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Okamejei kenojei* | 0 | 0 | 6 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 8 | 0.043 |
| *Urolophus aurantiacus* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Dasyatis akajei* | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0.011 |
| *Anguilla japonica* | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0.029 |
| *Muraenesox cinereus* | 3 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0.052 |
| *Conger myriaster* | 14 | 5 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 22 | 0.126 |
| *Coilia nasus* | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.023 |
| *Engraulis japonicus* | 13 | 2 | 1 | 2729 | 11 | 0 | 0 | 150 | 3 | 0 | 2909 | 16.653 |
| *Thryssa adelae* | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 80 | 0.458 |
| *Thryssa kammalensis* | 155 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 156 | 0.893 |
| *Clupea pallasii* | 0 | 18 | 9 | 972 | 1 | 1 | 0 | 10 | 0 | 6 | 1017 | 5.819 |
| *Etrumeus teres* | 0 | 0 | 0 | 86 | 4 | 2 | 2 | 0 | 0 | 0 | 94 | 0.538 |
| *Konosirus punctatus* | 223 | 28 | 44 | 42 | 0 | 0 | 0 | 5 | 327 | 524 | 1193 | 6.827 |
| *Sardinella zunasi* | 44 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 64 | 0.366 |
| *Sardinops melanosticta* | 0 | 0 | 0 | 0 | 2 | 6 | 0 | 85 | 4 | 0 | 97 | 0.555 |
| *Spratelloides gracilis* | 0 | 0 | 0 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 0.077 |
| *Tribolodon hakonensis* | 0 | 82 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 84 | 0.481 |
| *Oncorhynchus keta* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 48 | 48 | 0.275 |
| *Oncorhynchus masou masou* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 221 | 605 | 827 | 4.734 |
| *Maurolicus japonicus* | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0.049 |
| *Benthosema pterotum* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.003 |
| *Trachipterus ishikawae* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0.006 |
| *Zu cristatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0.011 |
| *Gadus macrocephalus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 27 | 0.155 |
| *Lophius litulon* | 0 | 0 | 3 | 0 | 0 | 0 | 11 | 14 | 12 | 26 | 66 | 0.378 |
| *Chelon haematocheilus* | 212 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 218 | 1.248 |
| *Mugil cephalus* | 29 | 32 | 14 | 2 | 0 | 0 | 2 | 0 | 17 | 40 | 136 | 0.776 |
| *Iso flosmaris* | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0.043 |
| *Cheilopogon doederleini* | 0 | 0 | 0 | 6 | 7 | 22 | 0 | 0 | 0 | 0 | 35 | 0.198 |
| *Cypselurus hiraii* | 0 | 0 | 0 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 37 | 0.209 |
| *Hyporhamphus sajori* | 11 | 0 | 0 | 12 | 0 | 0 | 1 | 2 | 6 | 0 | 32 | 0.180 |
| *Ablennes hians* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0.011 |
| *Strongylura anastomella* | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 0.017 |
| *Cololabis saira* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 11 | 0.063 |
| *Zenopsis nebulosa* | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 33 | 78 | 0 | 124 | 0.710 |
| *Zeus faber* | 0 | 0 | 11 | 1 | 13 | 16 | 0 | 2 | 1 | 15 | 59 | 0.335 |
| *Syngnathus schlegeli* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.003 |
| *Fistularia commersonii* | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 5 | 0.029 |
| *Fistularia petimba* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Inimicus japonicus* | 0 | 1 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 5 | 0.029 |
| *Sebastes inermis* | 0 | 5 | 6 | 2 | 0 | 11 | 0 | 0 | 0 | 6 | 30 | 0.169 |
| *Sebastes schlegelii* | 0 | 0 | 3 | 1 | 0 | 0 | 53 | 7 | 8 | 25 | 97 | 0.555 |
| *Sebastes thompsoni* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0.011 |
| *Sebastiscus marmoratus* | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 4 | 0.023 |
| *Chelidonichthys spinosus* | 1 | 0 | 15 | 2 | 0 | 0 | 10 | 4 | 1 | 18 | 51 | 0.289 |
| *Platycephalus indicus* | 5 | 1 | 6 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 13 | 0.074 |

**Table A1.** Continued

| Station / Scientific name | GG | GY | GD | GJ | GA | HR | PH | SC | JM | GO | Sum | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Hexagrammos agrammus* | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.017 |
| *Hexagrammos otakii* | 0 | 9 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 1 | 14 | 0.080 |
| *Pleurogrammus azonus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 0.572 |
| *Alcichthys elongatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 4 | 0.023 |
| *Gymnocanthus herzensteini* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 | 0.017 |
| *Gymnocanthus intermedius* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 11 | 16 | 0.092 |
| *Hemilepidotus gilberti* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0.011 |
| *Trachidermus fasciatus* | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0.029 |
| *Hemitripterus villosus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0.011 |
| *Aptocyclus ventricosus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 6 | 14 | 22 | 0.126 |
| *Eumicrotremus orbis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 0.011 |
| *Liparis tanakae* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 6 | 0.034 |
| *Lateolabrax japonicus* | 8 | 25 | 10 | 1 | 0 | 0 | 3 | 1 | 3 | 14 | 65 | 0.369 |
| *Lateolabrax maculatus* | 7 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 | 0.229 |
| *Acropoma japonicum* | 0 | 0 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0.100 |
| *Doederleinia berycoides* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0.011 |
| *Epinephelus chlorostigma* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.0057 |
| *Cookeolus japonicus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0.006 |
| *Apogon lineatus* | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 0.020 |
| *Apogon notatus* | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 9 | 0.052 |
| *Apogon semilineatus* | 0 | 0 | 1 | 0 | 10 | 5 | 0 | 0 | 0 | 0 | 16 | 0.092 |
| *Sillago japonica* | 30 | 7 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 39 | 0.223 |
| *Scombrops boops* | 0 | 0 | 1 | 1 | 9 | 2 | 0 | 0 | 0 | 0 | 13 | 0.074 |
| *Coryphaena hippurus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 79 | 0 | 88 | 0.504 |
| *Rachycentron canadum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0.011 |
| *Caranx sexfasciatus* | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.017 |
| *Decapterus macrosoma* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.009 |
| *Decapterus maruadsi* | 0 | 0 | 6 | 45 | 0 | 0 | 6 | 1 | 5 | 0 | 63 | 0.358 |
| *Kaiwarinus equula* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 3 | 0.017 |
| *Seriola aureovittata* | 0 | 0 | 0 | 1 | 3 | 1 | 0 | 0 | 1 | 0 | 6 | 0.031 |
| *Seriola dumerili* | 0 | 0 | 0 | 3 | 5 | 7 | 1 | 0 | 15 | 0 | 31 | 0.177 |
| *Seriola quinqueradiata* | 0 | 1 | 1 | 0 | 1 | 1 | 58 | 7 | 17 | 52 | 138 | 0.790 |
| *Trachurus japonicus* | 0 | 124 | 163 | 1421 | 141 | 812 | 114 | 76 | 916 | 6 | 3773 | 21.597 |
| *Nuchequula nuchalis* | 589 | 124 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 713 | 4.082 |
| *Hapalogenys analis* | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0.011 |
| *Parapristipoma trilineatum* | 0 | 0 | 0 | 0 | 22 | 10 | 0 | 0 | 0 | 0 | 32 | 0.183 |
| *Acanthopagrus schlegelii* | 23 | 20 | 13 | 0 | 0 | 0 | 0 | 0 | 27 | 56 | 139 | 0.796 |
| *Evynnis tumifrons* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Pagrus major* | 0 | 0 | 18 | 0 | 0 | 4 | 0 | 1 | 0 | 0 | 23 | 0.132 |
| *Johnius grypotus* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Larimichthys polyactis* | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0.046 |
| *Nibea albiflora* | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0.029 |
| *Pennahia argentata* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0.011 |
| *Parupeneus ciliatus* | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Parupeneus spilurus* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Pempheris japonica* | 0 | 0 | 0 | 1 | 9 | 0 | 0 | 0 | 0 | 0 | 10 | 0.054 |

**Table A1.** Continued

| Scientific name \ Station | GG | GY | GD | GJ | GA | HR | PH | SC | JM | GO | Sum | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pempheris schwenkii* | 0 | 0 | 0 | 0 | 16 | 1 | 0 | 0 | 0 | 0 | 17 | 0.097 |
| *Girella leonina* | 0 | 0 | 0 | 1 | 1 | 5 | 0 | 0 | 0 | 0 | 7 | 0.037 |
| *Girella punctata* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Kyphosus bigibbus* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Microcanthus strigatus* | 0 | 0 | 7 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 12 | 0.069 |
| *Chaetodon modestus* | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.009 |
| *Chaetodon wiebeli* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Rhynchopelates oxyrhynchus* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.003 |
| *Oplegnathus fasciatus* | 0 | 0 | 41 | 2 | 1 | 27 | 4 | 5 | 0 | 1 | 81 | 0.464 |
| *Oplegnathus punctatus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0.006 |
| *Ditrema temminckii* | 0 | 2 | 1 | 7 | 0 | 0 | 1 | 0 | 20 | 2 | 33 | 0.186 |
| *Neoditrema ransonnetii* | 0 | 0 | 241 | 6 | 0 | 0 | 20 | 0 | 277 | 0 | 544 | 3.111 |
| *Chromis notata* | 0 | 0 | 0 | 0 | 42 | 6 | 0 | 0 | 0 | 0 | 48 | 0.275 |
| *Choerodon azurio* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Halichoeres poecilepterus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0.006 |
| *Halichoeres tenuispinis* | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 0.023 |
| *Pseudolabrus eoethinus* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Pseudolabrus sieboldi* | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 3 | 0.014 |
| *Pteragogus flagellifer* | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 0 | 0 | 0 | 5 | 0.029 |
| *Chirolophis japonicus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0.006 |
| *Pholis nebulosa* | 10 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0.069 |
| *Champsodon snyderi* | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.009 |
| *Arctoscopus japonicus* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 10 | 41 | 2 | 54 | 0.306 |
| *Ammodytes* sp. | 0 | 0 | 0 | 227 | 0 | 0 | 0 | 41 | 0 | 0 | 268 | 1.534 |
| *Repomucenus curvicornis* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Acanthogobius flavimanus* | 3 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0.069 |
| *Synechogobius hasta* | 47 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 52 | 0.298 |
| *Siganus fuscescens* | 0 | 0 | 1 | 0 | 27 | 22 | 0 | 0 | 0 | 0 | 50 | 0.286 |
| *Sphyraena japonica* | 0 | 0 | 0 | 1 | 3 | 4 | 2 | 0 | 1 | 0 | 11 | 0.063 |
| *Sphyraena pinguis* | 0 | 1 | 3 | 44 | 11 | 9 | 0 | 0 | 0 | 0 | 68 | 0.389 |
| *Trichiurus japonicus* | 0 | 0 | 1 | 126 | 0 | 7 | 1 | 0 | 0 | 0 | 135 | 0.773 |
| *Auxis rochei* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.006 |
| *Auxis thazard* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Scomber australasicus* | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 1 | 0 | 9 | 0.052 |
| *Scomber japonicus* | 0 | 0 | 5 | 23 | 79 | 88 | 882 | 118 | 22 | 2 | 1219 | 6.976 |
| *Scomberomorus niphonius* | 0 | 0 | 0 | 1 | 0 | 20 | 3 | 6 | 35 | 0 | 65 | 0.369 |
| *Thunnus orientalis* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Hyperoglyphe japonica* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 85 | 0 | 86 | 0.492 |
| *Psenopsis anomala* | 0 | 0 | 0 | 12 | 0 | 0 | 4 | 9 | 14 | 0 | 39 | 0.220 |
| *Pampus echinogaster* | 0 | 0 | 0 | 8 | 0 | 0 | 2 | 2 | 0 | 0 | 12 | 0.066 |
| *Pampus punctatissimus* | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 0.023 |
| *Paralichthys olivaceus* | 13 | 0 | 3 | 0 | 3 | 5 | 2 | 0 | 8 | 44 | 78 | 0.447 |
| *Pseudorhombus cinnamoneus* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Pseudorhombus pentophthalmus* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Cleisthenes pinetorum* | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 28 | 31 | 0.177 |
| *Eopsetta grigorjewi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 6 | 0.034 |

**Table A1.** Continued

| Scientific name \ Station | GG | GY | GD | GJ | GA | HR | PH | SC | JM | GO | Sum | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Glyptocephalus stelleri* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 10 | 13 | 0.074 |
| *Hippoglossoides dubius* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0.006 |
| *Kareius bicoloratus* | 1 | 8 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 11 | 0.063 |
| *Platichthys stellatus* | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0.011 |
| *Pseudopleuronectes herzensteini* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 5 | 0.029 |
| *Pseudopleuronectes yokohamae* | 1 | 23 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 0.155 |
| *Cynoglossus joyneri* | 11 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0.092 |
| *Cynoglossus robustus* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0.011 |
| *Paraplagusia japonica* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0.006 |
| *Aluterus monoceros* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 3 | 0 | 32 | 0.183 |
| *Rudarius ercodes* | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.011 |
| *Stephanolepis cirrhifer* | 0 | 0 | 11 | 2 | 7 | 31 | 10 | 201 | 5 | 3 | 270 | 1.546 |
| *Thamnaconus modestus* | 0 | 0 | 5 | 2 | 3 | 12 | 132 | 629 | 13 | 62 | 858 | 4.909 |
| *Ostracion immaculatus* | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 0.017 |
| *Arothron firmamentum* | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 2 | 0 | 6 | 0.034 |
| *Lagocephalus wheeleri* | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.009 |
| *Takifugu alboplumbeus* | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 4 | 0.023 |
| *Takifugu niphobles* | 92 | 27 | 0 | 1 | 4 | 0 | 0 | 0 | 1 | 0 | 125 | 0.713 |
| *Takifugu pardalis* | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0.023 |
| *Takifugu poecilonotus* | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 3 | 0.017 |
| *Takifugu porphyreus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 4 | 8 | 18 | 0.103 |
| *Takifugu stictonotus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 0 | 4 | 0.023 |
| *Takifugu vermicularis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 0.029 |
| *Takifugu snyderi* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 5 | 7 | 0.040 |
| *Takifugu xanthopterus* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 2 | 6 | 0.034 |
| *Diodon holocanthus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 1 | 0 | 28 | 0.160 |
| Sum | 1649 | 617 | 667 | 5906 | 479 | 1161 | 1370 | 1530 | 2303 | 1786 | 17468 | 100 |

GG: Gangjin; GY: Gwangyang; GD: Keojedo; GJ: Gijang; GA: Gangjeong; HR: Harim; PH: Pohang; SC: Samcheok; JM: Jumunjin; GO: Goseong.

**Table A2.** Levels of contributions to average dissimilarity between A and B (dissimilarity = 70.6%), group A and C (dissimilarity = 80.7%), B and C (dissimilarity = 82.7%)

| Group | Species name | Average individuals | | | Contribution (%) | Cum. contribution (%) |
|---|---|---|---|---|---|---|
| | | A | B | C | | |
| A and B | *Oncorhynchus masou masou* | 3 | 0 | | 2.5 | 2.5 |
| | *Konosirus punctatus* | 3 | 1 | | 2.3 | 4.8 |
| | *Thamnaconus modestus* | 3 | 0 | | 2.8 | 9.4 |
| A and C | *Nuchequula nuchalis* | 0 | | 4 | 3.7 | 3.7 |
| | *Thamnaconus modestus* | 3 | | 0 | 3.0 | 6.6 |
| | *Scomber japonicus* | 3 | | 0 | 2.8 | 9.4 |
| B and C | *Nuchequula nuchalis* | | 0 | 4 | 4.1 | 4.1 |
| | *Chelon haematocheilus* | | 0 | 3 | 2.6 | 6.7 |
| | *Trachurus japonicus* | | 4 | 2 | 2.6 | 9.4 |