Journal of Coastal Research	SI	116	588-592	Charlotte, North Carolina	2023

Distribution of Food Resources for Two Species of the Skate Family (*Beringraja pulchra* and *Okamejei kenojei*) in the South Sea of Korea

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ABSTRACT

Kim, H.J.; Baeck, G.W.; Lee, J.H.; Lee, S.-J.; Kang, S., and Jeong, J.M., 2023. Distribution of food resources for two species of the skate family (*Beringraja pulchra* and *Okamejei kenojei*) in the South Sea of Korea. *In:* Lee, J.L.; Lee, H.; Min, B.I.; Chang, J.-I.; Cho, G.T.; Yoon, J.-S., and Lee, J. (eds.), *Multidisciplinary Approaches to Coastal and Marine Management*. *Journal of Coastal Research*, Special Issue No. 116, pp. 588-592. Charlotte (North Carolina), ISSN 0749-0208.

Beringraja pulchra and *Okamejei kenojei* belong to the Rajidae family of the order Rajiformes. They have similar morphological features, and both species are bottom fishes. *B. pulchra* and *O. kenojei* used in this study were caught by the National Institute of Fisheries Research in Tamgu 21, 22, and 23 with bottom trawl in the South Sea. Major food organisms were identified by calculating the relative importance index ratio for the two species, and food quality was compared by analyzing changes in food organisms and nutritional levels according to season and growth. A total of 192 *B. pulchra* were used in this study, of which 160 were analyzed except for empty stomachs, and a total of 202 *O. kenojei* were analyzed for 169 other than empty stomachs. The appearance width of the *B. pulchra* was 9.8–53.1 cm, and the apparent width of the *O. kenojei* was 8.3–41.2 cm. As a result of analyzing the relative importance index of the two species, macrura were the highest in both species, with 63.8 % of *B. pulchra* and 97.4 % of *O. kenojei*, which indicates that the main prey of the two species was macrura. The two species mainly consume macrura, but it is believed that they avoid competition and divide food resources by consuming preferred food organisms other than macrura.

ADDITIONAL INDEX WORDS: *Beringraja pulchra, Okamejei kenojei, food organisms, resources*.

INTRODUCTION

Beringraja pulchra and *Okamejei kenojei* belong to the Rajidae family of the order Rajiformes and are known for their widespread distribution throughout the Yellow Sea, the East Sea, the southern North Sea of Japan, and the South China Sea (Kim *et al.*, 2005). The two species are hypochondrial fish with similar morphological characteristics. *B. pulchra* and *O. kenojei* are highly commercial species in Korea. Particularly, *B. pulchra* has been designated as a resource recovery management target and is managed by the TAC, and is also registered as "Vulnerable" in the World Resource Conservation Federation (http://www.iucnredlist.org) (Jeong *et al.*, 2018).

Previous studies on *B. pulchra* and *O. kenojei* include ecological studies, such as the diet of *O. kenojei* in the West Sea and eastern of the South Sea as well as several nutritional studies on the same (Jeong *et al.*, 2015; Kim and Cho, 2008; Youn *et al.*, 2020). Meanwhile, *B. pulchra* has been studied in the West Sea and the focus has been on diet and a few nutritional studies (Jeong *et al.*, 2018; Jo *et al.*, 2013).

This study aims to identify the main prey of *B. pulchra* and *O. kenojei* in the South Sea, and to elucidate the way *B. pulchra* and *O. kenojei* coexist by identifying the form of resource division through analysis of the feeding habits of the two species.

Since research on feeding habits is used as data to know the form of the food map in the habitat area and the form of resource division between species, it is important to find the feeding habit of species through analysis of the abovementioned contents.

Major food organisms were identified by calculating the relative importance index ratio for the two species, and food quality was compared by analyzing changes in food organisms and nutritional levels according to growth.

METHODS

Beringraja pulchra and *Okamejei kenojei* used in this study were caught by the National Institute of Fisheries Research in investigation of fisheries science ships No. 21, 22, and 23, and the species studied live in the South Sea (Figure 1).

The collected species were measured in units of 0.1 cm and 0.01 kg, respectively. Thereafter, the stomach of each individual was extracted, stored in a 10 % neutral formalin solution, transported to the laboratory, and the stomach contents were analyzed under an anatomical microscope. In addition, food organisms were identified to the level of species as much as possible, and after counting the population, the wet weight was measured up to 0.0001 g using an ultra-precision electronic scale. The above content analysis results were expressed as the

DOI: 10.2112/JCR-SI116-119.1 received 6 March 2023; accepted in revision 21 April 2023.
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frequency of appearance (%F), population ratio (%N), and wet weight (%W) of each food organism, and were obtained using equation (1). The Index of Relative Importance (IRI) of food organisms was calculated using the expression of Pinkas, Oliphant, and Iverson (1971):

$$IRI = (\%N + \%W) \times \%F \quad (1)$$

The relative importance index was converted into a percentage and expressed as the relative importance index ratio (%IRI) using equation (2):

$$\%IRI = \sum_{i=1}^{n} IRI \times 100 \quad (2)$$

The trophic level representing ecological status was expressed using the TrophLab (Pauly *et al.*, 2000) composed of the following equation (3):

$$TROPH_i = 1 + \sum_{i=1}^{G} DC_{ij} \times TROPH_j \quad (3)$$

Here, $TRPOH_i$ is the nutritional stage of i-life, DC_{ij} is the ratio of j-food organisms that appear in the stomach of i, G is the total number of food organisms, and $TROPH_j$ is the nutritional stage of j-food organisms.

For analyze ontogenetic in size classes, It according to size for 7 size classes(1: ≤20 cm, 20-25 cm, 25-30 cm, 30-35 cm, 35-40 cm, 40-45cm, 45< cm).

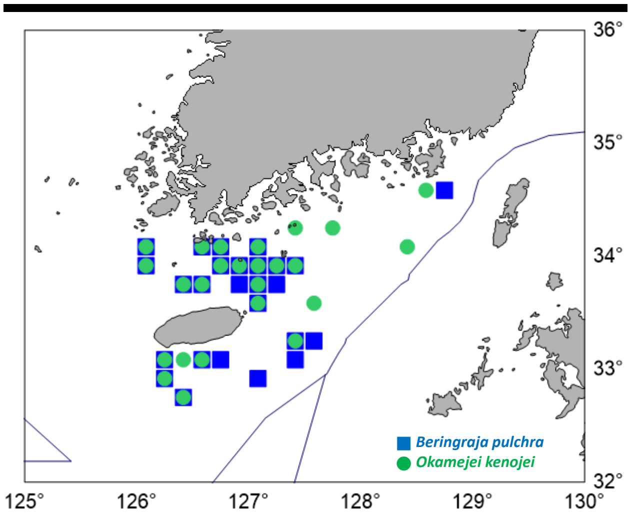

Figure 1. Location map for the stations (■, ●).

To examine the dietary differences between size classes and seasons, dietary data for the species were sorted into size subgroups that each size and the averages of the percentage weight data for each prey taxon were determined for each of the resultant groups. Weight dietary data were square root-transformed to avoid any tendency of the main dietary components to be excessively dominant, and Bray−Curtis similarity/Non-metric MDS were constructed for the species. PERMANOVA had significant differences ($p<0.05$). To visualize the differences found in PERMANOVA, we performed the canonical analysis of principal coordinates (CAP). All analyses were performed using routines in the PRIMER v7 multivariate statistics package (www.primer-e.com) and the PERMANOVA+ add-on module (Anderson, Gorley, and Clarke, 2008).

RESULTS

Among a total 192 individuals of *B. pulchra* collected from the eastern part of the South Sea, 32 individuals that did not feed on any prey showed an empty stomach rate of 16.7 %; the above contents were also analyzed for 160 individuals of *B. pulchra* that fed regularly. In the case of *O. kenojei*, 33 out of 202 individuals did not feed on any food, and showed an empty stomach rate of 16.3 %; the above contents were also analyzed for 169 *O. kenojei* that fed regularly. In addition, the appearance disc width of the *B. pulchra* was 9.8–53.1 cm, and the *O. kenojei* was 8.3–41.2 cm (Figure 2).

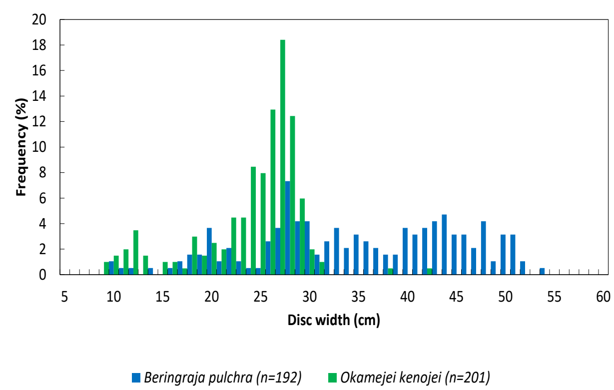

Figure 2. Length-frequency distribution of of *Beringraja pulchra* and *Okamejei kenojei* in the south sea of Korea.

Upon analyzing the stomach contents of *B. pulchra* and *O. kenojei*, macrura showed the highest value in both species(Table 1). In *B. pulchra* it was analyzed with 66.3 % frequency of occurrence, 63.3 % number ratio, and 22.6 % wet weight ratio, 63.8 % index of relative importance. In it was *O. kenojei* analized with 90.5 % frequency of occurrence, 91.3 % number ratio, 76.3 % wet weight ratio, and 97.4 % index of relative importance. Among macrura, *B. pulchra* mainly fed on *Plesionika izumiae* and *O. kenojei* mainly fed on *Leptochela sydniensis*. In addition, in the case of *B. pulchra*, the second most important food organisms after macrura were brachyura and pisces with index of relative importance 17.1 % and 15.8 %, respectively. Other prey items are cephalopoda, amphipoda, and Anomura with less than 2.8 % index of relative importance. A small quantity of prey items. *O. kenojei* had small quantity of prey with brachyura, pisces, and amphipoda less than 1.8 % index of relative importance.

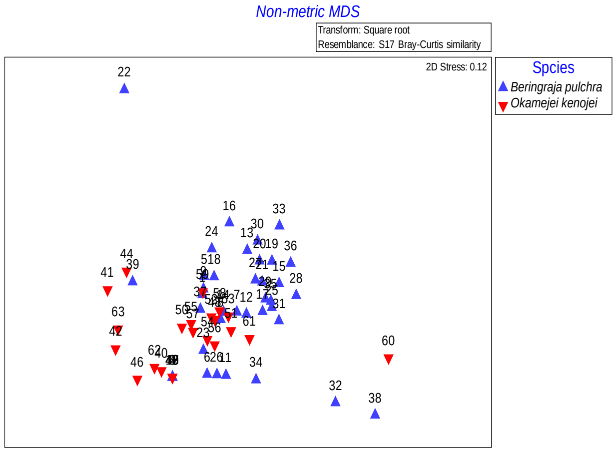

Figure 3. Non-matric MDS of wet wight of prey items for *Beringraja pulchra* and *Okamejei kenojei.*

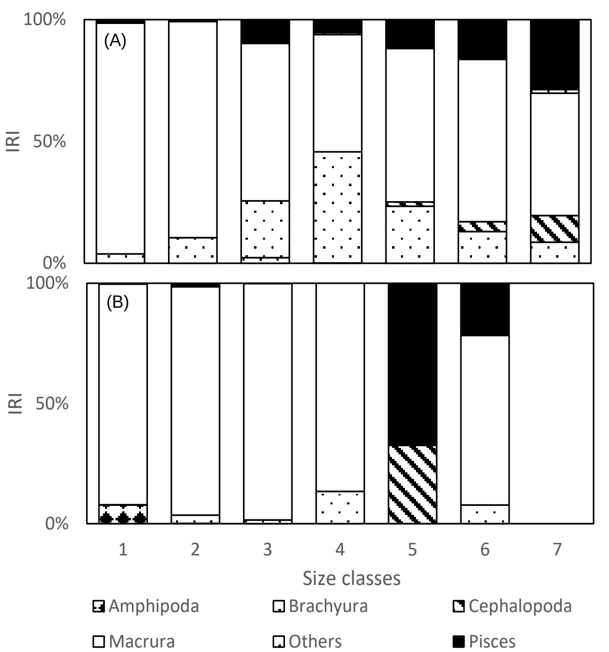

Figure 4. Ontogenetic changes in composition of stomach contents by index of relative importances (%IRI) of of *Beringraja pulchra* (A) and *Okamejei kenojei* (B) in the south sea of Korea.

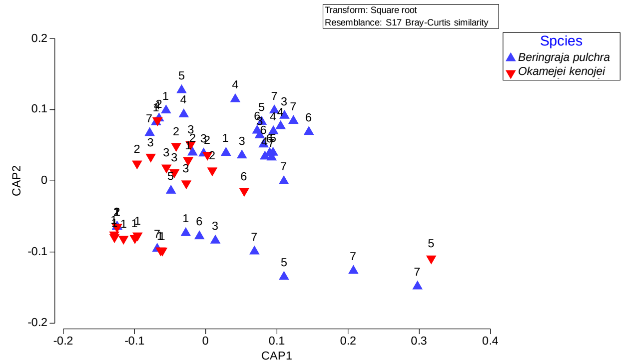

Figure 5. Cap analyze of wet wight of prey items in size classes for *Beringraja pulchra* and *Okamejei kenojei.*

Analyzed of Non-matric MDS in *B. pulchra* and *O. kenojei* presented (Figure 3), They have 2 type of pattern in prey items, also they distributed food resource division.

As a result of examining the changes in the composition of the above contents by size group of the *B. pulchra* and *O. kenojei* (Figure 4), it was divided into seven size groups. In *B. pulchra*, macurua were the most dominant prey in all size classes with index of relative importance of 48.2~94.9 %. In addition, macura of index of relative importance is reduced from smallest size classes to largest size classes. However, the pisces index of relative importance is increased from smallest size classes to largest size classes. Moreover, in *O. kenojei*, macurua were the most dominant prey in all size classes with index of relative importance of 70.5~98.3 %. In addition, macura of index of relative importance is highly maintained in almost all size classes. From number 5, size class increased pisces ratio.

Analyzed of CAP (Figure 5) in size classes of *B. pulchra* and *O. kenojei* presented, They have similler pattern in Number 2 and 3 size classes, others size classes are different pattern in feeding habits, also they distributed food resource division

In this study, the trophic level of *B. pulchra* was 3.74 and that of *O. kenojei* was 3.57 (Figure 6). Each size classes trophic level of *B. pulchra* was 3.59–3.95and *O. kenojei* was 3.59–4.5.

Figure 6. Ontogenetic changes in trophic level of *Beringraja pulchra* and *Okamejei kenojei* in the south sea of Korea.

Table 1. *Composition of the stomach contents of Beringraja pulchra and Okamejei kenojei by frequency of occurrence (%F), number (%N), wet weight (%W), and index of relative importance (%IRI) caught in the south Sea, Korea.*

	Beringraja pulchra	*Okamejei kenojei*
Empty stomach rate	16.7	16.3
Prey organism	*%IRI*	*%IRI*
Amphipoda	**0.1**	**0.1**
Gammaridae	**0.1**	+
Anomura	**0.1**	+
Galathea orientalis	+	
Munida japonica	+	+
Unidentified Anomura	+	
Bathynellacea		+
Brachyura	**17.1**	**1.8**
Cancer gibbosulus	**0.0**	
Charybdis bimaculata	**2.9**	**1.1**
Majidae		+
Mursia trispinosa	+	
Ovalipes punctatus	+	
Paradorippe granulata	+	
Portunidae	+	
Unidentified Brachyura	**4.3**	**0.1**
Cephalopoda	**2.8**	+
Euprymna morsei		+
Sepiidae	+	
Sepiola birostrata		+
Unidentified Cephalopoda	**2.6**	+
Euphausiacea		+
Euphausia spp.		+
Macrura	**63.8**	**97.4**
Acetes chinensis	+	
Alpheus digitalis	+	+
Alpheus japonicus		**0.1**
Alpheus sp.	**0.0**	
Crangon hakodatei	**0.7**	**0.7**
Eualus spathulirostris	+	
Latreutes planirostris	+	**0.1**
Leptochela gracilis	+	
Leptochela sydniensis	**0.7**	**35.2**
Lucifer sp.		+
Metanephrops thomsoni	**0.1**	
Metapenaeopsis lata		+
Palaemon gravieri	+	**0.2**
Parapenaeopsis fissuroides		+
Plesionika izumiae	**2.3**	
Plesionika orientalis	+	
Plesionika ortmanni	**1.5**	**0.2**
Plesionika sp.	+	
Solenocera melantho	+	
Spirontocaris arcuata		+
Trachysalambrisa curvirostris	**0.1**	**1.5**
Unidentified Macrura	**10.3**	**2.7**
Mysidacea	+	+
Pisces	**15.8**	**0.6**
Ammodytes personatus	+	
Callyonimidae	+	
Gobiidae	+	
Hypodytes rubripinnis	+	
Ophidiidae	+	
Platycephalidae	+	
Pleuronectidae		+
Scorpaenidae		+
Synodontidae	**0.1**	
Unidentified Pisces	**9.1**	**0.3**
Unidentified Pisces Eggs	+	
Stomatopoda	**0.3**	**0.0**
Total	**100.0**	**100.0**

+: less than 0.1 %

DISCUSSION

Beringraja pulchra and *Okamejei kenojei* have similar distribution in the southern region of Korea. Also, It is believed that *B. pulchra* and *O. kenojei* individuals less than 30 cm total length share the same habitat.

It was found that the main prey of the two species was macurura. It is believed that they live in similar areas in the southern region of Korea and mainly feed on similar prey. They also share habitats and some prey organisms. It was found that they did not avoid competition in such situations. However, they preferentially consumed different macurura species in order to avoid competition and coexist through the division of prey organisms.

It is also known that fish have feeding preferences depending on the environment (Paloheimo, 1979). Previous studies have confirmed the tendency of *B. pulchra* and *O. kenojei* to mainly feed on other food organisms due to geographical or size differences (Jeong *et al.*, 2018; Youn *et al.*, 2020). *O. kenojei* living in the West Sea of Korea also preferred macrura, but it increased its feeding efficiency by feeding on *Crangon hakodatei* which mainly appears in the West Sea of Korea (Youn *et al.*, 2020). Family of skate such as *O. kenojei* that live in other seas also feed on crustaceans, and are known to feed on some fish during the adult(large size) (Orlov, 1998)

In the case of the *B. pulchra*, that appeared in the West Sea of Korea mainly consumed pisces in *Ammodytes personatus*, which was found to prefer fish because it was a relatively larger size than the *B. pulchra* used in this study (Jeong *et al.*, 2018). However, in the group of *B. pulchra* similar to this study, the proportion of *B. pulchra* appearing in the West Sea was higher than that used in this study. This is believed to be because the West Sea has a high number of *Ammodytes personatus*, which is a small fish that is easy for *B. pulchra* to feed on, and hence, the fish obtains more prey and gains more nutrition with lorenzoni (Kalmijn, 2003)

In this study also found ontogenetically increased proportion of pisces, and it is believed that the large-sized *B. pulchra* in the South Sea of Korea will prefer pisces in the the same area as well as in the West Sea of Korea (Jeong *et al.*, 2018).

B. pulchra and *O. kenojei* was the most eaten food by macrura in all size groups, and pisces were relatively high in the large size. In case of class size number 5 with *O. kenojei* has error of result. This may be attributed to few samples distribution of *O. kenojei* was also smaller than *B. pulchra*.

The proportion of *O. kenojei* appearing in the West Sea of Korea gradually increased from the 27.0 cm sized group with pisces, which is a typical method of changing according to the efficiency of prey organisms as it grows, although they consumed easy to dominate bottom pisces. The consumption rate of *B. pulchra* also increased from individuals over 25 cm, and it is believed that *B. pulchra* begins to feed fish in a smaller group than *O. kenojei*. This is an important data that can help predict that the swimming and digestion ability of *B. pulchra* is more developed than that of *O. kenojei* in the same size group. The tropical level according to growth shows relatively the same pattern, and the neutral niches appear to be similar.

It is believed that the two species sharing the same space could avoid competition and coexist in different appearance size groups, different feeding organisms, and maintain their stable ecological status through resource division.

ACKNOWLEDGMENTS

This research was supported by the National Institute of Fisheries Science, Ministry of Oceans and Fisheries, Korea (R2023001)

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