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Qualitative and quantitative changes in dietary composition of marbled flounder *Pseudopleuronectes yokohamae* between periods of different stock sizes in Tokyo Bay, Japan

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Abstract

We compared the feeding patterns of marbled flounder *Pseudopleuronectes yokohamae* in Tokyo Bay between 1980s (high abundance) and 2000s (low abundance). The stomach contents weight was significantly lower in 2000s compared to that in 1980s. The dietary composition changed substantially between 1980s and 2000s; main constituents of the stomach contents were annelids, molluscs and echinoderms during 1980s. In 2000s, however, they fed predominantly on annelids. Observed changes in the stomach contents may be associated with changes in abundance and species composition of macrobenthic community, and could have affected changes in the growth and reproductive patterns between 1980s and 2000s.

Key words: abundance, feeding habit, flatfish, life history trait, macrobenthos

The marbled flounder *Pseudopleuronectes yokohamae* is distributed around Japan from southern Hokkaido to Oita Prefecture in Kyushu, and also inhabits in the Yellow Sea, the Bohai Sea, and the northern part of the East China Sea (Sakamoto 1984). It is a commercially important flatfish species in Japan and is usually caught by gill net or by bottom trawl. In Tokyo Bay, the marbled flounder is one of the dominant species in the megabenthic assemblage during the mid-1980s (Kodama et al. 2002); however, its abundance-based density (i.e., the number of individuals per unit area) has markedly decreased since the late 1980s (about 1500 individuals km^{-2} in the late 1980s to about 250 individuals km^{-2} in the mid-2000s; Kodama et al. 2010). According to statistics from the Shiba Branch of the Yokohama City Fisheries Cooperative Association, the annual catch reached its peak at 490 t in 1986, but the catch declined abruptly in the late 1980s and decreased to approximately 50 t by the mid-2000s.

To understand the population dynamics of the marbled flounder in Tokyo Bay, information on the life history traits (e.g., growth, reproduction, and feeding habits) in both high and low stock-size periods is necessary, because life history traits are affected by change in stock size (Jennings et al. 2001; Rijnsdorp and Van Leeuwen 1996; Trippel 1995). Comparative studies on growth and reproduction of the marbled flounder in Tokyo Bay between the mid-1980s (high stock-size period) and mid-2000s (low stock-size period) have been conducted and suggested that changes in growth and reproduction occurred between the two periods

(Kume et al. 2006; Lee et al. 2009). During periods of low stock size, growth rate increased after age 2 for both sexes and onset of maturity in females was delayed.

Feeding habit is one of the major life history traits that may affect changes in growth and gonadal maturation (Wootton 1998). Reports on the feeding habit of the marbled flounder in different coastal regions have shown that the major prey taxa are polychaetes in Mutsu Bay (Takahashi et al. 1987), polychaetes, bivalves, opisthobranchs and actiniarians in Senday Bay (Takahashi et al. 2018), and polychaetes, molluscs and crustaceans in Harima Nada and Osaka Bay (Tanda 2008). The difference in the prey composition among these regions is probably attributed to inter-regional difference in the abundance and species composition of the macrobenthic assemblage in the habitat of the marbled flounder (Tanda 2008). In Tokyo Bay, the marbled flounder also mainly fed on polychaetes, bivalves and crustaceans during the high stock-size period in the mid-1980s (Park 1988). However, there has been no study comparing feeding habits of the marbled flounder in Tokyo Bay between the high and low stock-size periods (i.e., the mid-1980s and mid-2000s), although the community structure of the prey organisms of the marbled flounder in Tokyo Bay might have changed between those periods.

In this study, we investigated the feeding habits of the marbled flounder during the low stock-size period in Tokyo Bay and compared our results with that of a previous study from the high stock-size period (Park 1988) to assess changes in dietary composition associated with stock size variations.

To compare dietary composition of the marbled flounder in Tokyo Bay between high and low stock-size periods, we adopted the same field sampling procedure of a previous study conducted in May, August, and November 1986 and February 1987 (Park 1988). We carried out daytime seasonal bottom trawl surveys in February, May, August, and November of 2006 and 2007 and February 2008 at 20 sampling sites across the inner part of Tokyo Bay (i.e., northern areas from the line between Cape Futtsu and Cape Kannonzaki; cf. Kodama et al. 2010 for the site location). In a preliminary analysis of dietary composition in the mid-2000s, we found no significant difference in the dietary composition between 2006 and 2008. Therefore, we combined data from the 2006-2008 survey. A beam trawl with a stretched mesh size of 5 cm and a cod end mesh size of 3 cm was used for sampling. Detailed procedures of the bottom trawl survey have been described previously (Park 1988; Kodama et al. 2010). A total of 228 fish were obtained from our field sampling, while 372 fish were used in the analysis of the dietary composition in the previous study (Park 1988). Samples were dissected on board, and the guts were fixed in 10% neutral formalin. In the laboratory, standard length (SL, mm) and body weight (BW, g) were measured to the nearest 0.1 mm and 0.1 g, respectively. Ranges of SL and mean BW of the specimens were 87~218 mm and 73.0 g in 1980s, while 64~391 mm and 134.2 g in 2000s, respectively. Dietary composition of the marbled flounder was determined by identifying the stomach contents to specific, generic, or higher taxonomic levels under a stereomicroscope (SZX-ILLB100; Olympus Optical Co. Ltd, Tokyo, Japan). Weight of the stomach contents was recorded for each specimen to the nearest 0.001 g. Unidentified stomach contents, such as digested materials, detritus, or mud, were classified as “other” and the weight was recorded.

We evaluated the quantitative change in dietary composition of the marbled flounder by examining stomach contents index (SCI) calculated by the following equation: SCI = (stomach contents weight)/(BW – stomach contents weight) × 100. Vacuity index (VI) was expressed as the number of specimens with empty stomachs divided by the total number of stomachs examined. In order to compare the qualitative dietary composition of the marbled flounder between high and low stock-size periods, the stomach contents data were categorized at the phylum level (annelids, molluscs, echinoderms, arthropods, and others), in accordance with Park’s (1988) study. The following three indices were calculated for each prey phylum: (1) the percentage of occurrence of a prey phylum to the total number of specimens (%F); (2) the percentage of a prey group’s weight in relation to the total weight of stomach contents (%W); and (3) the ranking index (RI), which was calculated by %F × %W. To examine the change in the contribution of each prey phylum to the stomach contents, we calculated the %RI for each prey item by the following equation: $\%RI_i = (RI_i/\sum RI)\times100$, where i is a prey phylum. Specimens with empty stomachs were excluded from the calculations of %F, %W and RI. We calculated SCI, VI, %F, %W, and %RI for the high stock-size period using data from the previous study (Park 1988).

To assess the relationship between changes in the stomach contents of the marbled flounder and abundance of the prey organisms, annual mean and standard deviation for densities of macrobenthic phyla or species that are principal prey taxon or species of the marbled flounder in Tokyo Bay were calculated using data of May, August, November and March in high stock-size period (1982–1983; Haraguchi 1984) and low stock-size period (2006–2007; Kodama et al. 2012). Mann-Whitney U-test was used to examine differences in feeding activity of the marbled flounder and abundance of macrobenthos between high and low stock-size periods. The dietary compositions between the two different stock-size periods were compared by the chi-square test.

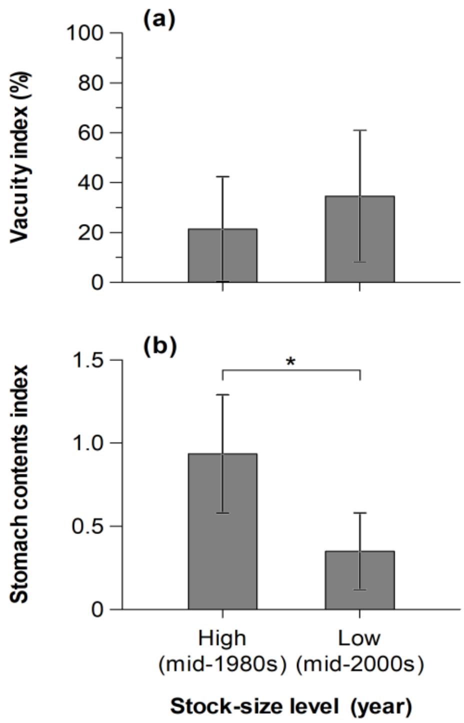

Fig. 1. Indices for the quantitative changes in the dietary composition of the marbled flounder *Pseudopleuronectes yokohamae* in Tokyo Bay, Japan, for high (mid-1980s) and low (mid-2000s) stock-size periods. (a) vacuity index, and (b) stomach contents index. Vertical bars represent the standard deviations. Data for the mid-1980s were obtained from Park (1988). * $p < 0.05$

We found significant changes in the dietary composition of the marbled flounder in Tokyo Bay between high and low stock-size periods. The mean VI showed a slight increasing trend from 21.4 ± 21.1% (n = 4) in the mid-1980s to 34.7 ± 25.0% (n = 9) in the mid-2000s, although the difference is not statistically significant ($p > 0.05$; Fig. 1a). On the other hand, the mean SCI showed a significant decrease from 0.9 ± 0.4 (n = 4) in the mid-1980s to 0.3 ± 0.2 (n = 4) in the mid-2000s ($p < 0.05$; Fig. 1b). Moreover, there was a significant difference in %F, %W and %RI between the mid-1980s and mid-2000s (chi-square test, $\chi^2 = 53.4$, 31.2 and 44.8 for %F, %W and %RI, respectively; $p < 0.01$ for all indices; Fig. 2a-c), suggesting that the quantitative dietary composition of the marbled flounder in Tokyo Bay changed between two different stock-size periods. In the mid-1980s, the marbled flounder fed on annelids (%F = 42.0; %W = 46.4; %RI = 58.6), molluscs (%F = 39.6; %W =26.1; %RI = 31.0), echinoderms (%F = 14.1; %W = 24.2; %RI = 10.2), and arthropods (%F = 2.4; %W = 2.6; %RI = 0.1; Fig. 2a-c). In the mid-2000s, however, the marbled flounder fed predominantly on annelids (%F = 51.4; %W = 65.7; %RI = 84.4), whereas molluscs (%F = 10.8; %W = 14.9; %RI = 4.0) and echinoderms (%F = 1.7; %W = 5.0; %RI = 0.2) contributed substantially less to the diet (Fig. 2a-c). In the mid-2000s, the occurrence of arthropods increased yet its weight decreased in the stomach contents (%F = 3.7; %W = 0.5; Fig. 2a-b), but the %RI remained the same (%RI = 0.1; Fig. 2c).

For other prey taxa, their occurrence and weight in the stomach contents as well as their %RI were higher in the mid-2000s (Fig. 2a-c), in which mud

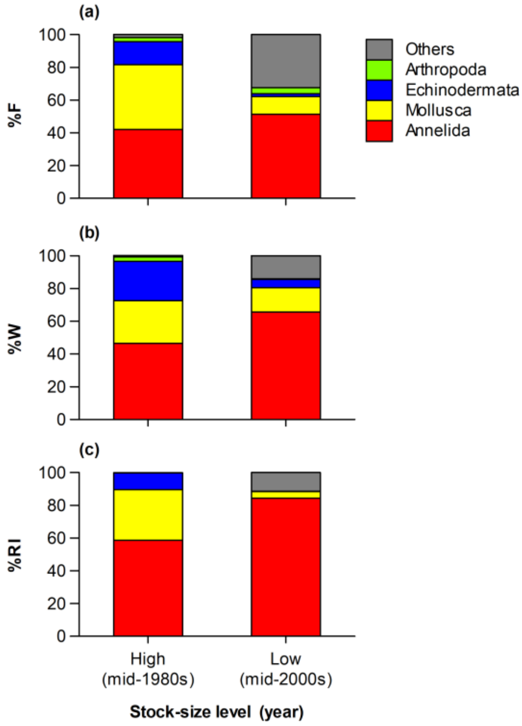

Fig. 2. Indices for the qualitative changes in the dietary composition of the marbled flounder *Pseudopleuronectes yokohamae* in Tokyo Bay, Japan, for high (mid-1980s) and low (mid-2000s) stock-size periods. (a) the percentage occurrence of prey phylum to the total number of individuals of prey in all stomachs examined (%F); (b) the percentage of a prey group's weight in relation to the total weight of stomach contents (%W), and (c) the percentage of ranking index for each taxon (%RI). Data for the mid-1980s were obtained from Park (1988).

was the dominant constituent. In the present study, unidentified stomach contents (the prey taxon "other") were recorded in 98 specimens (42%). Of these, 73% contained mud with digested materials. We included mud in our analyses because it was difficult to separate mud from other digested prey items. We therefore recalculated the data, omitting the unidentified stomach contents in both high and low stock-size periods, and confirmed that the trends in changes in feeding habits as well as statistical significance were the same as those with the inclusion of the unidentified stomach contents (results of statistical test for specimens excluding the prey category "others"; Mann-Whitney U-test for the mean VI and SCI, $p > 0.05$ and $p < 0.01$, respectively; chi-square test for difference in the dietary composition between mid-1980s and mid-2000s, $p < 0.01$ for %F, %W and %RI).

Table 1. Relative frequency of occurrence (%F) and relative weight (%W) of each prey taxon or species in the stomach of the marbled flounder *Pseudopleuronectes yokohamae* in Tokyo Bay, Japan, during low stock-size period (2006–2007).

Taxon		%F	%W
Annelida	Spionidae	65.9	40.6
	Nereididae	35.9	18.7
	Others	35.3	6.3
Arthropoda	Gammaridea	1.8	0.06
	Decapoda	6.2	0.4
Mollusca	*Theora fragilis*	14.4	2.5
	Others	6.2	12.4
Echinodermata	Ophiuroidea	1.7	5.0
Others	Unidentified	57.5	14.0

Although the mean SCI significantly differed between the two different stock-size periods (Fig. 1b), the annelids remained as the primary prey for the marbled flounder in both stock-size periods (Fig. 2a-c). In the mid-2000s, the family Spionidae was the dominant prey among annelids (Table 1), and exhibited the highest in two indices (%F = 65.9 and %W = 40.6). Meanwhile, a bivalve *Theora fragilis* was the main prey species among molluscs (%F = 14.4; %W = 2.5). Changes in dietary composition of the marbled flounder in Tokyo Bay between high and low stock-size periods may be caused by changes in density and species composition of macorbenthos which is the principal food source for megabenthos including the marbled flounder. In Tokyo Bay, the annual mean densities of annelids and molluscs that are principal prey taxa of the marbled flounder were not significantly different between high and low stock-size periods (Mann-Whitney U-test, $p > 0.05$; Table 2). Among annelids, however, the annual mean density of the spionid *Paraprionospio coora*, which is one of the dominant species among spionid polychaetas in Tokyo Bay, has significantly increased in 2000s compared with 1980s (Mann-Whitney U-test, $p < 0.05$; Table 2). Meanwhile, the annual mean density of bivalve *T. fragilis*, the main prey species for the marbled flounder in Tokyo Bay, did not significantly change between the two periods (Mann-Whitney U-test, $p > 0.05$; Table 2). These results suggest that the increased density of the spionid *P. coora* in macrobenthos community might have influenced the elevated relative proportion of annelids in the stomach contents of the marbled flounder in the mid-2000s. In fact, the spionid *P. coora* was found frequently during our microscopic observation of the stomach contents of the marbled flounder that were caught in the mid-2000s. However, density data of spionid species other than *P. coora* in the macrobenthic community in Tokyo Bay is not available. Besides, we could not separate the spionid *P. coora* from other species of the family Spionidae in the stomach of the marbled flounder (as shown in Table 1) due to damage in the body of the spionid during digestion in the stomach. Therefore, we could not accurately assess the contribution of increasing density of the spionid *P. coora* to the elevated relative proportion of the family Spionidae in the stomach contents of the marbled flounder during the low stock-size period in the mid-2000s.

On the other hand, the decreased feeding intensity and the changes in the taxonomic composition of the stomach contents may be

Table 2. Annual mean and standard deviation for densities of principal prey taxon or species of the marbled flounder *Pseudopleuronectes yokohamae* in Tokyo Bay, Japan, in during high stock-size period (1982–1983) and low stock-size period (2006–2007). Data for high and low stock-size periods were obtained from Haraguchi (1984) and Kodama et al. (2012), respectively. Statistical significance for the annual mean densities between two periods was examined using Mann-Whitney U-test.

Taxon	Species	Density (individuals m^{-2}) 1982–1983	Density (individuals m^{-2}) 2006–2007	Mann-Whitney U-test
Annelida		971.5±134.2	1005.7±517.5	$p > 0.05$
	Paraprionospio coora	11.8±9.6	49.3±28.8	$p < 0.05$
Mollusca		47.8±23.7	33.0±43.5	$p > 0.05$
	Theora fragilis	11.8±13.6	25.9±33.0	$p > 0.05$

related to altered allocation of the resource to growth and reproduction, which could be attributed to observed changes in the growth (increased growth rate after age 2 for both sexes; Kume et al. 2006) and reproductive traits (delay in the onset of maturity for females; Lee et al. 2009) of the marbled flounder in Tokyo Bay between the mid-1980s (high stock-size) and the mid-2000s (low stock-size).

In the present study, however, the reason why the feeding intensity of the marbled flounder decreased in the mid-2000s compared with that in 1980s, as well as the effects of changes in the feeding habits on the growth and reproductive traits of the marbled flounder, remains unclear. Further studies are needed to clarify the reasons as well as the detailed mechanism.

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