Differences in Growth of Young Japanese Flounder *Paralichthys olivaceus* in Two Semi-enclosed Bays of the Sea of Japan, Kyoto

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**Abstract:** In order to clarify the growth of young Japanese flounder *Paralichthys olivaceus* (ca. 2 months to 15 months post-hatch, size ca. 9 to 40 cm TL) in semi-enclosed waters, we examined their somatic growth and condition factor in two bays, Kumihama Bay and Aso Bay. Specimens sampled from Kumihama Bay showed lower growth rates and condition factor values compared to those from Aso Bay. The stomach content analysis revealed that most of the flounder preyed extensively on fish throughout the year in Aso Bay, whereas approximately half of the fish sampled in spring and summer showed stomach contents of the flounder had changed their diet from fish to crustaceans in Kumihama Bay. Although there were no significant differences in the mean stomach contents indices used as an index of feeding intensity between the two bays, these indices for fish that fed on crustaceans were significantly lower than those that fed on fish. These results indicate that the inferior growth of young flounder in Kumihama Bay was due to the low availability of small fish prey such as Japanese anchovy and gobies during the high growing season in spring and summer.

**Key words:** *Paralichthys olivaceus*; Feeding; Growth; Semi-enclosed bay

The Japanese flounder *Paralichthys olivaceus* is widely distributed in the coastal waters of Japan from Hokkaido to Kyushu (Minami 1997). This species is one of the most important commercial fishes because of its high market value. In Japan, with the exception of Pacific halibut *Hippoglossus stenolepis* (Ochiai and Tanaka 1998), the flounder grows faster and larger than any other flounder species, e.g. finespotted flounder *Pleuronichthys cornutus* (Masaki et al. 1985), marbled sole *Pleuronectes yokohamae* (Masaki et al. 1986a), stone flounder *Kareius bicoloratus* (Masaki et al. 1986b), flathead flounder *Hippoglossoides dubius* (Yagishita et al. 2006). Therefore Japanese flounder has been selected as a main target species for stock enhancement and more than 20 million hatchery-raised juveniles have been released off Japanese coast each year since 1994 (Fish Ranching and Aquaculture Division in Resources Enhancement Promotion Department in Fisheries Agency 2006).

Generally, total length of the flounder of 1-year-old fish is larger in southwest Japan, south coast of Honshu and around Kyushu, than in northeast Japan, Tohoku and Hokuriku Districts, because of the longer growing season under optimum water temperature conditions (Kitagawa et al. 1994; Ozawa et al. 1995). However, in the Sea of Japan, the growth rate of juvenile stage flounder (size ca. 3 to 4 cm SL) in northern area, Tohoku and Hokuriku Districts, is faster than in southern area, Sanin District, which has been concluded to be due to the higher abundance of prey (Tanaka et al. 1997, Tanaka et al. 1998, Yamashita et al. 2004). These findings indicate that the growth rate of the flounder shows marked variability depending on trophic and environmental conditions (Minami 1997).
In order to select the optimum releasing ground for stock enhancement, the growth of young flounder sampled from two semi-enclosed bays in Kyoto Prefecture, where hatchery-raised flounder have been released, was examined.

**Materials and Methods**

**Sampling areas**

Sampling areas were located in Kumihama Bay (35°37´N, 134°54´E) and Aso Bay (35°34´N, 135°11´E), Kyoto, facing the Sea of Japan. Kumihama Bay is a typical semi-enclosed bay with an area of 7.1 km² and connects to the open sea by a narrow channel (Fig. 1). Aso Bay is also semi-enclosed with an area of 5.0 km² and connects with the western part of Wakasa Bay by two narrow channels. The maximum depth in Kumihama Bay and Aso Bay is 22 m and 14 m, respectively. The water volume of Kumihama Bay and Aso Bay is estimated to be about 50 million tonnes and about 30 million tonnes, respectively. These semi-enclosed bays are essentially an estuarine environment.

Water temperature and dissolved oxygen concentration data for both bays were quoted from water quality surveys by Environmental Measure Section in Hygienic Environment Department, Kyoto Prefecture, 1991, 1992 and 1993. Water temperature and dissolved oxygen concentration were measured once a month at depths of 0.5, 2 and 10 m in both bays near the major fishing grounds for the flounder, and used to calculate the mean values for these three depths for the period July 1989 to August 1991.

**Examinations of the flounder**

Specimens were mainly caught by gill net at depths of less than 10 m in two bays from July 1989 to August 1991. A total of 2,055 specimens of the 1989 year-class and 1,532 specimens of the 1990 year-class sampled from Kumihama Bay, and 67 specimens of the 1989 year-class and 190 specimens of the 1990 year-class sampled from Aso Bay were used in this study. After landing, specimens were stored at below −10°C in a freezer until analysis. In the laboratory, specimens were thawed at room temperature, and total length (TL) to the nearest 0.1 cm, wet body weight (BW) and wet weight of stomach contents (SCW) to the nearest 0.1 g were measured, respectively. Sex of specimens was determined by macroscopic examination of the gonads. The condition factor (K) was used as an index of nutritional status and calculated as follows: $K = \left( \frac{BW - SCW}{TL^2} \right) \times 100$. Stomach

![Fig. 1. Map showing study areas, Kumihama Bay and Aso Bay, the Sea of Japan. Solid circles show observation points of water temperature and dissolved oxygen in both bays.](image-url)
contents were sorted and prey items were identified to the lowest possible taxonomic level. Age determination was conducted by annual ring reading on the sagitta using a profile projector (Takeno et al. 1999).

The stomach empleness index (SEI) was calculated as follows: SEI = (the number of specimens with an empty stomach/the total number of specimens examined) × 100. Excluding specimens with an empty stomach, the stomach content index (SCI) was used as an index of the feeding intensity of the flounder was calculated as follows: SCI = |SCW/(BW-SCW)| × 100. The occurrence of each prey item in the stomach contents (F%) was calculated as follows: F% = |the number of specimens containing each prey item / (total number of specimens examined – the number of specimens with empty stomach)| × 100.

Significant differences in TL, K and SCI of specimens were examined by Mann-Whitney U-test (Kitada 1997) and a level of P < 0.05 was considered as significant.

**Results**

**Water temperature and dissolved oxygen concentration**

Monthly water temperatures in Kumihama Bay and Aso Bay ranged from 8.7 to 26.0°C and 8.7 to 26.5°C, respectively (Fig. 2). The fluctuations of water temperature during the investigation period showed a similar trend in both bays. Although the mean water temperature in the period was higher in Aso Bay (17.3°C) than Kumihama Bay (16.7°C), the difference of the mean between the two bays was less than 1°C.

Monthly dissolved oxygen concentrations in Kumihama Bay and Aso Bay ranged from 4.8 to 10.0 mg/l and 4.6 to 11.0 mg/l, respectively (Fig. 2). Monthly oxygen concentrations in the two bays had a similar trend in which the values were low in the summer and autumn and high in the winter and spring. The mean oxygen concentration in the investigation period was higher in Kumihama Bay (7.6 mg/l) than Aso Bay (6.9 mg/l).

**Growth of the flounder**

In Kumihama Bay, male flounders of the 1989 year-class showed minimal growth in the mean TL from September 1989 to May 1990 (Fig. 3). The mean TL of males was 18.3 cm at 12-month-old in May. Then, they grew slowly and their TL increased to 21.8 cm by August 1990. Females of the 1989 year-class showed almost the same growth rate as males. Their mean TL was 18.7 cm at 12-month-old in May and 22.3 cm in August 1990. In case of the 1990 year-class, both sexes showed almost the same growth rate as the previous year-class, and their mean TL was less than 20 cm at 12-month-old in May and increased to about 22 cm by August 1991.

In Aso Bay, the mean TL of males of the 1989 year-class grew to about 25 cm at 12-month-old in May and was significantly larger than Kumihama Bay. Then, their TL increased to about 30 cm by August 1990. As for females, their mean TL was about 26 cm in December 1989 and 34 cm in August 1990. In the case of the 1990 year-class, both sexes showed similar growth and grew to more than 26 cm TL at 12-month-old in May and about 32 cm TL by August 1991.

The mean wet body weight of a male flounder excluding the stomach contents of the 1989 and 1990 year-classes at 15-month-old in August was 92 g and 86 g in Kumihama Bay, and 268 g and 346 g in Aso Bay, respectively. The mean wet body weight of a female flounder excluding the
The mean condition factor ($K$) of the flounder by size and sex were compared between the two bays (Fig. 4). In the case of the 1989 year-class, the mean $K$ of the flounder in Kumihama Bay tended to be lower than the values in Aso Bay. There were significant differences in $K$ for males in the range of 15–30 cm TL and females in the range of 20–25 cm TL between the two bays. In case of the 1990 year-class, the values of $K$ for males in the range of 15–25 cm TL and females in the range of 15–20 cm and 25–30 cm TL in Kumihama Bay were significantly lower than those in Aso Bay.

**Stomach content analysis**

Specimens used for the stomach content analysis were 1,952 individuals of the 1989 year-class stomach contents of the 1989 and 1990 year-classes at 15-month-old in August was 106 g and 100 g in Kumihama Bay, and 445 g and 343 g in Aso Bay, respectively.

Fig. 3. Seasonal changes in total length of male and female Japanese flounder *Paralichthys olivaceus* sampled from Kumihama Bay (solid circles) and Aso Bay (open circles). Circles with vertical lines show means with standard deviations “n” indicates the number of samples with upper numerals from Kumihama Bay and lower ones from Aso Bay. Asterisks indicate significant difference in Mann-Whitney’s *U*-test at $P<0.05$ between the two bays.

Fig. 4. Seasonal changes in condition factor ($K$) by size class of male and female Japanese flounder *Paralichthys olivaceus* sampled from Kumihama Bay (solid circles) and Aso Bay (open circles). Circles with vertical lines show means with standard deviations. “n” indicates the number of samples with upper numerals from Kumihama Bay and lower ones from Aso Bay. Asterisks indicate significant difference in Mann-Whitney’s *U*-test at $P<0.05$ between the two bays.
and 1,479 individuals of the 1990 year-class sampled from Kumihama Bay, and 64 individuals of the 1989 year-class and 172 individuals of the 1990 year-class sampled from Aso Bay.

Monthly SEI of the 1989 and 1990 year-classes in Kumihama Bay varied from 31.6 to 78.5% and 25.0 to 79.4%, respectively (Fig. 5). Monthly SEI of the 1989 and 1990 year-classes in Aso Bay varied from 0.0 to 100.0%. The fluctuations of monthly SEI of the flounder were large in Aso Bay because of the small sample size.

The monthly mean SCI of the 1989 and 1990 year-classes in Kumihama Bay ranged from 0.56 to 2.42 and 0.47 to 4.86, respectively (Fig. 5). The monthly mean SCI of the 1989 and 1990 year-classes in Aso Bay ranged from 0.19 to 2.93 and 0.40 to 4.52, respectively. There were no significant differences in the mean SCI values of both year-classes between the two bays.

The flounder preyed on teleost fishes, crustaceans, decapods and polychaetes in Kumihama Bay, and preyed on teleost fishes and crustaceans in Aso Bay. The percentage occurrence ($F$) of teleost fishes in Kumihama Bay were 65.8% in the 1989 year-class and 58.4% in the 1990 year-class. These values in Aso Bay were 81.0% in the 1989 year-class and 94.3% in the 1990 year-class (Table 1). Main prey items of the teleost fishes were gobies in both bays and Japanese anchovy *Engraulis japonicus* in Aso Bay. However, the $F$ values of crustaceans in Kumihama Bay were 38.1% in the 1989 year-class and 48.1% in the 1990 year-class, while 19.0% in the 1989 year-class and 7.5% in the 1990 year-class in Aso Bay. In Kumihama Bay, many flounder preyed only on crustaceans such as mysids, macrurans and gammarids.

From seasonal changes in the $F$ of each prey item, most flounder (>80%) preyed only on fish in Aso Bay in all seasons (Fig. 6). In Kumihama Bay, most flounder (>80%) preyed only on fish in autumn and winter, but the $F$ of fish prey decreased in spring and summer. However, the $F$ of crustaceans increased in spring and summer in Kumihama Bay. In particular, nearly half of the flounder shifted their diet from

Fig. 5. Seasonal changes in stomach emptiness index (SEI) and stomach contend index (SCI) of Japanese flounder *Paralichthys olivaceus* sampled from Kumihama Bay (solid circles) and Aso Bay (open circles). "n" indicates the number of samples with upper numerals from Kumihama Bay and lower ones from Aso Bay.
fish to crustaceans in spring and summer of ca. 1-year-old in Kumihama Bay (Fig. 6). Additionally, some flounder preyed on gamma-rids, crabs and/or polychaetes in these seasons in the bay.

In Kumihama Bay, the mean SCI of the 1989 and 1990 year-classes of fish that had consumed only fish prey was 1.47 and 1.56, respectively. On the other hand, the mean SCI of the 1989 and 1990 year-classes of fish that had consumed only crustaceans was 0.39 and 0.45, respectively. In Aso Bay, the mean SCI of the 1989 and 1990 year-classes of fish that had consumed only fish prey was 1.64 and 1.55, respectively. On the other hand, the mean SCI of the 1989 and 1990 year-classes that had consumed only crustaceans was 0.21 and 0.22, respectively. The SCI values of the flounder that preyed only on crustaceans were significantly lower than those of the flounder preyed only on fish in both bays.

### Discussion

In this study, we compared the growth of young Japanese flounder between Kumihama Bay and Aso Bay until the summer of 1-year-old (ca. 15 months) and we found that the total lengths of specimens sampled from Kumihama Bay were significantly smaller than Aso Bay. The mean total length of specimens at 12-month-old in May in Aso Bay (25 – 27 cm TL) was almost equal to the mean size previously detailed for the western part of Wakasa Bay (28 cm TL) off Kyoto Prefecture (Takeno et al. 1999), whereas the mean TL in Kumihama Bay (18 cm TL) was 7 to 10 cm smaller than those from above two bays. These results clearly indicate that the growth rates of young flounder in Kumihama Bay were slower than those in Aso Bay and other waters of western

### Table 1. Percentage occurrence for each prey taxon in the stomach contents of young Japanese flounder *Paralichthys olivaceus* in Kumihama Bay and Aso Bay

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Kumihama Bay</th>
<th>Aso Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1989 year-class</td>
<td>1990 year-class</td>
</tr>
<tr>
<td><strong>Polychaeta</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unidentified Polychaeta</td>
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<td>0.2</td>
</tr>
<tr>
<td><strong>Crustacea</strong></td>
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<td></td>
</tr>
<tr>
<td>Mysidacea</td>
<td>38.1</td>
<td>48.1</td>
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<tr>
<td>Oniscoidea</td>
<td>24.6</td>
<td>28.9</td>
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<td>Gammaridea</td>
<td>1.5</td>
<td>2.0</td>
</tr>
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<td>Caprellidea</td>
<td>11.0</td>
<td>21.7</td>
</tr>
<tr>
<td>Brachyura</td>
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<tr>
<td>Unidentified Crustacea</td>
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<tr>
<td><strong>Cephalopoda</strong></td>
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</tr>
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<td>Decapoda</td>
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<td><strong>Osteichthyes</strong></td>
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<td>Clupeidae</td>
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<td>Atherinidae</td>
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<td>Percichthiidae</td>
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<td>Terapontidae</td>
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<tr>
<td>Leiognathidae</td>
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<tr>
<td>Sparidae</td>
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<td>11.0</td>
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<td>Embiotocidae</td>
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<td>0.2</td>
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<td>Mugilidae</td>
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<td>0.9</td>
</tr>
<tr>
<td>Callionymidae</td>
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<td>11.0</td>
</tr>
<tr>
<td>Gobiidae</td>
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<td>0.2</td>
</tr>
<tr>
<td>Pleuronectidae</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Unidentified Osteichthyes</td>
<td>48.8</td>
<td>45.2</td>
</tr>
<tr>
<td>Number of flounder with prey identified</td>
<td>480</td>
<td>447</td>
</tr>
</tbody>
</table>
Differences in Growth of Young Japanese Flounder

Wakasa Bay.

Ambient water temperature, quality and quantity of food, body size, and dissolved oxygen have been reported to induce difference in the growth rate of flounder (Yamashita et al. 2001). Kumihama Bay and Aso Bay are located in nearly the same latitude and both are typical semi-enclosed waters. There are no significant differences in water temperature between the two bays throughout the year (Fig. 2). Dissolved oxygen concentrations decreased in summer and autumn in both bays and tended to be lower in Aso Bay than Kumihama Bay. Therefore, it was thought that differences in the growth rate of the flounder between the two bays were not mainly caused by these abiotic environmental factors such as water temperature and dissolved oxygen.

The stomach content analysis revealed that there were significant differences of the prey items consumed between the two bays. In Aso Bay, most flounder fed extensively on fish such as Japanese anchovy and gobies throughout the year, whereas half of them changed their diets from fish to crustaceans such as mysids and macrurans during spring and summer in Kumihama Bay. Furthermore, some flounder fed on gammarids, crabs and polychaetes in the bay. It has been reported that the stomach content composition of the flounder closely correlates with the abundance of food organisms in their habitat (Kojima et al. 1985; Yamada et al. 1998; Yamamoto et al. 2004; Tanaka et al. 2006). Young and adult flounder are classified as piscivorous fish (Matsubara et al. 1979) mainly consuming Japanese anchovy, Pacific sand lance *Ammodytes personatus* and Japanese jack mackerel *Trachurus japonicus* and gobies (Kiyono and Sakano 1972, Ochiai and Tanaka 1998). Therefore, it was considered that the dietary change of the flounder from fish to crustaceans and other prey items in Kumihama Bay indicated a decrease of small prey fish abundance in spring and summer.

In addition, the SCI values of the flounder that fed only on crustaceans were significantly lower than those of the flounder fed only on fish in both bays. Although crustaceans contain as high

![Fig. 6. Seasonal changes in the occurrence (F%) of fish and crustaceans in stomach contents of Japanese flounder *Paralichthys olivaceus* sampled from Kumihama Bay (solid circles) and Aso Bay (open circles).](image-url)
a calorific content per weight as fish (Thayer et al. 1973), the weight of an individual mysid is much less than that of a fish and thus for flounder specimens larger than juvenile stage may be an inefficient source of nutrition. The dietary shift from fish to crustaceans and other prey items represents a change of feeding on nutritionally less rewarding prey items in Kumihama Bay during the period from spring to summer. Since the mean $TL$ of the flounder in both bays increased from May to August, the period of low fish prey content in the diet in Kumihama Bay continued until the end of the high growing season for the flounder. As well as their slow growth rates in total length, their condition factor in Kumihama Bay tended to be lower than those in Aso Bay. Therefore, it was considered that the inferior growth of young flounder in Kumihama Bay was mainly due to the low availability of prey fish in spring and summer.

However, this hypothesis may be incorrect if young flounder migrate between bays and outside inshore areas. In western Wakasa Bay, spawning occurs in offshore areas and larval flounder are transported to shallow coastal waters where they settle and remain until the summer of 1-year-old (Kiyono and Sakano 1972; Takeno et al. 2001a,b). Previous tagging experiment of hatchery-raised young flounder in Kumihama Bay and Aso Bay showed that most flounder remained in these bays until the autumn of 1-year-old (Tojima et al. 1987; Kyoto Inst. Ocea. Fish. Sci. 1991, 1993). Although the possibility that some of the large-sized flounder migrated out of the bay should not be neglected, this does not affect the conclusions of this study.

The mean body weight of a flounder at 15-month-old in August in Aso Bay was 2.9 to 4.2 times heavier than in Kumihama Bay. The growth of hatchery-raised flounder released in the two bays were much the same as wild fish examined in this study (Kyoto Inst. Ocea. Fish. Sci. 1992). The mean market prices per kilogram of the flounder from the two bays were about 2,500 yen. The market prices of a flounder from Aso Bay were three to four times higher than from Kumihama Bay. The recapture rates of hatchery-raised juvenile flounders released in Aso Bay at 6 to 7 cm in $TL$ in 1989 and 1990 (2.50% and 0.26%) were equal to or higher than those of same sized juveniles released in Kumihama Bay on the same years (1.24% and 0.24%) (Kyoto Inst. Ocea. Fish. Sci. 1993). These findings show that the stocking effectiveness of hatchery-raised flounder is much higher in Aso Bay than in Kumihama Bay. Various previous studies on the feeding habits of juvenile flounder have suggested that mysids are the most important prey for their growth in the juvenile stage (Imabayashi 1980; Hirota et al. 1990; Minami and Tanaka 1992; Fuji and Noguchi 1996; Yamada et al. 1998; Yamamoto and Tominaga 2007). Therefore, a common concept for stock enhancement of the flounder has been to target releases of juvenile flounders in areas where mysids are abundant. However, a dietary shift from mysids to fish prey generally occurs from 5 to 10 cm in $TL$ (Imabayashi 1980). This ontogenetic dietary shift of the flounder from crustaceans to fish in young stage is considered a feeding strategy to maximize the growth rate (Yamada et al. 1998). Our results showed that small fish such as juvenile anchovy and gobies are important food to enhance the growth of young flounder. Hatchery-raised flounders, which were released in Tokyo Bay, preyed mainly on small fish such as gobies and grew faster than those released in nearby area with lower availability of fish (Nakamura 1996). Therefore, we think that hatchery-raised flounder juveniles which are large enough to consume small fish should be released in areas having a high availability of small fish prey. To further evaluate this hypothesis release-recapture studies using hatchery-raised piscivorous stage juveniles are considered to be the next step.

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References


京都府の2つの閉鎖性内湾でみられた若齢期のヒラメの成長差

竹野功璽・濱中雄一・岡野 敷

京都府内の2つの閉鎖性内湾（久美浜湾と阿蘇海）で若齢期のヒラメの成長を比較した。久美浜湾のヒラメは阿蘇海と比べて成長が顕著に遅く、肥満度も低い傾向が認められた。ヒラメの胃内容物を調べた結果、阿蘇海ではほとんどの個体がほぼ周年魚類を専食していたのに対し、久美浜湾では春から夏にかけて約半数の個体がアミ類やエビ類などの甲殻類を専食していた。また、甲殻類を専食していた個体の胃充満度指数は、魚類を専食していた個体より顕著に低かった。これらのことから、久美浜湾での若齢期のヒラメの成長不良は、成長適期に最適餌料のカタクチイワシやハゼ類などの小型魚類が不足したことにより起こったものと考えられた。