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Growth and Spawning Period of Ridged-eye Flounder *Pleuronichthys lighti* Wu 1929 in the Central Seto Inland Sea, Japan

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Abstract

Ridged-eye flounder *Pleuronichthys lighti* Wu 1929 is a commercially important flatfish in East Asia. Its growth and spawning period in the central Seto Inland Sea, western Japan were examined. The gonadosomatic index increased from September to November, with a peak in November, and decreased from December. Females ≥1 year had mature eggs in November. The results suggest that the main spawning period was November. Using otolith sectioning and etching methods, the opaque zone in sectioned sagittal otoliths was found to be formed annually, during the spawning period. The maximum ages were 5 years old for both sexes. The parameters for the von Bertalanffy growth equation of both sexes were TL_{∞}= 262 mm, k = 1.18·year^{-1}, t_0 = 0.10 year, indicating that ridged-eye flounder grows rapidly until they are 1 year old.

Introduction

Successful fisheries management generally requires accurate stock assessment and appropriate fishing regulations (Matsumiya 1996; Sakuramoto 1998; Rutherford 2002). Age composition and life history traits such as growth, mature age/size and spawning period are the fundamental data used to assess stock population and develop fisheries management policy. Precise age information is essential for such analysis. Ridged-eye flounder *Pleuronichthys lighti* Wu 1929 (former nomenclature: *Pleuronichthys cornutus* (Temminck & Schlegel 1846); Yokogawa et al. 2014) is distributed in the East China Sea and the coastal waters of Japan, with the exception of Hokkaido (Nakabo 2000). This species is a commercial flatfish in East Asia (Yamada et al. 2007). Ridged-eye flounder is a commercially important fish for small trawl fisheries in the Seto Inland Sea (Masaki and Ito 1984; Tokai 1993; Okamoto and Tanda 1997; Tanda et al. 2008b). The annual catch varied between 220 and 400 tonnes since 2000, and the species accounts for more than 50% of the catch of flounders in the Kagawa Prefecture section of the central Seto Inland Sea (Kagawa prefectural fisheries excremental station, unpubl. data).

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Many small ridged-eye flounder, which are of low value are caught by trawl nets together with the target species of demersal fish and small shrimp in the Seto Inland Sea (Tokai 1993; Okamoto and Tanda 1997). For stock management and to avoid overfishing, flounders smaller than 15 cm in total length are voluntarily released by fishermen in Kagawa Prefecture (Kagawa prefectural government 2007). However, the effect of the release of these small flounders cannot be accurately evaluated, because there is no available information regarding their growth rate.

In the 1980s and 1990s, the age and growth of ridged-eye flounder was determined by conducting surface observation of whole otoliths (Masaki et al. 1985; Ichimaru and Tashiro 1994). However, in several flatfishes (Yamamoto et al. 2008; Lee et al. 2009; Earl et al. 2014), age determined by the surface observation method were underestimated. Additionally, outer opaque zone of large otolith for ridged-eye flounder is frequently unclear (Ichimaru and Tashiro 1994). Katayama et al. (2010) focused on the dense grooves and direction changes in otolith growth and established an ageing protocol based on interpretation of the sectioned otolith structure (sectioning and etching methods). Since then the sectioning and etching methods have been used to study the age and growth in eastern Seto Inland Sea (Katayama et al. 2010) and the coastal water off Fukushima Prefecture, northeastern Japan (Ito 2013).

Ridged-eye flounder is not a large-scale migrating fish (Masaki and Ito 1984), and the growth and spawning period vary geographically (Ito 2013). Therefore, detailed ecological information regarding the ridged-eye flounder in each location is required for stock management. However, compared with information from the eastern and western Seto Inland Sea (Masaki et al. 1985, 1987; Watanabe and Ueta 1990; Watanabe et al. 1996; Katayama et al. 2010), in the central Seto Inland Sea there is limited information available on the life history traits of ridged-eye flounder. In this study, the age and growth of ridged-eye flounder using the otolith sectioning and etching methods and their spawning period based on seasonal variation in gonad weight were studied in the central Seto Inland Sea. The information gathered will help to understand the stock exploitation by fishing and evaluate the impact and timing for the release of small fish and to propose useful fishing regulations.

Materials and Methods

Study area

The sampling site was located in the central Seto Inland Sea, western Japan (Fig. 1). The Seto Inland Sea is one of the most productive enclosed waters in the world (Takeoka 1996). The water depth is 10–40 m, and the sediment at the sampling site was gravel and sand.

Fish sampling

A number (5−18) of ridged-eye flounder caught by small trawl nets were randomly purchased monthly from October 2005 to March 2007. The total length (TL), body weight (BW) and gonad weight (GW) of each fish were measured to the nearest 1 mm, 0.01 g and 0.01 g, respectively, and sex was determined. Female with mature eggs were easily identified by observing their gonad (Wtatanabe et al. 1996).

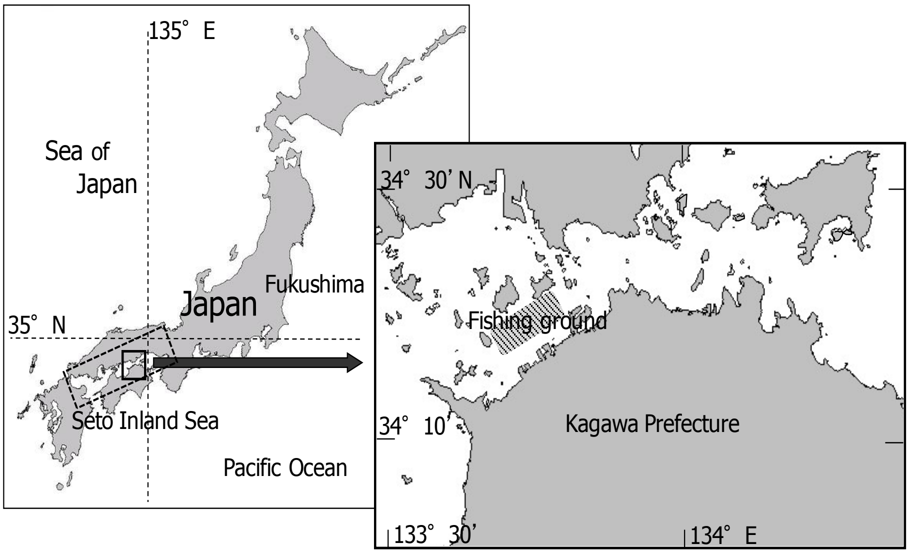

Fig. 1. Map showing the sampling site of ridged-eye flounder (shaded area) in the central Seto Inland Sea, western Japan. The portion surrounded by a dotted line is the Seto Inland Sea

Ridged-eye flounders smaller than 15 cm in TL could not be purchased, because small fish are voluntarily released back to the sea by fishermen. Therefore, a number (18−55) of small fish < 15 cm in TL, considered as young-of-the-year (YOY) fish, were obtained directly from a fisherman of small trawl fisheries monthly from February to June in 2006. The TL and BW of each fish were measured.

Otolith treatment

Sagittal otoliths were extracted from each fish, cleaned, and stored in micro plates with 48 wells until further observations were made. Otoliths were mounted and embedded in polyester resin. The embedded otoliths were cut into approximately 0.3 mm transverse sections using a diamond saw (Leica sp1600; Leica Microsystems GmbH, Wetzlar, Germany). The sections were mounted on glass slides and their surfaces were ground to finer grades using carborundum paper. Finally, they were etched with 0.2N HCl for 40–60 s and examined with a binocular microscope at 40× or 100× magnification, using a published observation technique for the fine microstructure of otolith annuli in ridged-eye flounder (Katayama et al. 2010). Similar to Katayama et al. (2010), the number of opaque zones and the appearance of each zone at the outer margin of each specimen based on directional changes in otolith growth were recorded.

Maturation and growth analysis

Maturation was determined using the gonadosomatic index (GSI):

$$GSI = GW/(BW - GW) \times 100.$$

To estimate the precision of age determination using the otolith sectioning and etching methods, the opaque zones of the otolith sections were counted again and the index average percent error (IAPE) were calculated following the method of Beamish and Fournier (1981).

Values below 5 indicated higher precision (Palla et al. 2016).The index was computed using the formula:

$$IAPE = \frac{100}{N}\sum_{i=1}^{R}\frac{|X_{ij}-X_j|}{X_j},$$

where N = number of fish aged, R = number of readings, X_{ij} = age of j^{th} fish at i^{th} reading and X_j = mean age calculated for the j^{th} fish. To estimate the parameters for the von Bertalanffy growth formula, a birth date of 15th November, which corresponds to the main spawning period (see results) was set, and the male and female ages were determined by counting the number of opaque zones. Using a nonlinear least-squares estimation, the age-length relationships to the following von Bertalanffy growth equation were fitted:

$$TL_t = L_\infty\{1-\exp[-k(t-t_0)]\},$$

where TL_t = TL (mm) at age t, L_∞ = asymptotic TL, k = growth coefficient/ year, t = age (year), and t_0 = hypothetical age when TL is 0. The difference in the growth curves between sexes was determined by Kimura's likelihood ration test (Kimura 1980; Haddon 2011). For small fish which could not be sexed, their age-length relationships were pooled to estimate the growth parameters.

Results

Fish size

A total of 242 fish were obtained from October 2005 to March 2007. Total length ranged from 150.1 to 316.9 mm. A total of 174 YOY fish were collected from February to June in 2006. Total length ranged from 37.7 to 146.2 mm. Size distribution consisted of a single, dominant mode (Fig. 2). The modes were 55 mm TL in February and March, after which the mode increased from April to June, i.e. 75 mm in April, 115 mm in May and 125 mm in June.

Seasonal changes in the GSI

Seasonal changes in the mean GSI of female (n = 113) and male (n = 129) ridged-eye flounder were observed (Fig. 3). The mean GSIs of both sexes remained at a low level from January to August, increased from September to November, and were highest in November. The GSI of females was higher in November than in other months (Scheffe's F-test, P <0.05) and the GSI of males was higher in November than in other months, except in October (Scheffe's F-test, P <0.05). The mean GSI decreased remarkably from December to January. Females with mature eggs appeared in November. The females ranged in TL from 172.6 to 274.1 mm and ranged in GSI from 5.80 to 11.15.

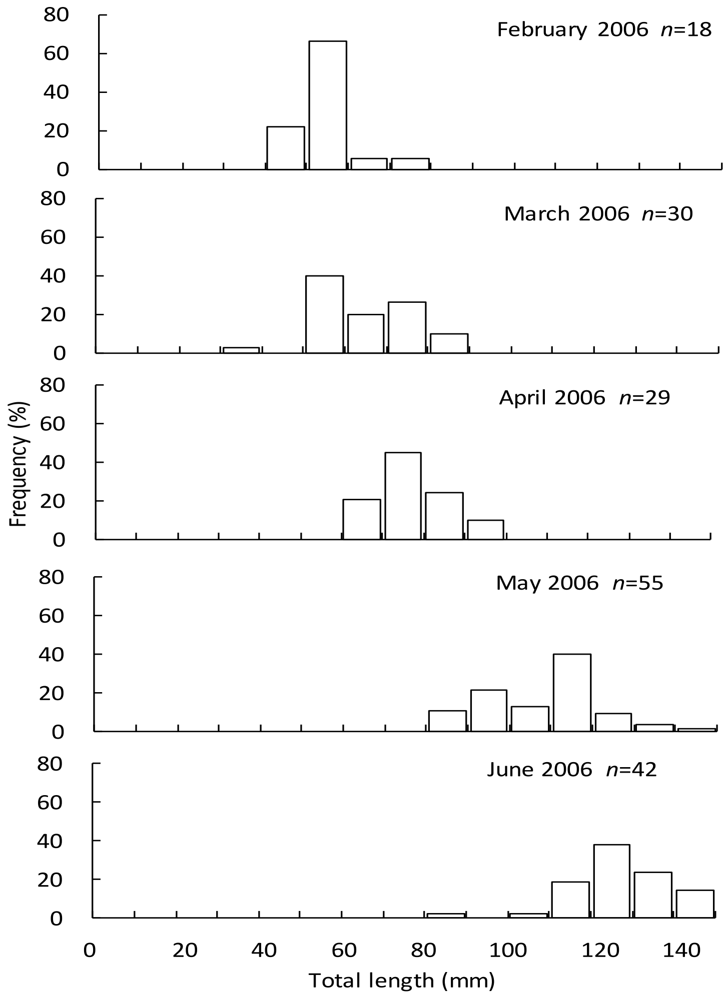

Fig.2. Monthly size distributions of young-of-the year ridged-eye flounder caught in the central Seto Inland Sea from February 2006 to June 2006.

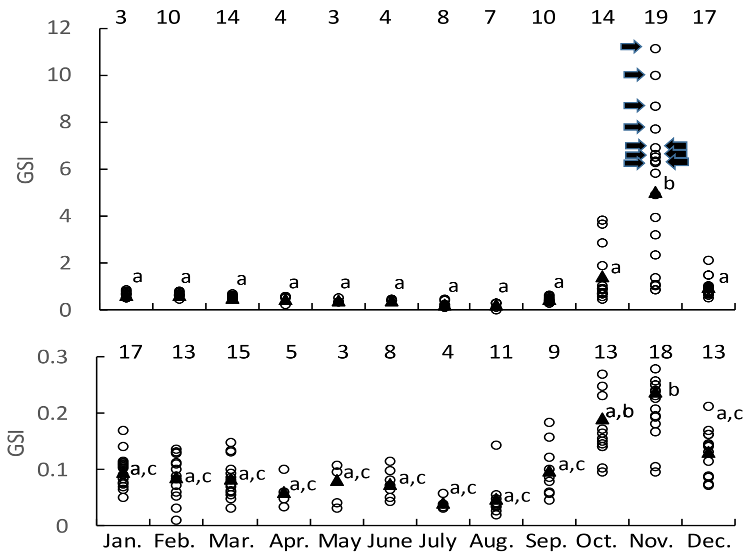

Fig.3. Seasonal changes in the gonadosomatic index (GSI, open circle) and mean GSI (solid triangle) of female (top) and male (bottom) ridged-eye flounder caught in the central Seto Inland Sea from October 2005 to March 2007. Different superscripts and arrows indicate significant differences in mean GSI (Scheffe's *F*-test) and females with mature eggs, respectively. Numerals above figure indicate the number of the specimens.

Growth equation

A total of 198 etched transverse otolith sections were produced from the ridged-eye flounder obtained from October 2005 to March 2007. It was easy to detect the opaque zones of the sections (Fig. 4). The precision of otolith reading was high, with IAEP of 3.42%.

The opaque zone at the outer margins of the otoliths developed from October to February (Fig. 5). The seasonal pattern indicates that ridged-eye flounder produce annual otolith rings from October to February. The maximum age was 5 years for males (274.4 mm TL) and 5 years for females (316.9 mm TL). The minimum age of females with mature eggs was 1 year.

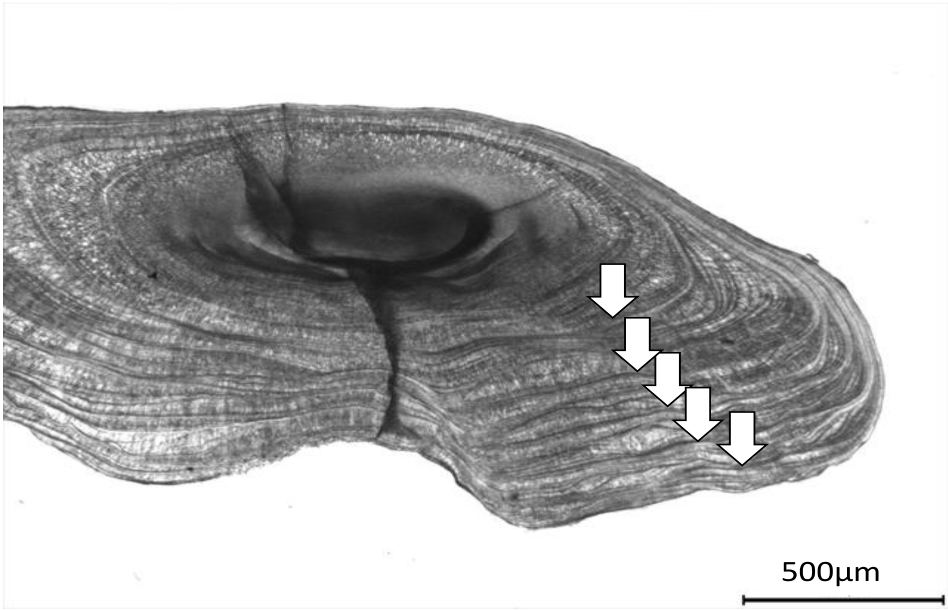

Fig. 4. Transverse sections of otolith from ridged-eye flounder (male 274.4 mm TL) caught on 27 October, 2005. Arrows indicate opaque zones.

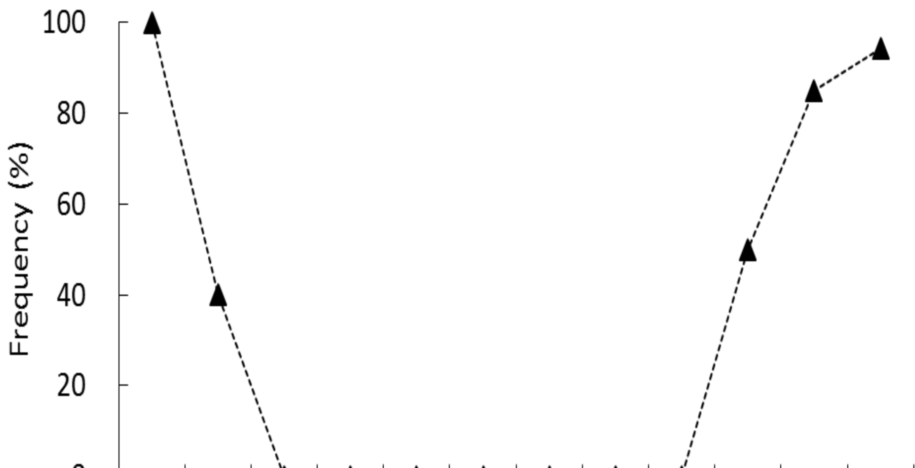

Fig.5. Seasonal change in the proportion of an opaque zone on the outer margin of sectioned otolith

Based on the age-length relationships of 198 ridged-eye flounder (female, 81; male, 117), the von Bertalanffy growth equations for females and males were estimated to be as follows:

$$\text{female:}\quad TL_t = 300\{1-\exp[-0.55(t+0.67)]\},$$

$$\text{male:}\quad TL_t = 281\{1-\exp[-0.62(t+0.61)]\}.$$

The equations did not differ significantly between males and females (P =0.12); moreover, all the parameters did not differ between sexes (L_∞: P =0.26, k: P=0.67, t_0: P =0.93). Therefore, based on the age-length relationships of 198 flounder and 147 YOY flounder (37.7−146.2 mm TL), the growth equations for both sexes was estimated to be as follows (Fig. 6):

$$TL_t = 262\{1-\exp[-1.18(t-0.10)]\}.$$

Total length estimated by the equation was 98 mm in ½ year olds, 171 mm in 1 year olds, 234 mm in 2 year olds, 253 mm in 3 year olds, 259 mm in 4 year olds and 266 mm in 5 year olds. Ridged-eye flounder grew rapidly in its first year and achieved approximately 65% of the L_∞ in 1 year olds, after which their growth rate gradually decreased.

The BW increased exponentially with TL, and the relationship between TL (mm) and BW (g) was expressed as follows:

$$BW = 1.10\times 10^{-5}\times TL^{3.03},\ r^2 = 0.99,\ n = 372.$$

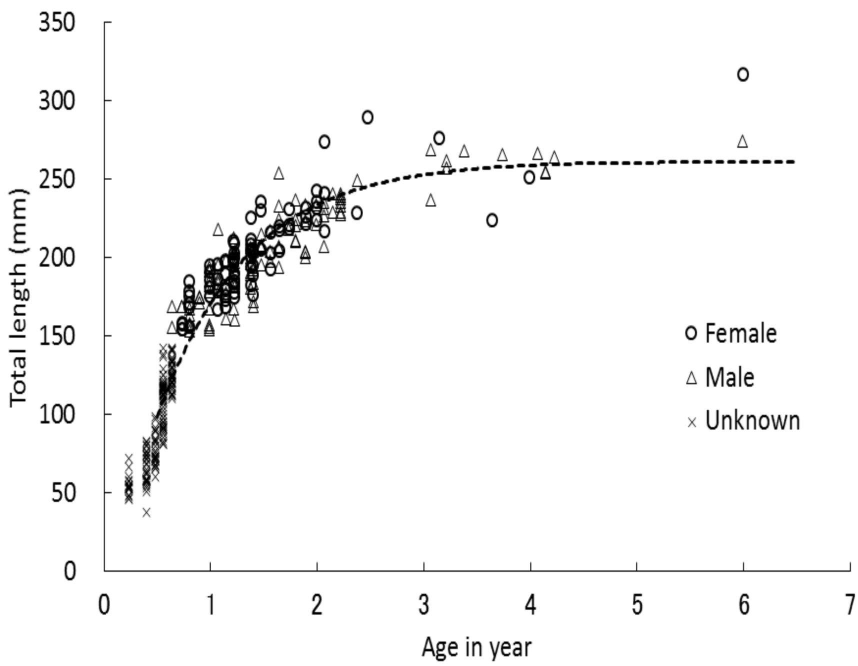

Fig.6. Von Bertalanffy growth equation fitted age-length relationships in ridged-eye flounder.

Discussion

The implementation of regulatory measures to protect fish being caught during the spawning period is an effective stock management measure (Matsumiya 1996; Sakuramoto 1998; Rutherford 2002). The seasonal changes in the GSI and appearance of the females with mature eggs suggest that the main spawning period is November. To sustain the fisheries, we propose fishing regulations such as closed season and/or closed area in November.

The eggs and larvae of ridged-eye flounder have been reported to occur in the central Seto Inland Sea in November (Kusaka et al. 2013) and between November and February, respectively (Shoji et al. 2002). The spawning period in the coastal waters of Japan, which is between November and January (Masaki et al. 1987; Ichimaru and Tashiro 1994; Watanabe et al. 1996; Ito 2013), is similar to the findings of this study. In contrast, the spawning period in the East China Sea, as reported by Matsuoka (1996) is between January and March, which is later than the coastal waters of Japan. In the present study the spawning period is synchronised with the annual formation of an opaque zone in otoliths. Similar phenomenon has been reported in other flatfish (Tanda et al. 2008a; Katayama et al. 2010; Yamamoto and Katayama 2013; Earl et al. 2014).

Using the sectioning and etching methods, the current study revealed the maximum age of ridged-eye flounder was 5 years in central Seto Inland Sea, whereas Katayama et al. (2010) reported 10 years in the eastern Seto Inland Sea and Ito (2015) reported 15 years in the coastal water off Fukushima Prefecture. The proportion of catch of older fish generally decreases with an increase in fishing pressure (Matsumiya 1996). Additionally, the fishing mortality coefficient of Japanese flounder *Paralichthys olivaceus* (Temminck and Schlegel 1846) caught mainly by trawl fisheries was higher in the Seto Inland Sea (Sakachi and Yamamoto 2015) than the north Pacific including the coastal water off Fukushima Prefecture (Kurita et al. 2015). The reports suggest that fishing pressure is higher in the study area than other waters. Significant difference in growth equation between sexes was not observed in this study and in the eastern Seto Inland Sea as reported by Katayama et al. (2010). However, the females grow larger than the male in the coastal water off Fukushima Prefecture (Ito 2013).

The TL_∞ of the growth equation in this study was as large as those reported in the eastern Seto Inland Sea (Katayama et al. 2010), and for males in the coastal water off Fukushima Prefecture (Ito 2013), but was smaller than values for females in the coastal water off Fukushima Prefecture (Ito 2013). Ridged-eye flounder females continued to grow even at ≥5 year old in the coastal water off Fukushima Prefecture (Ito 2013), whereas >3 year old flounder grew very little in other waters (Masaki et al. 1987; Ichimaru and Tashiro 1994; Katayama et al. 2010). The observations indicate that ridged-eye flounder females in the coastal water off Fukushima Prefecture grew faster, were larger, and lived longer than in other waters. In general, fish growth is greatly influenced by food and water temperature (Yamashita 2010). Further studies are necessary in order to understand the cause of the growth difference of ridged-eye flounder in various water bodies which could be due to factors such as physical environment, prey availability and food intake.

In the present study the growth equation and seasonal variation in size distribution demonstrate that the YOY fish grow rapidly. The release of small sized fish is useful for avoiding overfishing (Matsumiya 1996). However, the estimated survival rate of the released fish is reported to be 20-77% (Okamoto and Tanda 1997; Yamamoto and Takasago 2005). The introduction of new technologies for increasing the survival rate of the released fish is required. An increase in the mesh size of a small bottom trawl net has been proposed to enable the small fish to escape from the nets in the Yamaguchi Prefecture section of the western Seto Inland Sea (Murata 2011). In the future, such fishing techniques should be introduced throughout the Seto Inland Sea to improve the protection of the small fish.

Conclusion

Ridged-eye flounder spawned mainly in November in the central Seto Inland Sea, as suggested by the seasonal changes in the GSI and appearance of females with mature eggs. Females ≥1 year had mature eggs. Using otolith sectioning and etching methods, the opaque zone in sectioned otoliths was shown to form annually, during the spawning period. The von Bertalanffy growth equation for both sexes was determined as: $TL = 262\{1-\exp[-1.18(t-0.10)]\}$. YOY fish grew rapidly, which suggests that the release of small fish is useful in enhancing recruitment to avoid overfishing.

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