Spawning seasons of adult and growth of 0-year-old deepsea smelt *Glossanodon semifasciatus* in Tosa Bay, Pacific coast of Shikoku

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The deepsea smelt *Glossanodon semifasciatus* is one of the most important fishes for the demersal fishery in the Pacific coastal waters of central and southern Japan. In the present study, the spawning season in Tosa Bay was estimated to be from January to April (spring spawning group), and also at a lower frequency in October to November (autumn spawning group) based on gonad somatic index changes and stages of the ovaries of adult fish landed by commercial fisheries in Tosa Bay. Furthermore, the abundances of 0-year-old fish of the two seasonal spawning groups were investigated by a trawl survey. The spring spawning group was much more abundant than the autumn spawning group. The growth of 0-year-old fish was traced by the modes of the histogram of the specimens by measuring the Scale Length (SCL) of fish caught by a monthly trawl survey using a research vessel from April 2002 to March 2005. The smallest specimen sampled was about 19 mm SCL in mid April 2002 at the depth of 150 m. Although the histograms consisted of polymodal classes and at least three or more growth lines were traced, the main mode of SCL of the spring spawning group from 2002 to 2003 was 25 mm in April, 50 mm in May, 75 mm in June, 90 mm in August, 105 mm in October, 110 mm in November and about 140 mm in March in the next year. The growth rate of the 0-year-old fish in Tosa Bay is higher than that estimated for the sub-population in the Sea of Japan, possibly due to the higher temperature of the nursery ground of the Tosa Bay. The recruitment index of the spring spawned group fluctuated between years however reasons for the fluctuations require further investigation.

Key words: deepsea smelt, spawning season, 0-year-old, growth, recruitment index

Introduction

The deepsea smelt (“Nigisu” in Japanese) is one of the most important demersal fish stocks in the Pacific coastal waters of central and southern Japan. The Japanese Danish seine, two-boat trawlers and small Danish seine fisheries caught slightly less than 1,000 metric tons in these waters in 2004. The total catch in the Pacific Ocean waters is currently at a low level (half of the peak in 1996) and showing a slight decreasing trend. The fish is also caught in the Sea of Japan with a current annual catch of more than 3,000 metric tons. These two sub-populations however are geographically isolated from each other, and the trend of annual catch between the two sub-populations is different.

Biological studies especially on the growth rates and age determinations have been conducted mainly using specimens from the Sea of Japan (Mio, 1969; Sinoda and Jayashinghe, 1971; Ogata and Ito, 1979). Mio (1969) studied the spawning season from the monthly changes in the stages of ovary and estimated that the two spawning seasons existed (March and September broods) and pointed out that the deepsea smelt was a multi-spawner within both spawning seasons. Sinoda and Jayashinghe (1971) distinguished two spawning groups (spring and autumn spawning ones) by the hyaline and opaque zone formation pattern of the otolith (sagitta). Only Hanyu (1956) studied the growth rate using specimens caught on the Pacific coast of southern Japan, and his study used the sagitta for age determination.

There are no studies regarding the spawning season of the deepsea smelt in the coastal waters of the Pacific Ocean. So we estimated spawning season of the adult specimens in the present study. In spite of the age determination of young and adult specimens, the growth of 0-year-old fish has rarely been studied, because it is difficult to collect 0-year-old specimens. So in the present study, we will show the growth of 0-year-old of deepsea smelt by tracing the modal shifts of body lengths in Tosa Bay, Pacific coast of southern Japan.

Materials and Methods

The spawning season was estimated using commercially caught adult samples landed by the Japanese Danish seine

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Table 1. Sampling date at Mimase Fisheries Co-operative Association by the Japanese Danish seine.

Year/Month/Day	No. of fish sampled	Fishing depth
2001/10/ 8	210	
2001/11/11	138	
2001/12/ 2	242	
2002/ 1/20	222	
2002/ 2/ 6	210	300 m
2002/ 3/10	201	
2002/ 4/10	286	160∼200 m
2002/10/ 9	271	
2002/11/ 5	247	
2002/12/ 5	224	250 m
2003/ 1/ 7	174	250 m
2003/ 2/19	213	250 m
2003/ 3/ 5	245	250 m
2003/ 4/ 7	263	250 m
2003/10/27	191	200 m
2003/11/20	216	200 m
2004/ 2/25	152	250 m
2004/ 3/21	449	250 m
2004/10/25	295	
2004/11/21	212	250 m
2005/ 1/26	213	250 m
2005/ 2/17	258	180∼200 m
2005/ 3/10	231	286 m
2005/ 4/25	251	190∼200 m
2005/10/13	197	178 m
2005/11/13	204	275 m
2005/12/ 8	158	200 m
2006/ 1/24	182	
2006/ 4/ 9	246	200∼210 m
2006/10/ 2	279	210∼220 m
2006/11/ 5	302	230∼280 m
2006/12/11	203	200∼250 m
2007/ 1/ 8	283	180∼200 m
2007/ 1/31	241	180∼200 m
2007/ 3/ 4	215	320∼340 m
2007/ 4/ 8	213	180 m

at the Mimase Fisheries Co-operative Association in Kochi City from October 2001 to April 2007 (Table 1). Within each sample 50 or 30 specimens were randomly picked up and dissected. As the Danish seine is off-season from May to September in Tosa Bay and the trawl net of our research vessel was not so efficient for sampling bigger adult fish (more than 180 mm), little information of the adult fish was available during the off-season period.

The scale length (SCL: mm) denotes from the posterior margin of the mouth to the end of body covered with scales. Based on the current sample data set from Tosa Bay, the total length (TL: mm) can be calculated from the scale length with the formula as follows,

$$TL=0.8754\times SCL+0.2984 \quad r^2=0.9983 \quad n=2{,}204 .$$

The Gonad Somatic Index (GSI) was calculated using the following formula,

$$GSI=\text{gonad weight (g)}\times 10^4/((SCL(cm))^3) .$$

Although there are no histological studies of the ovary of ripening females in the present area, we defined that a female specimen is ripening when the GSI value is over 1 during the spawning season in the present study. We also defined "ripe egg" in the present study that the female specimen has large hydrated eggs, clearly visible to the naked eye, in the ovary. The ovary (ripe or not) was checked visually whether the fish will spawn or not within the season.

The trawl survey was conducted monthly from April 2002 to March 2005 in Tosa Bay using R.V. "Kotaka Maru" (30 m long, 59 tons, 1,000 ps), off Shikoku Island, Pacific Ocean (Fig. 1). The gear used was a small otter trawl net (cod-end mesh size 1.3 mm). The trawling stations were chosen according to depth as Horikawa *et al.* (1991). We trawled at 100 m, 125 m, 150 m, 175 m and 200 m in 2002. From May to October, two lines were set to investigate wider range of habitat. In 2003, trawling depths were 100 m, 150 m and 200 m. Stations at 250 m depth were additionally trawled from May to October. From April 2004, the trawling depths were 100 m, 150 m and 200 m throughout the year (see Table 2). All trawls were conducted during the daytime. Trawl courses were set bathymetrically as much as possible. The duration of the each trawl survey was 10 or 15 min (mostly 15 min) from the set of the towing line (stainless steel 8 mm in diameter) until the start of the retrieval of the net. The towing speed was approximately 2 kt. The samples were divided into taxonomical groups and 0-year-old deepsea smelt were picked up and preserved in 5% seawater neutralized formalin, and in the laboratory they were washed with tap water and then preserved in 100% (2002) and 80% (2003–2005) ethanol within 24 h after sampling. The percentage of shrinkage of scale length by the formalin and ethanol was not checked in the present study.

A photograph of *G. semifasciatus* juvenile (SCL is about 25 mm) sampled in Tosa Bay was shown in Fig. 2. The eleven transverse bands are the most typical index of *G. semifasciatus*. Numbers of 0-year-old specimens (SCL $<$150 mm, Table 3) were counted after Hanyu (1956), and total weight was weighed for each station. Later, the SCL were measured to the nearest 1 mm with digital solar calipers (Mitutoyo Co. Ltd. Japan). The SCL of every specimen data were calculated and histograms (5 mm interval) of SCL at each depth were constructed using a personal computer. Males and females were not differentiated.

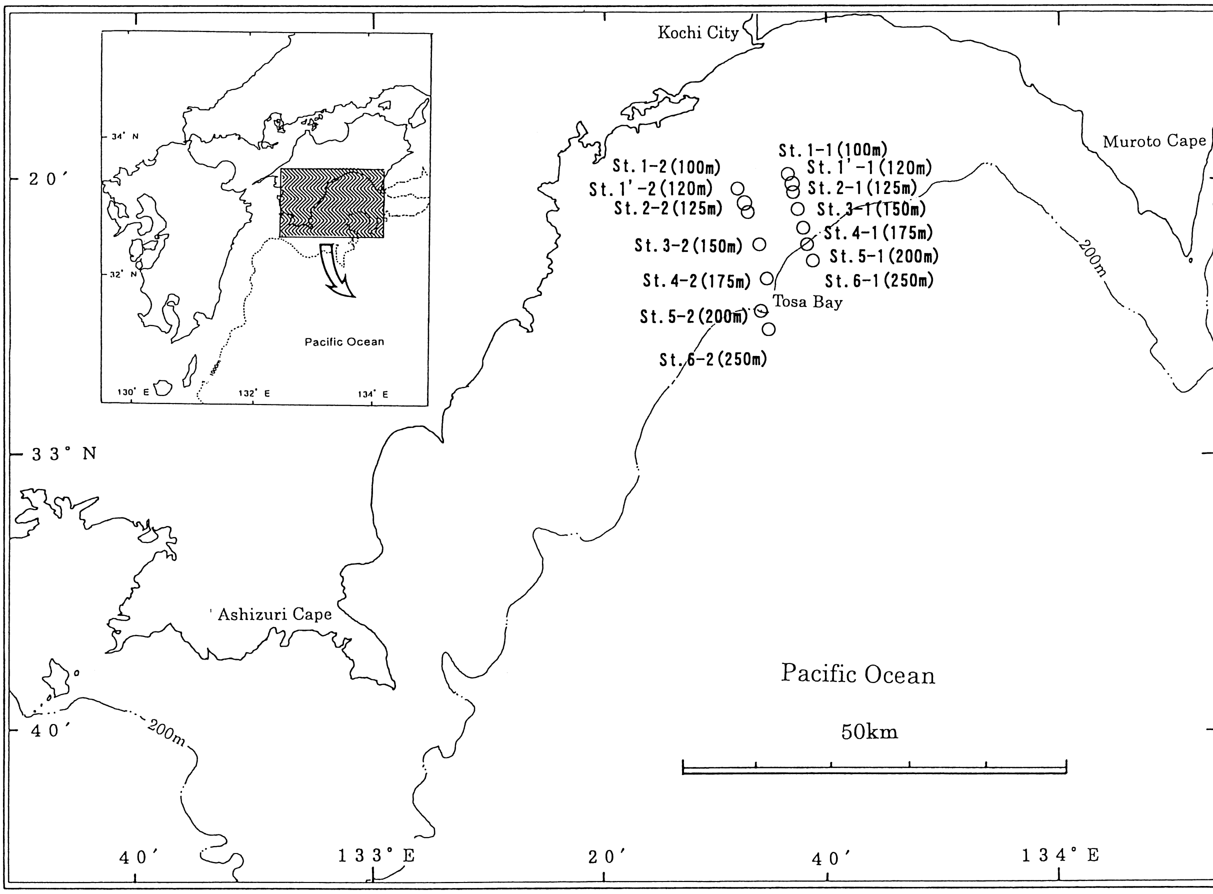

Figure 1. Sampling stations of the R.V. Kotaka Maru from April 2002 to March 2005. Sampling data are shown in Table 2.

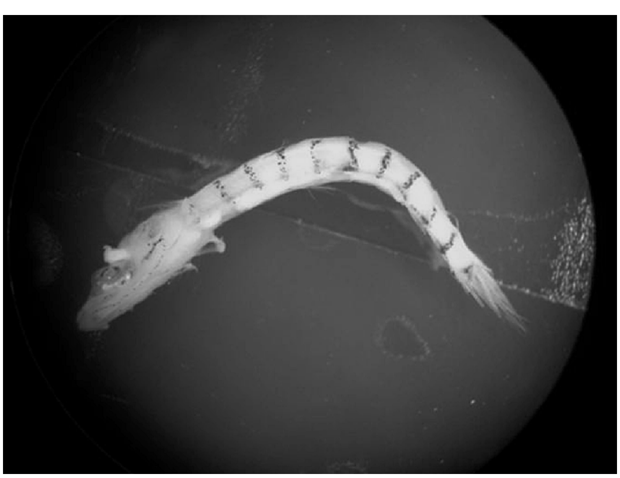

Figure 2. Photograph of the deepsea smelt juvenile *G. semifasciatus*. The Scale Length (SCL) of the specimen was about 25 mm. The 11 transverse bands are the typical index to distinguish from another related species *Argentina kagoshimae*.

We traced the growth of 0-year-old specimens by tracing modal shifts of body length data in Tosa Bay. From the samples during the three years, we estimated the recruitment index (0-year-old). The recruitment index was estimated from the average number of 0-year-old specimens (SCL<50 mm, these specimens were estimated to be less than 120 days after hatching, Nashida *et al.*, unpublished data) per haul every month at each depth.

Results

The averaged GSI values and variations by month from October 2001 to April 2007 are shown in Fig. 3. The values fluctuated between years. Although in spring distinct peaks of GSI were observed, no peaks were observed from October to November. Only in 2005, were distinct peaks observed in December in both sexes. From October to November, the values were less than 1 (both sexes), and gradually increased from December and peaked in February. In March, the values slightly decreased but were still high, and in April the values decreased though the values were mostly more than 1 in both sexes.

Table 2. Trawling stations of R.V. "Kotaka Maru" from April 2002 to March 2005. The numbers in the table are the towing duration (minutes) and "—" denotes lack of trawling because of adverse weather or obstructions on the bottom.

Station No. depth in m	St.1-1 100	St.2-1 125	St.3-1 150	St.4-1 175	St.5-1 200	St.6-1 250	St.1-2 100	St.2-2 125	St.3-2 150	St.4-2 175	St.5-2 200	St.6-2 250
Date of trawling												
April 16, 2002	15	15	15	15								
May 15, 2002	15	15	15	15								
May 16, 2002							15	15	15	15		
May 17, 2002					15						15	
June 19, 2002	15	15	15	15								
June 20, 2002					15						15	
June 21, 2002							15	15	15	15		
July 29, 2002	15	15	15	15								
July 30, 2002							15	15	15	15		
August 26, 2002	15	15	15	15								
August 27, 2002							15	15	15	15		
September 18, 2002	15	15	15	15								
September 19, 2002							15	15	15	15		
September 26, 2002					15						15	
October 16, 2002	15	15	15	15								
October 17, 2002					15						15	
October 18, 2002							15	15	15	15		
November 13, 2002	15	15	15	15								
December 14, 2002	15	15	15	15								
January 14, 2003	15	15	15	15								
February 3, 2003	15	15	15	15								
March 4, 2003	15	15	15	15								
April 7, 2003	15		15		15							
May 19, 2003	15		15		15							
May 20, 2003							15		15		15	
May 21, 2003						15						15
June 16, 2003						10						10
June 17, 2003	10		10		10							
June 18, 2003							10		10		10	
July 24, 2003	15		15		15							
July 25, 2003							15		15		10	
August 27, 2003	15		15		15							
August 28, 2003							15		15		15	
September 18, 2003	—		15		15							
September 19, 2003							15		15		15	
October 6, 2003	15		15		15							
October 7, 2003							15		15		15	
October 8, 2003						15						15
November 18, 2003	15		15		15							
December 15, 2003	15		15		15							
January 28, 2004	15		15		15							
February 16, 2004	15		15		—							
March 8, 2004	15		15		15							
April 16, 2004	15		15		15							
May 18, 2004	15		15		15							

Table 2. Continued.

Station No. depth in m	St.1-1 100	St.2-1 125	St.3-1 150	St.4-1 175	St.5-1 200	St.6-1 250	St.1-2 100	St.2-2 125	St.3-2 150	St.4-2 175	St.5-2 200	St.6-2 250
May 19, 2004							15		15		15	
June 16, 2004	15		15		15							
June 17, 2004							15		15		15	
July 21, 2004	15		15		15							
July 22, 2004							15		15		15	
August 23, 2004	15		15		15							
August 24, 2004							15		15		15	
September 13, 2004	15		15		15							
September 18, 2004							15		15		15	
October 12, 2004	15		15		15							
October 13, 2004							15		15		15	
November 15, 2004	15		15		15							
December 13, 2004	15		15		15							
January 17, 2005	15		15		—							
February 9, 2005	15		15		—							
March 14, 2005	15		15		—							

Table 3. Body length (Scale Length) of 1-year-old specimens in the Sea of Japan, and Pacific coast of central Japan. Units : mm.

Authors	Spawning group	1-year-old	Comment	Survey areas
Hanyu (1956)*		130–150		Kumano-nada, Kii straight
Mio (1969)	Spring spawning group	91		Off-coast of Niigata Prefecture
	Autumn spawning group	92		Off-coast of Niigata Prefecture
Sinoda and Jayashinghe (1971)**	Spring spawning group	74	7 month-old	Off-coast of Kyoto Prefecture
	Autumn spawning group	101		Off-coast of Kyoto Prefecture
Ogata and Ito (1979)***	Spring spawning group	51	7 month-old	Off-coast of Niigata Prefecture
	Autumn spawning group	110		Off-coast of Niigata Prefecture
Present study	Spring spawning group	130–140		Tosa Bay

* Only Hanyu studied the specimen caught in the coastal areas of the Pacific Ocean. Other authors studied in the Sea of Japan
** Sinoda and Jayashinghe (1971) measured the fish sampled in October
*** Ogata and Ito (1979) measured the fish sampled in October

The relationships between SCL and GSI for female specimens larger than 170 mm SCL from January to April, and October and November in 2003 are shown in Fig. 4. The closed circles show ripe eggs which were visually checked, and the open ones show specimens that did not have any ripe eggs in the ovary. In January, though many GSI values were over 1, no ripe eggs were observed. From February to March, the GSI values peaked and there were some ripe eggs. In April, although the percentage of specimens of GSI value (over 1) decreased, some ripe eggs were observed. In October, the GSI values of all specimens were under 1, but two specimens had ripe eggs. In November, the GSI values increased and several specimens had ripe eggs. As mentioned in the introduction, the deepsea smelt is a typical multi-spawner, and judging from the results, there are two spawning groups, namely spring and autumn ones, but the spring spawning group was much more dominant than the autumn one.

The monthly recruitment indexes of the 0-year-old deepsea smelt in Tosa Bay were relatively high both in 2002 and 2004 (especially in May 2004 at St.2-1 and St.2-2), but low in 2003 (Fig. 5). The maximum value was 895 individuals/haul in May 2004 at the depth of 150 m and rapidly decreased in June. No peaks were observed in 2003 throughout the year. The autumn spawning groups were very few in the present study.

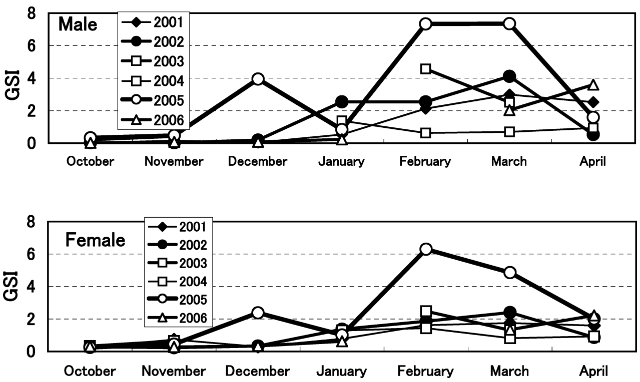

Figure 3. Seasonal variation of Gonad Somatic Index (GSI) of the adult deepsea smelt caught by commercial Japanese Danish seine in Tosa Bay from October 2001 to April 2007. Each symbol indicates the average value by month.

The histograms (SCL) of the deepsea smelt by month (all stations are included) from April 2002 to March 2003 are shown in Fig. 6. The smallest specimen sampled was about 19 mm (SCL) in mid April 2002 at the depth of 150 m. Although some modes were not observed in subsequent months, these histograms showed the main modes of the specimens, namely 25 mm (25≦SCL<30 mm) in April, 50 mm in May, 75 mm in June, 90 mm in August, 105 mm in October, 110 mm in November and about 140 mm in March in the next year. In December, the smaller size classes (25–30 mm SCL) occurred at 125 m depth, but the number of specimens sampled was very small in contrast to April and May 2002. From January, a 45 mm mode emerged and became 70 mm in February and 80 mm in March 2003.

The same analysis was applied to the specimens from April 2004 to March 2005 (Fig. 7). In this case, four series of modal progressions were observed, but none continued throughout the year. The main mode appeared at 25 mm in April, 50 mm in May, 80 mm in June and 100 mm in July, but the series disappeared in August. This series possibly became 130 mm in February 2005. From June, another mode emerged at 50 m in June, and became 75 mm in July, 80 mm in August, 90 mm in September, 95 mm in October, 100 mm in November and 105 mm in December. These two series were apparently different. From January, 25 mm mode emerged and this mode shifted to 50 mm in March 2005.

Discussion

The results of this survey showed that there are two spawning groups, that is the spring and autumn spawning groups in the present study area. But the spring spawning group is far more abundant than the autumn group. Based on the commercially caught adult samples, the spring spawning group is considered to spawn from January to April, and the autumn spawning group from October to November. The authors preliminary studied otolith daily rings of the specimens and estimated the birth date and found that the

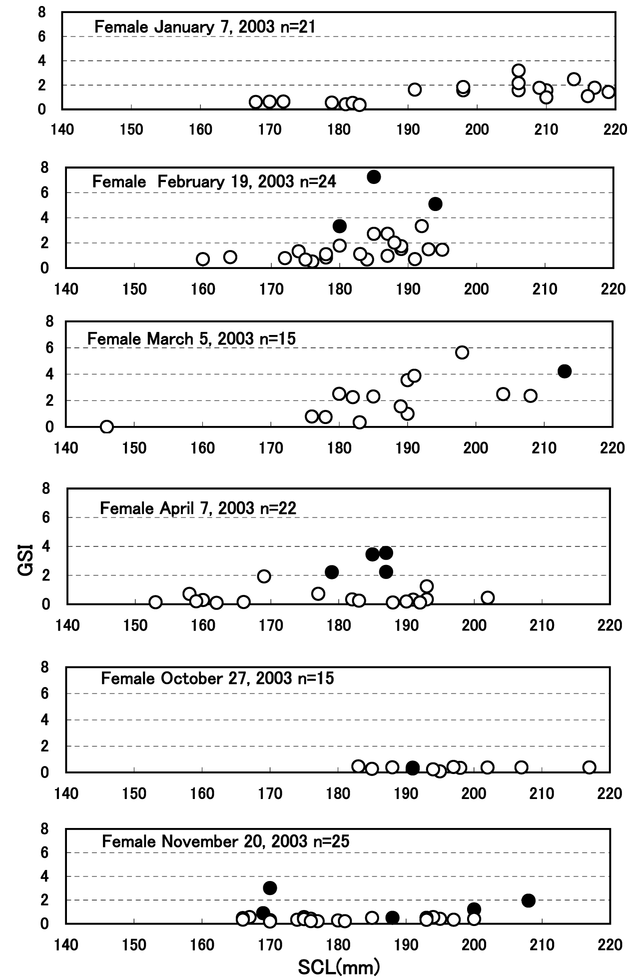

Figure 4. Relationship between Scale Length (SCL) and Gonad Somatic Index (GSI) of females by month during January to April, and October to November in 2003. Ripening females are defined that the GSI value is over 1 during the spawning season in the present study. The open circles show that the specimen had no ripe eggs in the ovary, and the closed ones show that the specimen had visually ripe (hydrated) eggs.

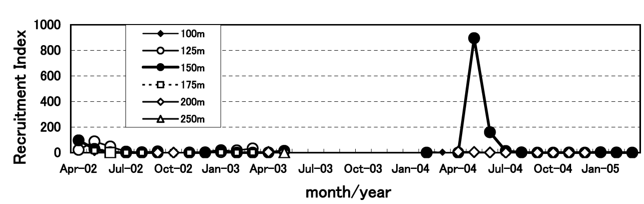

Figure 5. Recruitment index of 0-year-old specimens at all stations according to depth from March 2002 to March 2005. The number of specimens (SCL<50 mm) were counted and averaged.

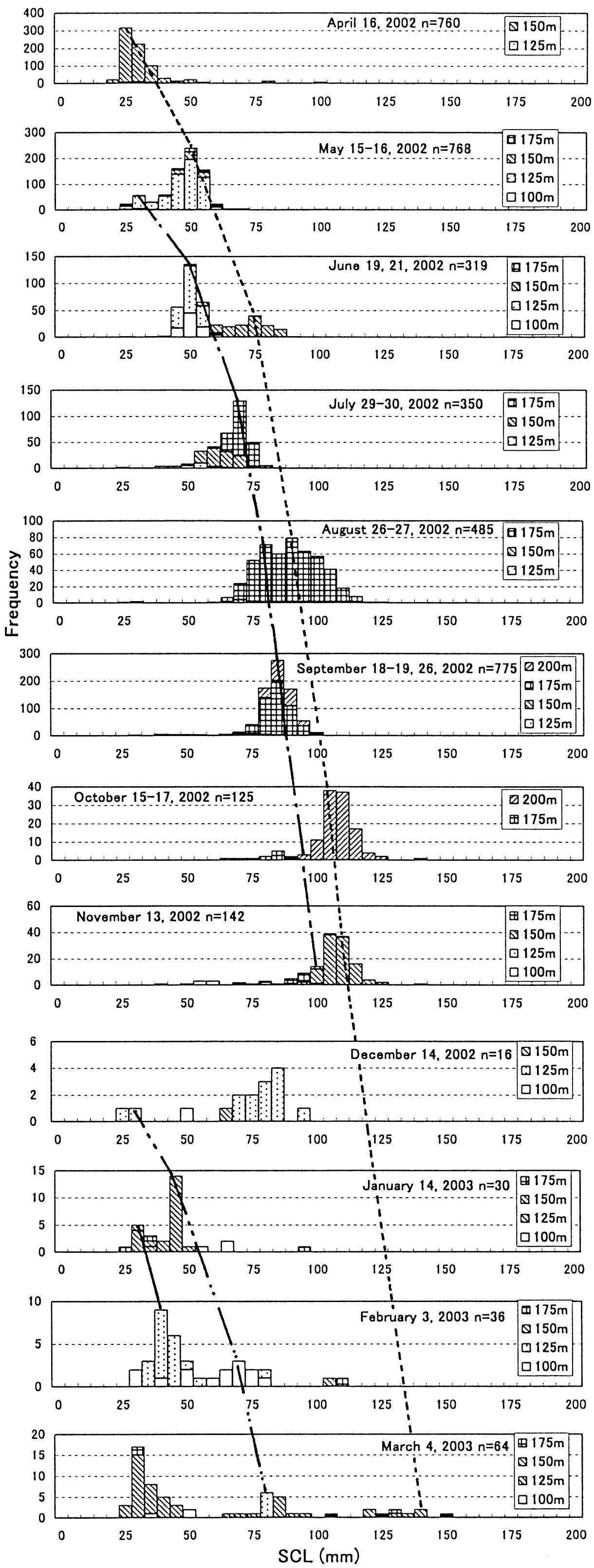

Figure 6. Histograms of Scale Length (SCL) of the deepsea smelt by month from April 2002 to March 2003. These histograms include all specimens from different depths.

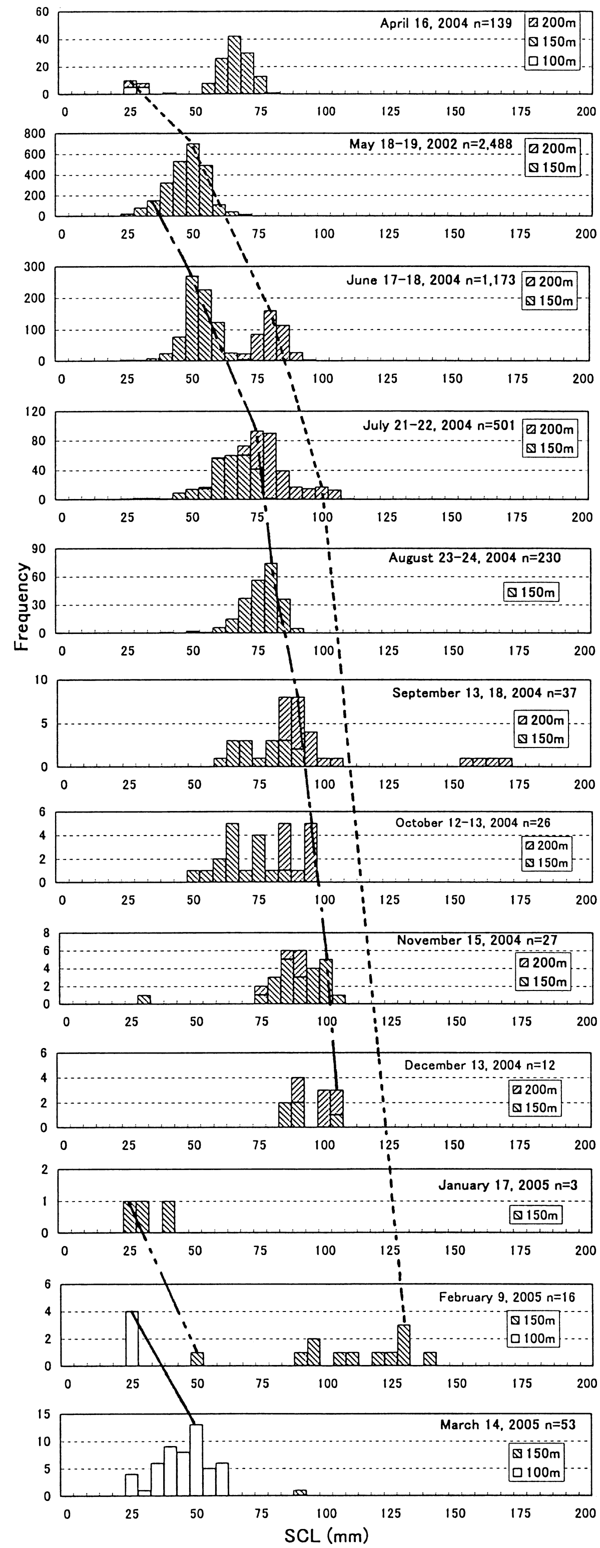

Figure 7. Histograms of Scale Length (SCL) of the deepsea smelt by month from April 2004 to March 2005. These histograms include all specimens from different depths.

main spring spawning season is from early March to late April, and the autumn spawning season is from late November to late December (unpublished data). Mio (1969) pointed out that the deepsea smelt is a multi-spawner, and the same phenomenon was observed in the present study. For instance, even in the spring spawning season, two or more modes emerged in the results.

The histograms of SCL sometimes consisted of polymodal distributions (Figs. 6 and 7). The present result is considered to be due to the following reasons. The first, the deepsea smelt moved to deeper areas as they grew especially from July 2002 (Fig. 6). The second, even in the spring spawning group, the spawning season varied and continued for up to four months, with the early offspring growing bigger than the late ones at a given time. The third, there are spring and autumn spawning groups as found by Sinoda and Jayashinghe (1971) and also in the present study area. The spring and autumn spawning groups could be distinguished from the histogram of SCL of 0-year-old fish. The fourth, there are potentially sampling errors due to the limited number of hauls.

Horikawa *et al.* (1990) showed that the main settlement occurred at the depth of about 100 m. We consider that the settlement occurred at various depths at the early settlement phase, but small specimens that settled in the deeper depth may be more prone to mortality because of the poor food conditions or predators. Horikawa *et al.* (1990) also pointed out that the main recruitment (70–100 mm SCL) occurred in August, and predicted the occurrence of two or more recruitment groups. These results closely agree with the present study.

The body length (SCL) of 1-year-old deepsea smelt is somewhat different between survey areas (Table 3). Hanyu (1956) obtained almost the same result as the present study, and estimated 130–150 mm (SCL) at 1-year-old. Mio (1969) estimated growth to about 90 mm in two spawning groups. Sinoda and Jayashinghe (1971) estimated 74 mm in the spring spawning group and 101 mm in the autumn one (both specimens were sampled in October, so the spring spawning group was estimated to be 7 month-old) off the coast of Kyoto Prefecture. Ogata and Ito (1979) demonstrated 51 mm in the spring spawning group and 110 mm in the autumn one (both specimens were sampled in October, so the spring spawning group was estimated to be 7 month-old) off the coast of Niigata Prefecture. In the present study, by tracing the modes of the histogram of the spring spawning group, 7 month-old specimens in October were 95 mm to 105 mm and about 1-year-old (12 months) specimens were about 130 mm to 140 mm, and the growth rate in the Pacific coast of southern Japan may be higher than that of the Sea of Japan. The difference in growth rate especially of 0-year-old fish of the two sub-populations (in the Sea of Japan and the Pacific Ocean) may be due to the difference in temperature of their nursery grounds. The average water temperature at 100 m depth in June is 16.93°C in Tosa Bay, while it is 10.42°C off the coast of Niigata Prefecture and 11.95°C off the coast of Kyoto Prefecture (data from JODC, J-DOSS, Japan). As the nursery grounds are not yet known in the Sea of Japan, the reason can not be fully clarified why the growth rates are different between the two subpopulations of the 0-year-old group.

The deepsea smelt in the Sea of Japan has two seasonal spawning groups (spring and autumn), but the relative abundances between the two groups are not known. Although the present study area was restricted to within Tosa Bay, the spring spawning groups were much more abundant than the autumn ones.

The specimens sampled in the present study were preserved in 80% ethanol for future analysis of the otolith. The otolith analysis (daily rings) will enable further clarification of the birth date and daily growth rates of the specimens. We will assess the growth by using otolith analysis in the near future.

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土佐湾におけるニギス (*Glossanodon semifasciatus*) 成魚の産卵期と0歳魚の成長

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ニギス *Glossanodon semifasciatus* は，日本海及び太平洋中・南部海域に生息し，沖合底びき網漁業や，小型底びき網漁業の主要な対象種の一つとなっている．土佐湾において着業船の漁獲物の卵の成熟状態から産卵期を調べたところ，1月から4月にかけて主要な産卵期となるが, 10月から11月にかけてもわずかながら産卵していることが確認された．本研究において2002年4月から2005年3月まで毎月，調査船を用いて底びき型幼魚ネット（コッドエンド目合1.3 mm）でニギスの0歳魚を採集した結果によって，当海域では「春生まれ群」が圧倒的に多いものと推定された．「春生まれ群」の被鱗体長のヒストグラムのモードを追跡した結果, 2002年4月中旬に約19 mmの最小個体が採集され，4月頃から本格的に加入が開始された．被鱗体長でみると複数のモードが観察されたが，2002年4月から2003年3月まで主たるモードを追跡したところ，4月に約25 mm，5月には50 mm，6月には75 mm，8月には90 mm，10月には105 mm，11月には110 mm，そして翌年の3月には約140 mmに成長するものと推定された．この結果は，日本海側で研究された満1歳魚の被鱗体長に比べると，いずれの研究結果よりも大きいが，この原因としては0歳魚の成育場の水温が太平洋側の方が日本海側より高いことによる可能性が考えられる．「春生まれ群」の0歳魚の月別加入量指数は年により大きく変動するが，この変動要因を究明するためにはさらに資料を集積する必要がある．

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