

Early Life History of Larvae of the Snailfish *Liparis tanakai* (Gilbert et Burke) in Sendai Bay, Northern Japan

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Development stage, growth and prey items of larval *Liparis tanakai* collected in Sendai Bay, northern Japan, are described. Almost all yolk-sac larvae (YSL; mean TL=5.22 mm) with no distinctive growth increments outside the nuclear area of sagittae had prey in their stomachs, which suggested they started feeding before exhaustion of yolk reserves. The relationship of sagittal radius on total length (TL) was allometric, whereas TL on age was linear. Individual growth rates (IGR) and mean growth rate (MGR) were estimated. MGR corresponded to the slope of regression between TL on age, and IGR were obtained back-calculating previous lengths using the relationship between otolith radius and larval total length. Mean growth rate and mean IGR for the first 25 days were 0.24 mm/d and 0.23 mm/d, respectively. Pre-flexion stage (PFL) ranged from 5.8 to 9.1 mm TL and was characterized by a gradual increase in increment width and IGR, whereas flexion stage (FL) began at about 9 mm TL at 15 days and showed a gradual decrease of IGRs. Mean mouth sizes (*i.e.* 50% of the maximum mouth width) were 0.51 mm for YSL, 0.74 mm for PFL, and 1.25 mm for FL. The size of copepod eaten correlated positively ($r=0.84$) to larval total length. Main prey item for YSL was bivalve veligers, while pre-flexion and flexion larvae fed mainly on copepod. *Coscinodiscus* spp. and *Podon* spp. had the minor frequency of occurrence in the whole range of larval size analyzed. The relationship between otolith microstructure, growth traits and feeding preference are discussed.

Key words: Larvae, otolith microstructure, prey item, growth rate, bivalve veligers

Introduction

Snailfishes are a family of the order scorpaeniformes inhabiting all oceans from the Arctic to the Antarctic with more than 150 species (Kido, 1986; Able, 1990; Stein *et al.*, 1991). In Japan snailfishes are represented by 8 genera with 40 species, among which *Liparis tanakai* is one of the most widely distributed. This species occurs from Amori to the Seto Inland Sea in Japan, Korean peninsula, the Gulf of Pohai, the Yellow Sea, and the East China Sea (Kido, 1984; Kobayashi and Hiyama, 1991).

Studies on snailfishes have been mainly focused on their taxonomy (Andriashev, 1990; Kido, 1988; Stein *et al.*, 1991), feeding ecology, and life history of adult fishes (Kawasaki *et al.*, 1983; Atkinson and Percy, 1992; Byers and Prach, 1988; Fujita *et al.*, 1995; Kobayashi and Hiyama, 1991). Except for studies addressing their larval development (Able *et al.*, 1984; Able *et al.*, 1986; Marliave and Peden, 1989; Kim *et al.*, 1986; Kojima, 1986) many aspects of the early life history of snailfishes remain un-

known. Recently it has been suggested that growth is critical for survival and subsequent recruitment of larval marine fishes (Leggett and DeBlois, 1994). By growing faster individuals within a cohort move faster through those early vulnerable stages increasing their probability of survival (Chambers and Leggett, 1987; Cowen and Sponaugle, 1997; Houde, 1987), in addition, faster growing larvae gain a size advantage with regards to avoid predation (Cowen and Sponaugle, 1997). However, estimation of reliable growth rates requires knowing the age during the early larval life, which can be achieved by otolith macrostructure analysis. The examination of otolith growth patterns also provides additional information to determine the relationship among age, size, and larval ontogeny. However, no attempt has been made to analyze the otolith microstructure of any species of snailfishes to date.

This study gives the first record of the otolith microstructure of wild larvae of *L. tanakai*. Furthermore, we examine age and growth traits, as well as preferred prey items during the early development of this snailfish. The assumptions for age analysis were that the growth increments were deposited daily, and the first increment was deposited after hatching. Although these assumptions have not been verified for any snailfish species, they have been validated for a number of other demersal fishes of the order Scorpaeniformes such as: various *Sebastes* species (Laidig *et al.*

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al., 1991; Yoklavich and Boehlert, 1987; Kokita and Omori, 1998; Plaza *et al.*, 2000).

Materials and Methods

Ninety-four *L. tanakai* larvae were collected in Sendai Bay (Fig. 1) in January and February, 2001 aboard the RV Kaiyo-Maru (Institute of Fisheries of Miyagi Prefecture). Larvae were caught with a BONGO net (with 70 cm of mouth diameter and 4.5 m long with 0.335 mm in mesh) obliquely towed from near the bottom to the surface. The surveyed area ranged from 20 to 102 m in depth, and from 5 to 10°C in surface-water temperature. All specimens were fixed immediately after death in 95% alcohol solution for otolith analysis.

In the laboratory, total length (TL) of larvae was measured to the nearest 0.01 mm without correcting for shrinkage. Before removing otoliths, the larval development and stomach contents were analyzed: head length (HL), the horizontal diameter of the eye (ED), and body depth (BD) at the base of pectoral-fin were measured, and pigmentation characters and fin-rays were described. Allometric relationships between the body portions and TL were determined. Maxillary length was measured for each larvae in order to estimate mouth size (MS) based on the relation of Shirota (1970) as $MS = \sqrt{2} \times ML$, where ML denotes maxillary length, and MS corresponds to mouth size at 50% of the maximum mouth width. The stomach was removed, and its contents were analyzed using an image analysis system (Quantimet 600, Leica) supplied by both a dissecting stereoscopic microscope and a light microscope. Sizes of identified prey items were measured to the nearest 0.01 mm. Measurements of prey size were total length for copepod, *Poddon*, and larval fishes; shell length for bivalve veligers; and horizontal diameter for eggs and *Coscinodiscus*.

Sagittal otoliths were removed and mounted on slide glass with a drop of transparent fingernail polish. Growth increments were clearly discernible, hence no further polishing was required. Growth increments were counted and measured using the image analyzer described above at magnifications of 400–1000×. Otolith radii were measured from the center of the focal area along the longer axis of the sagitta to the nearest 0.1 μm.

Results

Morphological development and otolith microstructure

Sagittae from 22 yolk-sac larvae (YSL) appeared round and displayed a unclear first check at a mean radius of 15.4 μm surrounding a darker primordium. The first check (FC) was bounded by an indistinctive zone, up to 25 μm in mean radius at the outer edge, with no visible increments even at magnification of 1000×. Sagittae from pre-flexion and flex-

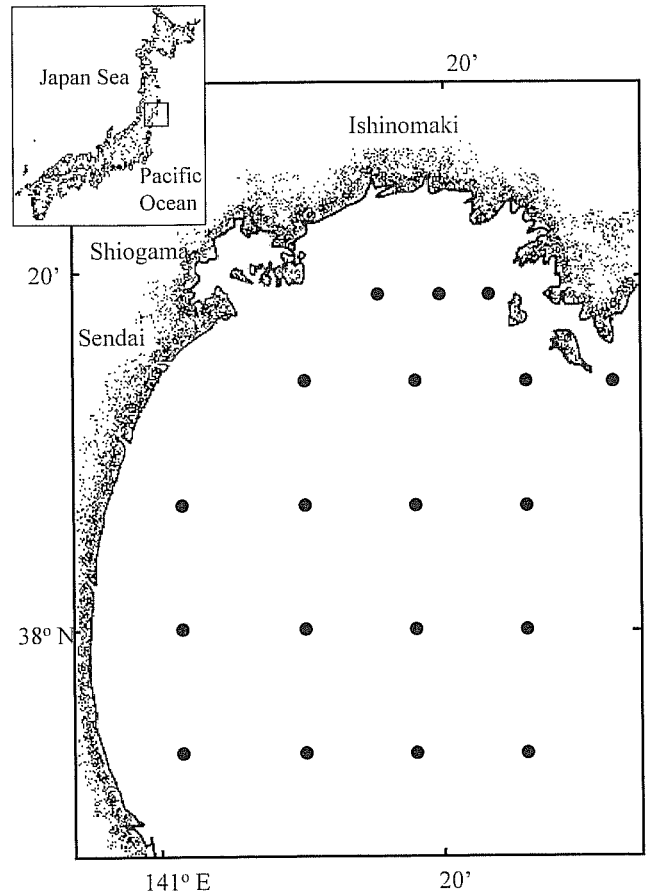


Figure 1. Sampling stations of larval *Liparis tanakai* off Sendai Bay, northern Japan.

ion larvae were disk-shaped with a distinctive second check (SC) surrounding the indistinctive zone after the FC. Four flexion larvae showed 1–3 diffuse atypical rings before SC (Fig. 2C), whereas in pre-flexion larvae the atypical rings were not visible at 1000× magnification (Fig. 2A). Well-formed, concentric increments immediately followed the second check (Fig. 2AB). Mean sagittal radius of YSL did not vary significantly (ANOVA $p > 0.05$) from radius at the second check of larvae at later developmental stages (*i.e.* pre-flexion and flexion larvae, Table 1). YSL showed a great amount of melanophores on the surface of the abdomen, 2 or 3 row of melanophores along the base of the pectoral fin, and a row of smaller melanophores along the base of the anal fin. YSL did not show evidence of disk formation or fin rays.

Flexion began at about 9 mm TL and at about 16 growth increments. No secondary growth centers were formed and increments were rather distinctive, with presence of sub-daily structures toward otolith margin where increments were markedly wider (Fig. 2CD). Flexion larvae had the full complement of dorsal fin, pectoral fin, and disk.

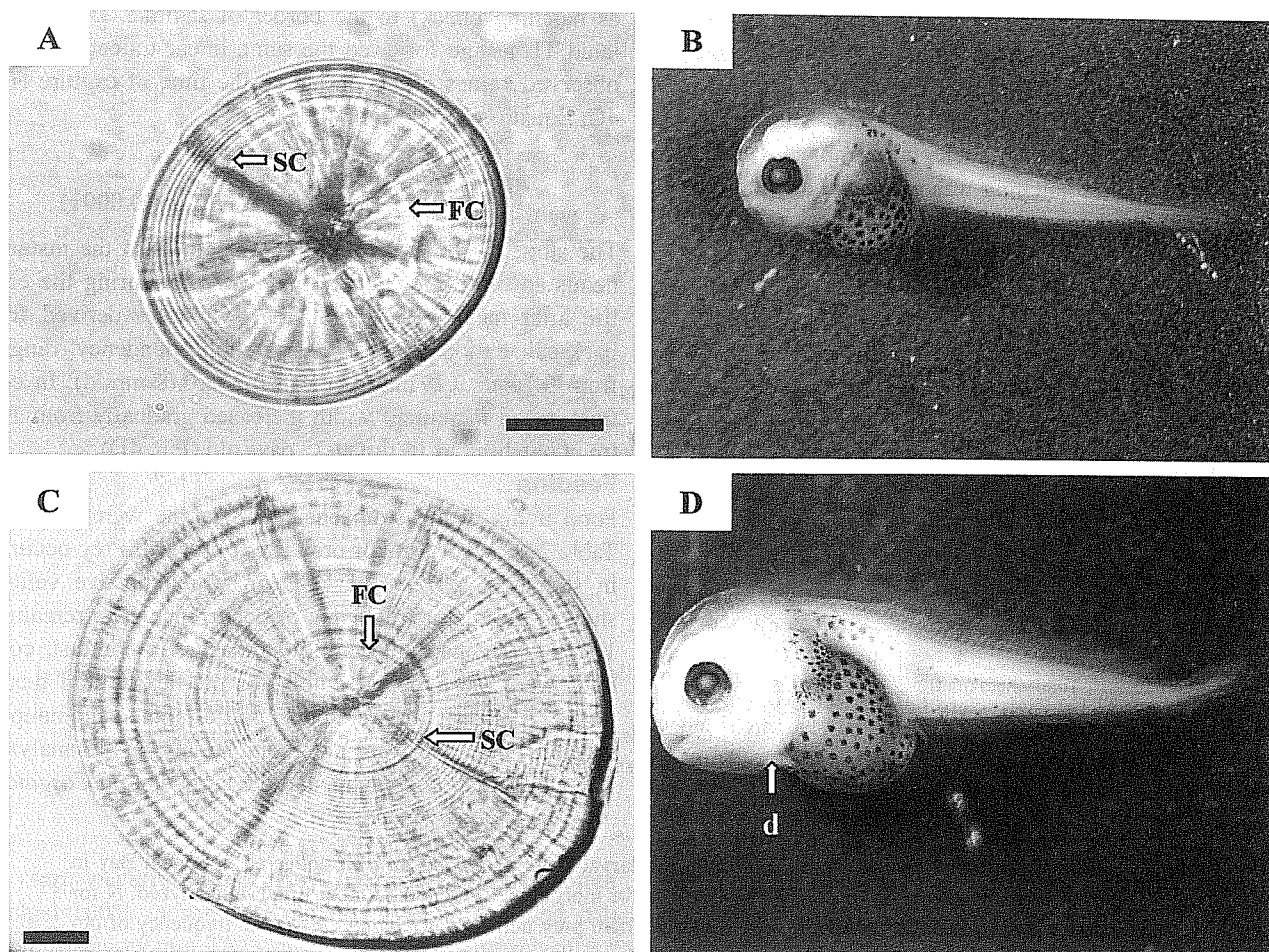


Figure 2. *Liparis tanakai*: LM photograph of sagittae from both a pre-flexion larva (A) of 6.5 mm TL (B) and a flexion larva (C) of 10 mm TL (D); FC=first check; SC=second check; d=disk. Scale bars=20 μm .

Table 1. Comparison of longer radius of sagittae at first and second check among larval stage of *Liparis tanakai* collected off Sendai Bay in 2001. Mean values, standard deviations, and number of individuals analyzed are given.

	Mean radius (mm)	Radius at first check (μm)	Radius at second check (μm)	n
Yolk sac larvae	25.09 \pm 2.13	15.39 \pm 1.43		22
Flexion larvae	103.22 \pm 12.23	15.82 \pm 2.15	26.12 \pm 3.34	26

Both the body depth and head length were slightly allometric respect to increasing progressively with larval development, while eye diameter decreased (Fig. 3; Table 2). The relationship between mouth size (MS) and TL was linear ($F=284.47$, $df=81$, $p<0.001$, Fig. 3).

Growth analysis using otolith increments

Estimated dates of the initial increment formation for pre-flexion and flexion larvae ranged from early January to late February (Fig. 4A) with two peaks around late January and mid February. YSL were not included in this analysis.

Growth of sagittae was exponential relative to growth in body length (Fig. 4B). When converting sagittae radius (R) to logs, a significant linear regression was obtained with homogenous variance:

$$TL=4.745 \times \text{Ln } R - 10.89 \quad (R^2=0.94, n=56) \quad (1)$$

therefore, we applied the biological intercept method to back-calculate body length (TL) using otolith radius (R) as:

$$TL=L_c + (\ln R - \ln R_c)(L_c - 5.22) (\ln R_c - \ln R_i)^{-1} \quad (2)$$

where L_c , R , and R_c are the larval total length, otolith radius at a previous length, and otolith radius at time of capture, respectively. The value “5.22” was the mean TL of YSL considered here as the biological intercept, and R_i the otolith radius at this biological intercept (Campana, 1990).

Age in days after hatching was estimated as the number of growth increments from the second check (assumed

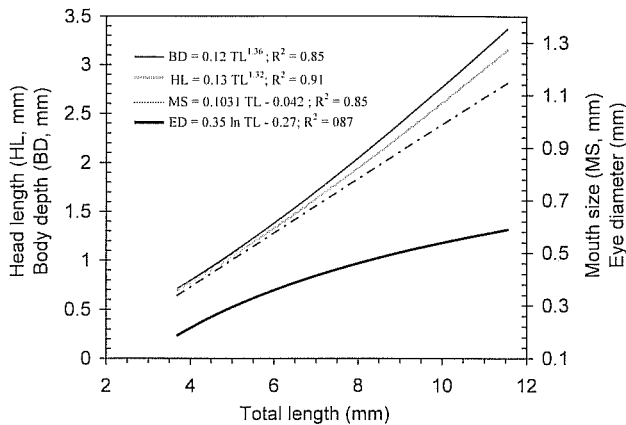


Figure 3. Morphometric relationships between total length and head length, body depth, mouth width, and eye diameter of pre-flexion and flexion larvae of *Liparis tanakai*.

as hatching check) to the border of sagittae. Back-calculated TL at age followed the same linear trajectory as the observed values of TL on age at the time of capture (Fig. 4C; Equation 3).

$$TL = 0.24 \times \text{age} + 5.0$$

$$(R^2 = 0.96, n = 56, F = 321.12, p < 0.0001) \quad (3)$$

The slope of the equation (3) corresponds to the instantaneous absolute growth rate of *L. tanakai* during the early life after hatching. Individual growth rates derived from back-calculations showed a parabolic tendency ranging from 0.16 to 0.29 mm/d (mean 0.23 ± 0.03 mm/d). In contrast, mean increment width increased gradually from 1.16 (m at hatching) to 16 μm at 25 days old (Fig. 4D).

Feeding

Food items in the stomachs of 78 larvae were observed. Table 2 shows the major prey taxa observed. Prey occurred in stomachs of 86% of YSL, in which bivalve veligers showed the major frequency of occurrence. The remaining 14% of YSL had only empty stomachs. In contrast, copepods were the main prey item for pre-flexion and flexion larvae. All copepods were copepodit or adults, and naupliar stages of copepod were not found in any larvae analyzed. The cladoceran *Podon* spp. and the large diatom *Coscinodi-*

Table 2. Summary of early life history traits within each larval stage of *Liparis tanakai* collected in Sendai Bay in 2001 concerning: morphometry, prey item, and age; N for morphometry denote number of larval analyzed. N for prey size denote number of stomachs in which the specified prey items occurred, and “F” is the frequency of occurrence in relation to the numbers of stomachs containing prey items (i.e. “N” for average prey size). Head length and body depths are expressed as a percentage of total length, and eye diameter as percentage of head length. Measurements of prey size were total length for copepod and *Poddon*, shell length for bivalve veligers, and horizontal diameter for eggs and *Coscinodiscuss*. Average prey size in flexion stage excluded fish larvae.

	Yolk sac larva				Pre-flexion larva				Flexion larva			
	Mean±SD	Range	N	F	Mean±SD	Range	N	F	Mean±SD	Range	N	F
Morphometry (mm)												
Head length	21.12±2.46	17.57–27.07	22		22.61±2.11	18.09–26.62	39		27.17±3.14	22.74–32.19	33	
Body depth	21.35±3.29	15.30–28.18	22		24.39±3.19	18.96–32.06	39		27.89±2.24	22.96–33.68	33	
Eye diameter	31.12±3.88	20.71–38.32	22		26.78±3.63	20.03–41.18	39		19.51±3.01	14.63–24.52	33	
Mouth size	0.51±0.07	0.26–0.63	22		0.74±0.12	0.46–1.19	39		1.25±0.09	1.16–1.41	33	
Total length	5.22±0.59	4.02–6.11	22		6.18±0.83	5.81–9.12	39		9.48±0.89	8.46–11.37	33	
Prey size (mm)												
Copepods	0.52±0.21	0.24–0.86	11	57.9	0.61±0.15	0.37–1.25	16	48.5	1.11±0.06	0.77–1.34	16	61.5
Bivalve veliger	0.22±0.09	0.12–0.42	15	78.9	0.24±0.07	0.15–0.31	5	15.2				
Podon spp.	0.51±0.23	0.51–0.67	7	36.8	0.65±0.13	0.51–0.78	9	27.3	0.56±0.13	0.42–0.68	10	38.5
Eggs	0.17±0.02	0.15–0.21	6	31.6	0.14±0.02	0.12–0.16	4	12.1				
<i>Coscinodiscuss</i> spp.	0.11±0.06	0.05–0.15	3	15.8	0.21±0.04	0.15–0.21	5	15.2	0.22±0.02	0.16–0.22	3	11.5
Average prey size	0.32±0.16	0.12–0.65	19		0.58±0.16	0.21–0.77	33		0.76±0.14	0.52–0.91	26	
Age (days)												
					6±4	2–15	32		19±4.4	15–28	24	

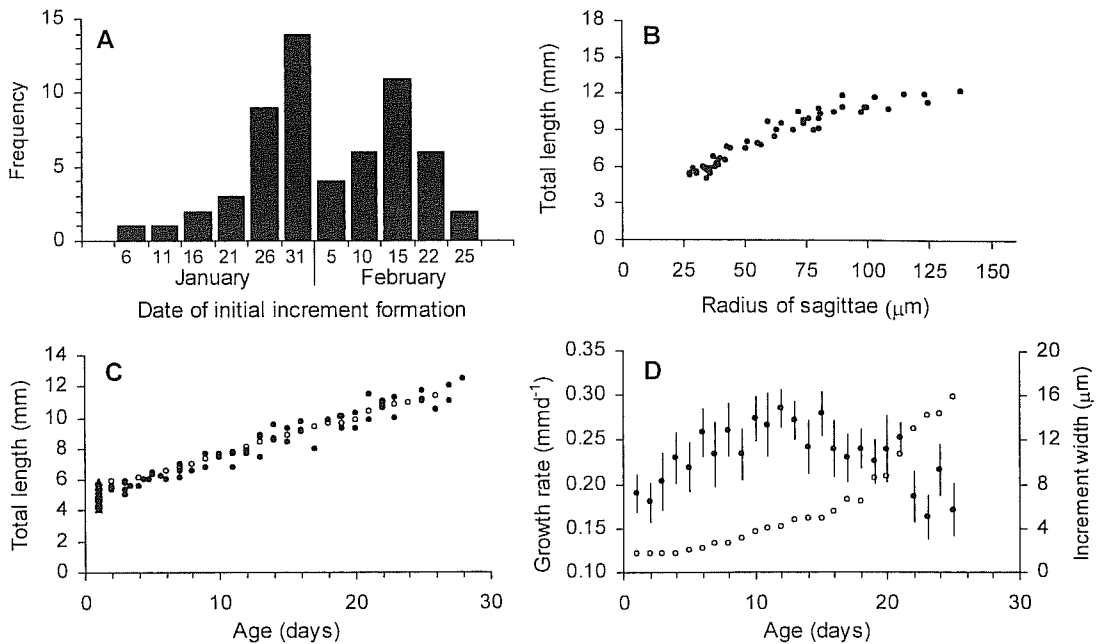


Figure 4. Dates of initial increment formation in otolith of *Liparis tanakai* (A). Relationship between total length and sagittal radius (B) and age (C); filled and open circles denote observed TL and back-calculated TL, and filled triangles denote observed TL of yolk-sac larvae. Relationship between age and mean increment width (open circles) and mean individual growth rates (filled circles) (D). First 25 days were analyzed; vertical bars are standard deviations.

cus spp. occurred less than copepods, although often reached 100% in some specimens. Two unidentified fish larvae (mean=2 mm TL) were found in the stomach of the largest larva.

Mean prey size (MPS, pooled for all prey taxa) increased significantly as larvae grew (ANOVA $p < 0.05$; Table 2). MPS analysis did not include larval fish or egg due to their small contribution. There was a significant correlation between pooled MPS and larval size, although the variance was high. Regression analysis by prey taxa only showed a strong positive correlation (with homogeneity of variance) for copepods ($\text{MPS} = 0.099 \times \text{TL} + 0.0177$, $r = 0.84$, $df = 43$, $F = 90.78$, $p < 0.001$; Fig. 5).

Discussion

Otolith microstructure and larval development

Published hatch sizes for *L. tanakai* ranged from 4.8 to 5.8 mm (Kojima, 1986), and from 4.8 to 5.4 mm TL (Aoyama, 1959). Kim *et al.* (1986) reported that larvae completely absorbed their yolk at about 6.46 mm TL 12 days after hatch. Therefore, larval ages would be underestimated by about 12 days in our study if the first distinctive growth deposited outside of the second check truly corresponds to the end of yolk-sac stage. However, we found that (i) the distinctive growth ring did not occur before second check within the resolution of the light microscope, except for the

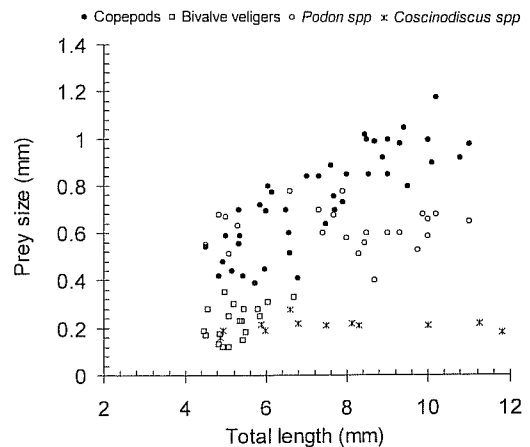


Figure 5. Relationship between larval size and mean prey size in pre-flexion and flexion larvae of the snailfish, *Liparis tanakai*. Each plot represents an individual mean value for each prey taxa within a stomach. Number of observations are given in the table 2.

few faint rings observed in some larvae; (ii) the mean size (5.22 mm TL) of early feeding larvae in our study fall within the size range at hatch reported by Kojima (1986) and Aoyama (1959); (iii) the mean radius at second check of older larvae were not significantly different from the mean radius at the outer border of sagittae of yolk-sac lar-

Table 3. Estimated of growth rates for larval demersal fishes under natural conditions based on otolith microstructure analysis. "Un"=unknown.

Species	Age (d)	Temperature (°C)	Growth rate (mm/d)	Source
Scorpaeniformes				Nagasawa (2001)
<i>Sebastes thompsoni</i> *	<40	Un	0.32	
<i>Sebastes schlegeli</i> *	<20	Un	0.31	
<i>Sebastes vulpes</i> *	<25	Un	0.15	
<i>Liparis tanakai</i>	<25	5–10	0.24	The present study
Pleuronectiformes				Jenkins (1987)
<i>Rhombosolea tapirina</i>	<25	10–15	0.23	
<i>Ammostretis rostratus</i>	<25	10–15	0.28	
Gadiformes				
<i>Melanogrammus aeglefinus</i>	<30	~4–13	0.21	Quiñones-Velázquez (1998)
<i>Pollachius virens</i>	<30	~4–13	0.18	Quiñones-Velázquez (1998)
<i>Gadus morpha</i>	15–30	4–6	0.18	Bolz and Lough (1983)

* Larvae of these species occur in spring in the Japan Sea.

vae; and (iv) 86% of yolk-sac larvae had food in their stomachs. These facts suggest that the onset of feeding of *L. tanakai* and the formation of the first increment could have occurred closer to hatching rather than to the end of yolk sack exhaustion. The atypical rings observed before the second in some flexion larvae probably are either growth increments formed prior to first feeding or visual artifacts produced by the absence of polishing. Although the formation of the first daily growth increment coincides with the onset of exogenous feeding in some larval fishes (Jenkins, 1987; Mailliet and Checkey, 1990; Sepulveda, 1994), most larval fishes are capable of beginning exogenous feeding before yolk is completely exhausted (Hunter, 1990), and the start of increment formation occurs immediately after hatching in some species (Radke and Waiwood, 1980; Quiñones-Velázquez, 1998). These facts also suggest that the time of first increment formation is close to hatching for *L. tanakai*. Beyond the unreliability of formation of hatch check, the dates of the initial increment formation show that most larvae appeared to have originated from two major events, i.e. hatch or onset of feeding, although data are insufficient to explain this phenomenon.

The following 4 facts suggest that the estimations of growth rate obtained in this study were reliable: 1) the relationship between sagittal radius and total length was allometric, which allowed back-calculating previous length; 2) back-calculated TLs overlapped the observed values of the relationship of TL on age; 3) the intercept of the function agreed with mean TL of yolk-sac larvae; and 4) the estimates of instantaneous absolute growth rate (0.25 mm/d)

was similar to the mean individual growth rate (0.24 mm/d) obtained by the back-calculations. Estimates of growth rates have not been obtained for either larvae of the family Liparididae or Cyclopteridae. But, in comparison with other demersal fishes (comparison only included growth rates derived from otolith microstructure during a similar range of age and length, Table 3), growth rate of the snail-fish were either similar or faster than most species included. The growth rate of *L. tanakai* only appeared slower than 2 larval rockfishes (*Sebastes thompsoni* and *Sebastes schlegeli*) collected in the Sea of Japan, although larvae of both species occurred in spring, in which water temperature is expected to be higher than the range of temperature observed in our study.

During the first 13–15 days, individual growth rate and increment width increased synchronously, which corresponded to the completion of pre-flexion stage, which suggests an increasing growth during the development of dorsal and pectoral fin ray. In contrast, a reduction in individual growth rate and a major increase in otolith width after 15th day was characteristic of the flexion stage. Both facts suggest that otolith growth patterns changed at the shift from pre-flexion to flexion stage, which might explain the allometric relationship found between otolith radius and larval size. The significant reduction in individual growth rate at daily temporal scale in the early development of fish larvae has been documented in the literature (Thorrold and Williams, 1989). However, it is difficult to distinguish whether these growth decreases are linked to poor larval condition (as a function of environmental factors such as

food availability and temperature) and/or larval ontogeny in *L. tanakai* without detailed data on these environmental conditions.

Feeding and larval development

The slope of the regression between body length and mouth size may be a quantifiable indicator of the prey that larval fishes are capable of ingesting and may be useful to test the differences among species in food selection. However, to date there have been little work done concerning inter-specific comparison (Hunter, 1984) due to the absence of standardized criteria to measure mouth size. Here, we use the empirical relation of Shirota (1970), which uses the maxillary length to estimate mouth size. Using this equation, Shirota showed that mouth size at onset of feeding of various larval fishes ranged from 0.2 to 1.0 mm, and that larval fishes having small mouth sizes such as *Hypomesus*, *Ammodytes*, *Silago*, *Konosirus* and *Oplegnathus* fed only on phytoplankton, protozoa and the nauplii of small copepods, whereas those having big mouth sizes such as *Thunnus*, *Katsuwonus*, *Seriola*, *Girella*, *Mugil*, *Lateolabrax* and *Clupea* were found to easily take large copepods. Larvae from the former group grew slower than those larvae with bigger mouths. If we consider that yolk-sac larvae of *L. tanakai* were present at onset of feeding, the mean mouth size of 0.51 mm falls between both groups, was similar to those of redfish *Sebastes* spp. (about 0.6 mm of mouth size at 6 mm of larval body size) reported by Anderson (1994). Strictly speaking from a point of view of mouth size *L. tanakai* seems to be a median growing fish at onset of feeding.

Both the frequency of occurrence and the positive correlation of mean copepod size on larval total length suggest that copepodids and adult copepods are important prey items for larval *L. tanakai* as they grow. Although copepods naupliare are considered as a major component of the diet of many larval fishes (Hunter, 1981; Turner, 1984) they were not present in any stomach of larval *L. tanakai*. Although our data do not explain the absence of copepod nauplii similar observation have been reported in the literature for other larval fishes such as gadids (Kane, 1984), sciaenids (Houde and Lovdal, 1994), as well as for both the spot *Leistomus xanthurus* and the Atlantic croaker *Micropogonias undulatus* (Govoni *et al.*, 1986). Diversity in prey taxa in yolk-sac larvae and pre-flexion larvae suggest that *L. tanakai* larvae may be more euryphagous during the earliest stages, feeding mainly on copepods as they reach the flexion stage; whereas the presence of larval fish in the oldest individual analyzed is early evidence of a piscivorous diet for later larval stages of this snailfish. The frequency of *Podon* spp. and the great diatom *Coscinodiscus* did not change with larval growth, and some larvae were full of only these prey; furthermore, these prey were smaller than the limit of mean mouth size. Young and Davis (1992)

found a similar feeding characteristic in some larvae of *Trachurus declivis*. They suggested that beyond the apparent selectivity for some prey items, within a species some larvae can be opportunistic feeders obtaining enough food from smaller prey, which can be very abundant at that moment in the plankton. This argument can be also useful to explain the occurrence of *Coscinodiscus*, whose blooms have been observed in temperate coastal waters of Japan (Nishikawa *et al.*, 2000; Tada *et al.*, 2000). The high occurrence of bivalve veligers in early feeding larvae was of interest. Bivalve veligers have been documented in the literature rather as occasional preys for fish larvae (Houde and Lovdal, 1984; Govoni *et al.*, 1986; Young and David, 1992), hence the occurrence of bivalve veligers might be only a result of prey availability such as we suggested above for *Podon* and *Coscinodiscus*. However, the absolute absence of bivalve veligers in pre-flexion and flexion larvae of *L. tanakai* argues against this explanation. Recently, Harding (1999) found strong preference for bivalve veligers in the naked goby, *Gobiosoma bosc*, in rearing conditions. She suggested that bivalve veligers seem to be morphologically and behaviorally more vulnerable to predation because they are smooth rounded in shape and move either passively or swimming slowly. These characteristics can facilitate their capture, particularly for younger fish larvae, such as that which occurred for yolk-sac larvae of *L. tanakai*. Harding (1999) also proposed that high abundance of a preferred prey would facilitate fast growth during the earliest critical period. Fast growing larvae can avoid predation, increasing their chance of survival. Consequently, she hypothesized that selective feeding on bivalve veligers might be an important mechanism developed in some reef fishes to reduce their larval duration increasing recruitment success. Further studies on feeding ecology and prey availability may disclose whether such a selective mechanism could be occurring in the sea for *L. tanakai*. Furthermore, the occurrence of bivalve veligers matched with the major euryphage found in preflexion larvae, and this larval stage was characterized by an increase in growth rate. Therefore, feeding on a wide variety of taxa during the vulnerable pre-flexion stage might be an adaptation developed by this snailfish to maximize growth increasing its probability of survival.

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References

- Able, K.W., D.F. Markle and M.P. Fahay (1984) Cyclopteridae: Development. In: Ontogeny and Systematics of Fishes, eds. H.G. Moser *et al.*, American Society of Ichthyology, Special Publication, **1**, 428–437.
- Able, K.W., M.P. Fahay and D.F. Markle (1986) Development of larval snailfishes (Pisces: Cyclopteridae: Liparidinae) from the western North Atlantic. *Can. J. Zool.*, **64**, 2294–2316.
- Able, K.W. (1990) A revision of Arctic snailfishes of the genus *Liparis* (Scorpaeniformes: Cyclopteridae). *Copeia*, 1990, 476–492.
- Anderson, J.T. (1994) Feeding ecology and condition of larval and pelagic juvenile redbfish, *Sebastes* spp. *Mar. Ecol. Prog. Ser.*, **104**, 211–226.
- Andriashev, A.P. (1990) Comments on the taxonomic status of the Antarctic species *Paraliparis endentatus* (Liparididae) and a description of a new genus. *Vosprosy Ikhtologii*, **30**, 179–184.
- Aoyama, T. (1959) On the egg and larval stages of *Liparis tanakai* (Gilbert et Burke). *Bull. Seikai Reg. Fish. Res.*, **49**, 367–377.
- Atkinson, E.G. and J.A. Percy (1992). Diet comparison among demersal marine fishes from the Canadian Arctic. *Polar Biol.*, **11**, 567–573.
- Bolz, G.R. and R.G. Lough (1983) Growth of larval Atlantic cod, *Gadus morhua*, and haddock, *melanogrammus aeglefinus*, on Georges bank, spring 1981. *Fish. Bull.*, **81**, 827–836.
- Byers, T. and R.W. Prach (1988) Diet of the kelp snailfish, *Liparis tunicatus* in Jones Sound Can. High Arctic. *Canadian Field Naturalist*, **102**, 242–245.
- Campana, S.E. (1990) How reliable are growth back-calculations based on otolith? *Can. J. Fish. Aquat. Sci.*, **47**, 2219–2227.
- Chambers, R.C. and W.C. Leggett (1987) Size and age at metamorphosis in marine fishes: an analysis of laboratory-reared winter flounder (*Pseudopleuronectes americanus*) with a review of variation in other species. *Can. J. Fish. Aquat. Sci.*, **44**, 1936–1947.
- Cowen, R.K. and S. Sponaugle (1997) Relationships between early life history traits and recruitment among coral reef fishes. In: Early Life History and Recruitment in Fish Population, eds. R.C. Chambers and E.A. Trippel, Chapman & Hall, Fish and Fisheries series **21**, 423–449.
- Fujita, T., D. Kitagawa, I. Okuyama, Y. Inada and T.Y. Jin (1995) Diets of the demersal fishes on the shelf off Iwate, northern Japan. *Mar. Biol.*, **123**, 219–233.
- Govoni, J.J., P.B. Ortner, F. Al-Yamani and L.C. Hill (1986) Selective feeding of spot, *Leiostomus xanthurus*, and Atlantic croaker, *Microsogonias undulatus*, larvae in the northern Gulf of Mexico. *Mar. Ecol. Prog. Ser.*, **28**, 175–183.
- Harding, J.M. (1999) Selective feeding behavior of larval naked gobies *Gobiosoma bosc* and blennies *Chasmodes bosquianus* and *Hypsoblennius hentzi*: preferences for bivalve veligers. *Mar. Ecol. Prog. Ser.*, **179**, 145–153.
- Hare, J.A. and R.K. Cowen (1994) Ontogeny and otolith microstructure of bluefish *Pomatomus saltatrix* (Pisces: Pomatomidae). *Mar. Biol.*, **118**, 541–550.
- Houde, E.D. and J.A. Lovdal. (1984) Seasonality of occurrence, foods, and food preferences of ichthyoplankton in Biscayne Bay, Florida. *Estuar. Coast. Shelf Sci.*, **18**, 403–419.
- Hunter, J.R. (1981) Feeding ecology and predation of marine fish larvae. In: Marine Larvae: Morphology, Ecology and Relation to Fisheries, ed. R. Lasker, Washington Sea Grant Program, 33–59.
- Jenkins, G.P. (1987) Age and growth of co-occurring larvae of two flounder species *Rhombosolea tapirina* and *Ammotretis rostratus*. *Mar. Biol.*, **95**, 157–166.
- Jordan, A.R. (1994) Age, growth and back-calculated birthdate distribution of larval jack mackerel, *Trachurus declive* (pisces: Carangidae), from eastern Tasmanian Coastal waters. *Aust. J. Mar. Fresh. Res.*, **45**, 19–33.
- Kane, J. (1984) The feeding habitats of co-occurring cod and haddock larvae from Georges Bank. *Mar. Ecol. Prog. Ser.*, **16**, 9–20.
- Kawasaki, T., H. Hashimoto, H. Honda and A. Otake (1983) Selection of life histories and its adaptive significance in a snailfish *Liparis tanakai* from Sendai Bay. *Bull. Japan. Soc. Sci. Fish.*, **49**, 367–377.
- Kido, K. (1984). *Liparis Tanakai* (Gilbert et Burke). In: The fishes of the Japanese Archipelago, eds. H. Masuda *et al.*, Tokai University Press, Tokyo, p. 338.
- Kido, K. (1986) Development of Larvae and Juvenile of *Rhinoliparis barbulfifer* (Liparididae). In: Indo-Pacific Fish Biology: Proceeding of the Second International Conference on Indo-Pacific Fishes, eds. T. Uyeno *et al.*, 697–702.
- Kido, K. (1988) Phylogeny of the family Liparididae with the taxonomy of the species found around Japan. *Mem. Fac. Fish. Hokkaido Univ.*, **35**, 125–256.
- Kim, Y.U., Y.S. Park and J.G. Myoung (1986) Egg development and larvae of the snailfish *Liparis tanakai*. *Bull. Korean Fish. Soc.*, **19**, 380–386.
- Kobayashi, T. and S. Hiyama. (1991) Distribution, abundance and food habits of the snailfish *Liparis tanakai* in the Suo Sea Seto Inland sea. *Japan J. Ichthyol.*, **38**, 207–210.
- Kojima, J. (1986) *Liparis Tanakai* (Gilbert et Burke). In: An Atlas of the Early Stage Fishes in Japan. ed. M. Okiyama, Tokai University Press, Tokyo, p. 885.
- Kokita, T. and M. Omori (1998) Early history traits of the gold-eye rockfish *Sebastes thompsoni*, in relation their successful utilization of drifting seaweed. *Mar. Biol.*, **32**, 279–589.
- Leggett, W.C., and E. DeBlois (1994) Recruitment in marine fishes: it is regulated by starvation and predation in the egg and larval stages? *Netherlands J. Sea Res.*, **32**, 119–134.
- Laidig, E.T., S. Ralston and J.R. Bence (1991) Dynamics of growth in the early life history of shortbelly rockfish, *Sebastes jordani*. *Fish. Bull.*, **89**, 611–621.
- Maillet, G.L. and D.M. Checkley Jr. (1990) Effects of starvation on the frequency of formation and width of growth increments in sagittae of laboratory-reared Atlantic Menhaden *Brevoortia tyrannus* larvae. *Fish. Bull.*, **88**, 155–166.
- Marliave, J. B. and A. E. Peden (1989) Larvae of *Liparis Fucensis* and *Liparis Callyodon*: Is it the cottoid bubblemorph phylogenetically significant? *Fish. Bull.*, **87**, 735–744.
- Nagasawa, T. (2001). Early life history of Rockfishes (Genus *Sebastes*) in the Sea of Japan. *Bull. Japan Sea Natl. Fish. Res. Inst.*, **51**, 1–132. (in Japanese)
- Nishikawa, T., Y. Hori, S. Nagai, K. Miyahara, Y. Yoshida, K. Kodama and Y. Sakai (2000) Relationship between the bloom of *Coscinodiscus wailesii* and water quality or meteorological factors in Harima-nada. *Nippon Suisan Gakkaishi*, **66**, 388–

- 394.
- Plaza, G., S. Katayama and M. Omori (2001) Otolith microstructure of the black rockfish, *Sebastes inermis*. *Mar. Biol.*, **139**, 797–805.
- Quiñones-Velázquez, C. (1999) Age validation and growth of larval and juvenile haddock, *Melanogrammus aeglefinus*, and pollock, *Pollachius virens*, on the Scotian Shelf. *Fish. Bull.*, **97**, 306–319.
- Radke, R.L. and K.G. Waiwood (1980) Otolith formation and body shrinkage due to fixation in larval cod (*Gadus morpha*). *Can. Tech. Rep. Fish. Aquat. Sci.*, **929**, p. 10.
- Sepulveda, A. (1994) Daily growth increments in the otoliths of European smelt *Osmerus eperlanus* larvae. *Mar. Ecol. Prog. Ser.*, **108**, 33–42.
- Shirota, A. (1970) Studies on the mouth size of fish larvae. *Bull. Japan. Soc. Sci. Fish.*, **36**, 353–368.
- Stein, D.L., C.R. Melendez and U.I. Kong (1991) A review of Chilean snailfishes Liparididae Scorpaeniformes with a description of a genus and three new species. *Copeia*, **1991**, 358–373.
- Tada, K., S. Pithakpol, K. Ichimi and S. Montani (2000) Carbon, nitrogen, phosphorus, and chlorophyll *a* contents of the large diatom *Coscinodiscus wailessi* and its abundance in the seto Inland Sea, Japan. *Fish. Sci.*, **66**, 509–514.
- Thorrold, R.S. and M.C.B. Williams (1989) Analysis of otolith microstructure to determine growth histories in larval cohorts of a tropical herring (*Herklotsichthys castelnaui*). *Can. J. Fish. Aquat. Sci.*, **46**, 1615–1624.
- Turner, J.T. (1984) The feeding ecology the some zooplankton that are important prey items of larval fish. NOAA Tech. Rep. NMFS 7.
- Yoklavich, M.M. and G.W. Boehlert (1987) Daily growth increments in otoliths of juvenile black rockfish, *Sebastes melanops*: an evaluation of autoradiography as a new method of validation. *Fish. Bull.*, **85**, 826–832.
- Young, J.W. and T.L.O. Davis (1992) Feeding ecology and interannual variations in diet of larval jack mackerel, *Trachurus declivis* (Pisces: Carangidae), from coastal waters off eastern Tasmania. *Mar. Biol.*, **113**, 11–20.

仙台湾におけるクサウオの初期生活史

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仙台湾におけるクサウオの初期生活史について、発育段階、成長、食性を調べた。ほとんどの前期仔魚 (Yolk-sac larva, 平均全長 5.22 mm) は、耳石 (扁平石) の核の外側に日周輪がみられなかったが、消化管内容物は観察された。全長に対する耳石半径の関係はアロメトリックであったが、日周輪に対する全長の関係は直線回帰で表された。その回帰式から推定された日周輪形成後 25 日間の平均成長速度は 0.24 mm/d であった。各個体の日周輪数と全長の関係から求めた成長速度の平均値は 0.23 mm/d であった。Flexion larvae は全長約 9 mm、日周輪が 15 本であった。Pre-flexion

larvae の体長は 5.8 mm から 9.1 mm の範囲であり、徐々に日周輪間隔が増加する傾向があった。口の平均サイズ (口幅の 50%) は、前期仔魚が 0.51 mm、Pre-flexion larvae が 0.74 mm、Flexion larvae が 1.25 mm と、成長に伴い増加した。食物サイズもこれに伴って増加し、カイアシ類については、カイアシ類の体長とクサウオの口サイズの間に強い相関が認められた ($r=0.84$)。前期仔魚は二枚貝ベリジャー幼生を、Flexion larvae はカイアシ類を主に摂食していたが、いずれの発育段階の稚仔魚においても、少数の植物プランクトンが観察された。

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