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Age and growth of *Sebastes vulpes* in the coastal waters of western Hokkaido, Japan

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ABSTRACT: Age and growth of *Sebastes vulpes* collected from the coastal waters of western Hokkaido were studied. Observation of the otolith margin verified that annuli (outer margins of the opaque zone) were produced chiefly from July to August. This period was associated with parturition and the birth season. The maximum age estimated by the surface method was 12 years but the oldest fish was aged at 35 years by the cross-section method. The surface method was inadequate for aging of *S. vulpes* older than 6 years because of the underestimation of age. No significant difference was found in the parameters of the growth equations between both sexes. The von Bertalanffy growth curve combined for both sexes was as follows: $SL_t = 358.6(1 - \exp^{-0.156(t+0.820)})$, where SL_t is standard length (mm) at age t (after parturition in years). It seems likely that *S. vulpes* grows slowly and lives longer than previously thought.

KEY WORDS: **age, cross-section method, growth, otolith, *Sebastes vulpes*.**

INTRODUCTION

Chen and Barsukov classified *Sebastes vulpes* complex into three species: *S. vulpes* Döderlein, *S. zonatus* Chen and Barsukov, and *S. ijimae* (Jordan and Metz), and described these three species as being sympatric around Japan.[1] Thereafter, Kanayama and Kitagawa, and Ishida recognized them as the same species (*S. vulpes*) because of the occurrence of intermediate individuals.[2,3] However, sufficient data were not represented in these two reports and therefore the taxonomy of these three species must be re-examined in the future.[4] According to the description of Chen and Barsukov,[1] our samples contained *S. vulpes*, *S. zonatus* and intermediate individuals between these two species. For this reason, in the present study *S. vulpes*, which occupied the majority of the specimens, was studied.

'Fox jacopever' (*Sebastes vulpes* complex) is distributed in the coastal waters from Funka Bay in Hokkaido to near Bousou Peninsula in the Pacific Ocean, from Ishikari Bay in Hokkaido to southern Korea in the Japan Sea.[5] The annual catch in Japan was approximately 500–1000 tons in the 1960s, but decreased to 100–200 tons in the 1990s.[5] For this reason the culture-fishery of 'fox jacopever' was proposed at some regions and an experimental stocking with cultured juveniles at Shimamaki in the western Hokkaido started in 1998. To predict and estimate its effect knowledge on age and growth is essential, but there is very little information.

Iizuka pointed out that the age determination of 'fox jacopever' from otoliths was more reliable than that from scales, and the section method was necessary to count annuli because the surface method was not reliable for the older fish.[5] However, previous age and growth estimates of 'fox jacopever' have been conducted using the surface method without exception. The purpose of the present paper is to estimate the growth of *S. vulpes* in the coastal waters of western Hokkaido.

MATERIALS AND METHODS

Samples were collected with commercial bottom set nets and gill nets at depths of 30–100 m in the coastal waters of Shimamaki and Suttsu, western Hokkaido, from April 1998 to May 1999 (Fig. 1; Table 1). Because of its low abundance, the number of specimens collected was not large, especially

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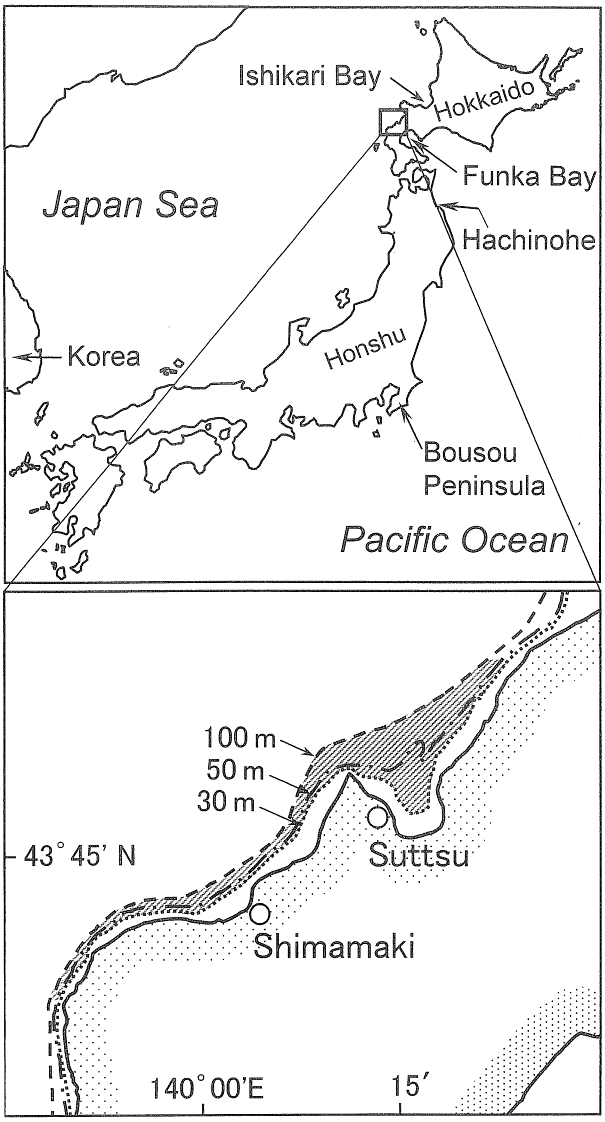

Fig. 1 Map showing sampling area (striped area) and contours of depth in the coastal waters of western Hokkaido.

for large fish. In the present study, samples were divided into three groups: *S. vulpes* (266 individuals), *S. zonatus* (85 individuals) and an intermediate type between these two species (two individuals) on the basis of classification by Chen and Barsukov.[1] *Sebastes zonatus* and the intermediate type between the two species were excluded in the present paper.

The *S. vulpes* collected were sexed and recorded along with total length (*TL*, mm), standard length (*SL*, mm), eviscerated body weight (*EBW*, nearest 0.1 g), and gonad weight (*GW*, nearest 0.01 g). The paired sagittal otoliths were removed then cleaned with water, and stored dry in plastic trays. Because the *SL* of *S. vulpes* taken in April 1998 were not measured, these values were calculated from the following equations:

$$\text{Male: } SL = 0.819TL - 1.40,\ r = 0.995,\ P < 0.001,\ n = 124$$

$$\text{Female: } SL = 0.796TL - 4.27,\ r = 0.994,\ P < 0.001,\ n = 117$$

In the present study the aging of *S. vulpes* was conducted by the surface method and the cross-section method. The cross-sections of otoliths were prepared according to the following procedure. The otoliths were placed on wood blocks and embedded in clear epoxy. Each block with otoliths was sectioned through the nucleus using a low-speed diamond wafering saw. Thin sections (0.5 mm) of otoliths were mounted on microscope slides with sticky wax, sanded with wet 600- and 1500-grade sandpaper, and polished on a 4000-grade emery paper. The surface of the whole otolith was observed and whether the outer perimeter of the otolith had an opaque zone or not was recorded. Opaque zones were counted under a binocular dissecting microscope at ×20–40 magnification with reflected light. In contrast, sectioned otoliths were observed with transmitted and/or reflected light and the opaque zones were counted. For both methods, opaque zones were counted at least three times by the senior author. Because no difference in the number of opaque zones was found between right and left otoliths, the right otolith was used as a rule. Von Bertalanffy growth curves for both sexes and both methods (surface and cross-section) were calculated from age–length data using the least-squares, non-linear regression procedure (Microsoft Excel solver routine).

In order to determine the period of the first annulus formation, the otoliths of 1-year-old *S. vulpes* (51 individuals) cultured in a tank at Shimamaki Village (parturition date: 26 May–4 June 1997) were sampled and observed in June 1998. The parturition and birth season was examined from seasonal change in gonadosomatic index (*GSI*) for female fish.

$$GSI = GW \times 10^2 / EBW$$

where *GW* is the gonad weight (g) and *EBW* is the eviscerated body weight (g).

RESULTS

Time of annulus formation

Because no significant difference in percentage occurrence of otoliths with an opaque edge was

Table 1 *Sebastes vulpes* samples

	Male		Female	
Sampling date	No. fish	SL (mm)	No. fish	SL (mm)
20–24 Apr. 1998	12	184–300	13	174–254
22–27 May 1998	8	159–281	6	174–233
3–22 June 1998	12	156–267	10	164–254
22 July 1998	1	257	0	
25–27 Aug. 1998	2	179–195	3	170–273
14–29 Sep. 1998	8	198–338	9	166–282
28–31 Oct. 1998	20	178–354	19	182–294
1 Nov. 1998	2	202–232	1	204
5 Dec. 1998	42	148–218	46	161–224
1–15 Mar. 1999	22	180–238	12	188–244
22–30 Apr. 1999	3	220–247	6	218–278
17 May 1999	4	246–278	5	242–262
Total	136	148–354	130	161–294

SL, standard length.

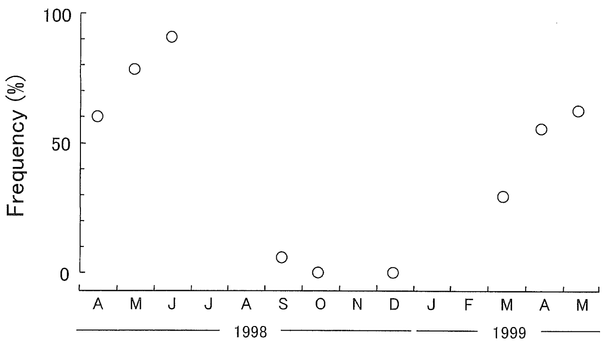

Fig. 2 Monthly change in percentage occurrence of opaque edge in otolith of *Sebastes vulpes.*

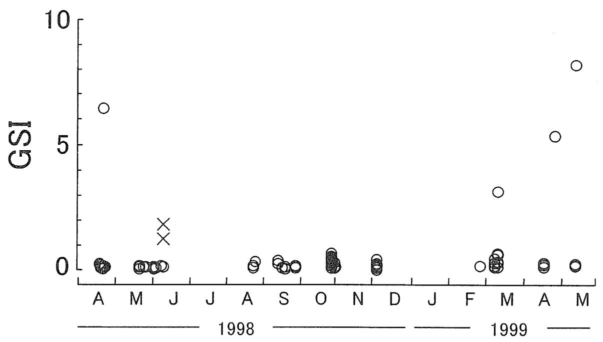

Fig. 3 Seasonal change in gonadosomatic index (*GSI*) of female *Sebastes vulpes* (×) with and (○) without spent ovary.

found between sexes (*G*-test, $G_{adj} = 0.65$, $P = 0.42$) through the sampling periods, the percentages for both sexes were combined. As shown in Fig. 2, in 1998 the percentage occurrence of otoliths with an opaque edge was at a maximum (90.9%) in June, and was low (5.9%) in September. In October and December all otoliths had translucent edges. In 1999 the percentage occurrence of otoliths with an opaque edge was 29.4% in March, and increased up to 62.5% in May. These results show that the annulus (outer margin of opaque zone) of the otolith is produced chiefly from July to August.

As for the 1-year-old fish cultured at Shimamaki, almost all of the otoliths (98.0%) had one peripheral opaque zone with a central opaque zone containing the nucleus, although the other fish (2.0%) had a translucent edge with a central opaque zone. This fact indicates that the first annulus is produced one year after birth.

Seasonal change in gonadosomatic index

Figure 3 shows the seasonal change in *GSI* for female *S. vulpes.* On 20 April 1998 an individual with a high *GSI* (6.45) was found, and two individuals with spent ovaries were observed on 12 June. Thereafter the *GSI* for each specimen was <0.8 until December. From March to May 1999, individuals having a high *GSI* (≥3.15) were found again, and the maximum value (8.22) was observed on 17 May. These results indicate that the parturition and birth season in this study area occurs approximately from May to June.

Comparison of annulus counts between the surface method and the cross-section method

Opaque zones in the otoliths of *S. vulpes* were easily identified using the cross-section method

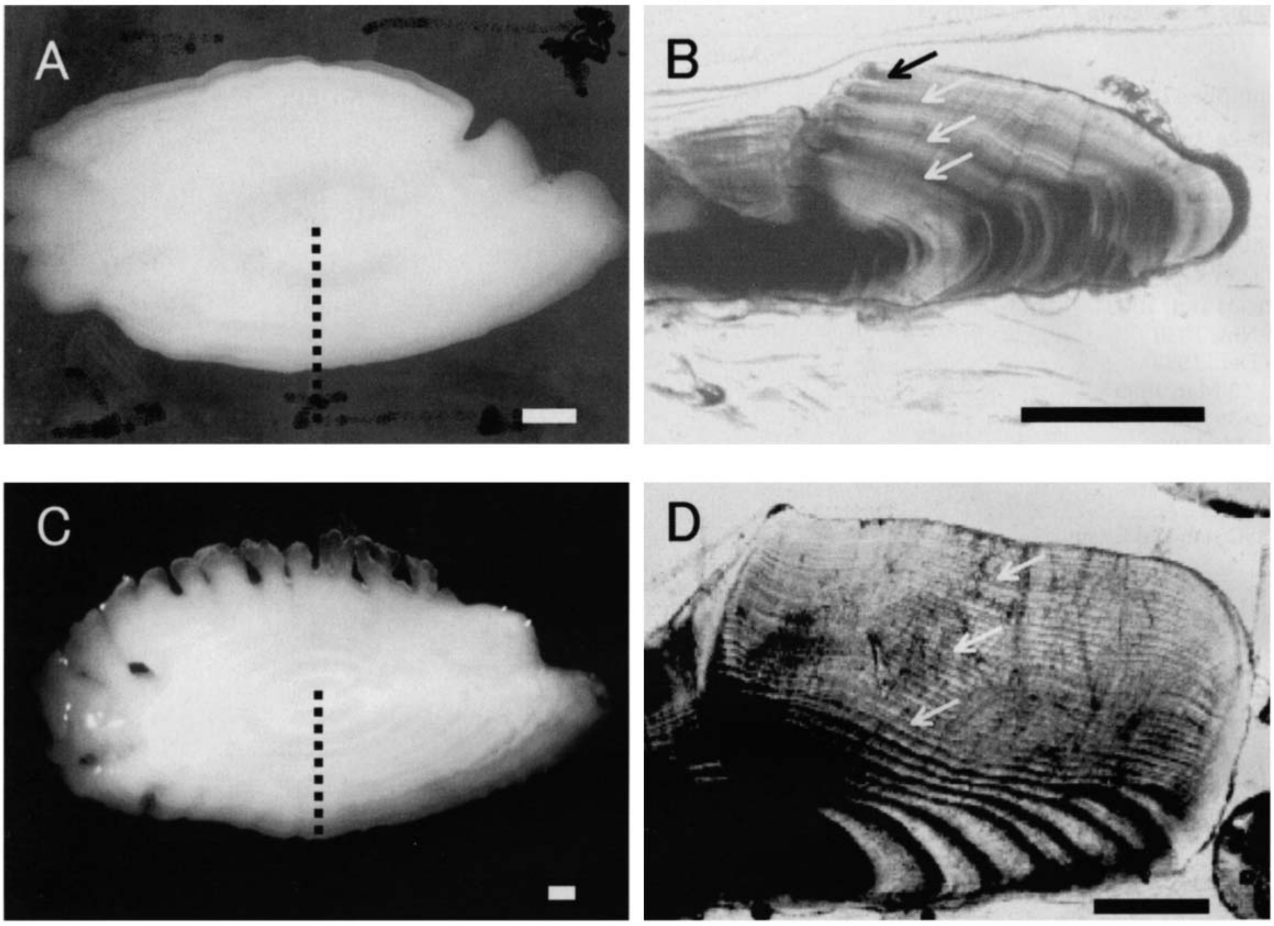

Fig. 4 Photographs of (a,c) surface and (b,d) cross-section otolith of *Sebastes vulpes*. (a,b) Male, 183 mm standard length (SL), April 1998. (c,d) Male, 354 mm SL, October 1998. Vertical dotted lines indicate a plane observed by cross-section. Bar = 500 μm. Arrows denote annulus from 1st to 4th in (b) and 10th, 20th and 30th annulus in (d), respectively.

Table 2 Comparison of annulus counts between surface method and cross-section method

	No. annuli by cross-section method										
No. annuli by surface method	3	4	5	6	7	8	9	10	13	35	Total
3	8										8
4		18									18
5			27	2							29
6				15	6						21
7					6	1					7
8						2	1				3
9								1	1		2
:											:
12										1	1
Total	8	18	27	17	12	3	1	1	1	1	89

(Fig. 4b,d). As shown in Fig. 4(c), in the case of a 354-mm *SL* male, the number of annuli counted by the surface method was 12 but 35 annuli were clearly observed by the cross-section method (Fig. 4d). Counts of annuli derived by these two methods of aging were compared using 89 otoliths (Table 2). The number of annuli recognized by the cross-section method coincided with that by the surface method in the case of annuli 3–5. But when the number exceeded 5, counts by the surface method were frequently lower than those by the cross-section method, and its discrepancy became larger as the fish grew older.

Growth curves

When a difference occurred between two readings, ages determined from the cross-section method were used for the growth analyses. The birthday of all individuals was assumed on 1 June, and decimal age was added to the number of annuli by captured month. Otherwise, there was a discrepancy of approximately 2 months between the time of annulus formation in the otolith (July–August) and the parturition and birth season (May–June). Accordingly, the ages of fish collected from June to August were treated as the number of each annulus plus 1. For example, the fish with two annuli captured on 1 July was treated as age 3.08. The von Bertalanffy growth parameters were estimated with the age and standard length at capture. The growth curves calculated were as follows:

$$\text{Male: } SL_t = 354.6(1 - \exp^{-0.167(t+0.580)}),\ r = 0.815,\ P < 0.001,\ n = 136$$

$$\text{Female: } SL_t = 403.4(1 - \exp^{-0.114(t+1.579)}),\ r = 0.755,\ P < 0.001,\ n = 130$$

where SL_t is the standard length (mm) at age t (after parturition in years). Likelihood ratio tests[6] did not show a difference between the male and female von Bertalanffy growth parameters ($\chi^2 = 0.859$, d.f. = 3, $P = 0.84$). The growth curve combined for both sexes was as follows:

$$SL_t = 358.6(1 - \exp^{-0.156(t+0.820)}),\ r = 0.791,\ P < 0.001,\ n = 266$$

DISCUSSION

In the present study the aging of *S. vulpes* was conducted by the surface and the cross-section methods. As a result, the underestimation of aging occurred for fish older than 6 years using the surface method. The cause of this was that in older fish the annuli that were layered lengthwise in sectioned otoliths could not be distinguished by the surface method, as Hayashi *et al.* stated on otoliths of marbled rockfish, *Sebastiscus marmoratus*.[7] Beamish stated that the otolith growth pattern of Pacific ocean perch, *Sebastes alutus*, changed near the age at which the growth rate decreased (i.e. ~20 years), and after this age the otolith continued to increase in thickness but increased little in length and width.[8] Kelly *et al.* observed the cross-section of otoliths of bluemouth rockfish, *Helicolenus d. dactylopterus*, and pointed out that between 1 and approximately 8 years of age the direction of otolith growth was along the anterior–posterior axis, but after 8 years of age there was a progressive shift in growth towards the external–internal axis.[9] Fujiwara and Hankin stated that the growth in the otolith radius of sablefish, *Anoplopoma fimbria*, decreased dramatically with age, but growth of otolith thickness continued to increase linearly with age.[10] These studies suggest that the surface method tends to produce underestimations of the age of old fish compared with the cross-section method. In the present study the difference in counts of annulus between both methods occurred at section age = 6. Accordingly, it is necessary for the aging of *S. vulpes* >5 years old to use the cross-section method.

A growth curve for 'fox jacopever' was reported only from the Hachinohe region of northern Honshu.[5] Compared with this report, the growth rates estimated using the cross-section method in the present study were apparently low after 6 years (Fig. 5). The report from the Hachinohe region probably contains *S. vulpes and S. zonatus* because these two species are sympatric around Japan.[1] The

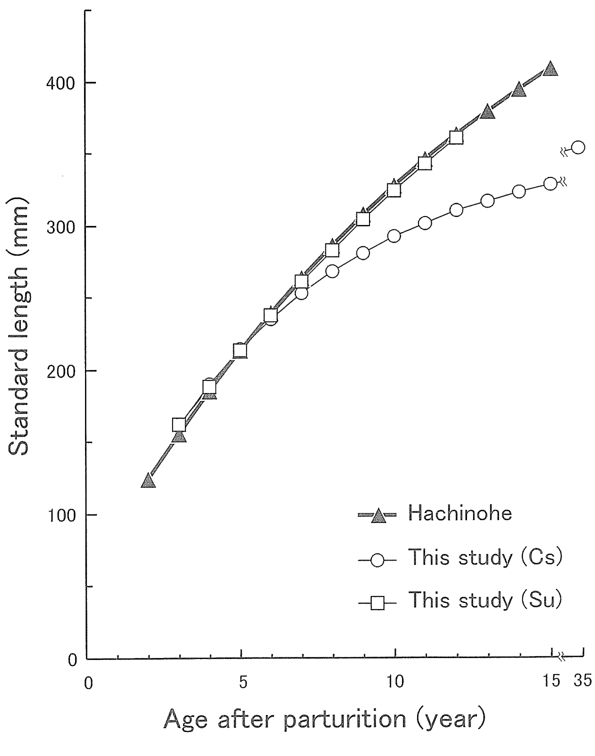

Fig. 5 Comparison of *Sebastes vulpes* growth curves for the present study area with that for Hachinohe region given by Iizuka.[5] Growth curve estimated by the surface method (Su) is as follows: standard length (SL) = 735.8 (1–exp($^{-0.047(t+2.230)}$), $r = 0.827$, $P < 0.001$, $n = 263$. Growth curve estimated on the basis of the cross-section method (CS) is shown in text.

difference in growth rates between these two species is unknown, and geographic variations in the growth are also unknown. However, the growth curves estimated by the surface method in the present study resembled that for the Hachinohe region (Fig. 5). Accordingly, it is possible that the difference in growth patterns between the Hachinohe region and the present study area was caused by the aging method, because the growth curve for the Hachinohe region was calculated from the surface age. Iizuka assumed that 'fox jacopever' grew up to 400 mm *SL* at 14 years, and their lifespan was more than two decades.[5] As aforementioned, however, ages of old fish based on the surface method were underestimated and the oldest fish was 35 years (354 mm *SL*). It seems likely that *S. vulpes* grows more slowly and lives longer than previously thought.

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