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Age and Growth of Brown Sole *Pleuronectes herzensteini* in the Coastal Waters of Western Aomori Prefecture, Japan

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Age and growth of brown sole *Pleuronectes herzensteini* collected from the coastal waters of western Aomori Prefecture from September 1989 to September 1990 were determined from otolith analysis. Observation of the otolith margin verified that annuli (outer margins of the translucent zone) were mainly produced between February and March. This period was associated with the spawning season. Growth of brown sole was expressed by the von Bertalanffy asymptotic growth function as $TL_t = 255.2(1-\exp^{-0.463(t-0.267)})$ for males and $TL_t = 350.2(1-\exp^{-0.308(t-0.300)})$ for females, where TL_t is the total length in mm and t is age in years. It was found that the growth rate of brown sole in this study area is very high as compared with the more southern population in the Niigata region.

In the northern Japan Sea, there is a tendency that the growth rate in the north is higher in length at comparable ages. It is possible that the growth of brown sole in the northern Japan Sea is closely related with bottom water temperature.

Key words: growth rate, geographical variation, brown sole, otolith, bottom temperature

Brown sole *Pleuronectes herzensteini* is one of the important fishery resources in the coastal waters of Japan. In the coastal waters of western Aomori Prefecture, this species is caught with set nets, Danish seines, and gill nets, amounting more than 100 tons annually.*3 Age and growth of brown sole has been investigated by many workers. Kawasaki and Hatanaka[1] pointed out that the resting zone on scales could be used for aging. Studies based on otoliths (sagittae) were made by Wada,[2] Nishiuchi,[3] Choi *et al.*,[4] Fukushima Pref.,[5] and Kato.[6] From these reports, a large geographical variation in growth was suggested.

However, the information on the growth of populations in other areas is poor. The present paper deals with the age and growth of brown sole in the coastal waters of western Aomori Prefecture. The difference in growth among areas is also discussed.

Materials and Methods

Samples were collected from the coastal waters of western Aomori Prefecture (Fig. 1) from September 1989 to September 1990. The majority of specimens (92%) were captured with a commercial Danish seine and set net. Remaining fish were taken from Danish seines operated by the Aomori Pref. Fish. Exp. Stn. In the laboratory, after defrosting, the total length and standard length of all specimens were measured to the nearest 1 mm, and the sex was recorded. The paired otoliths were then removed and kept dry.

The otolith growth of brown sole is larger on the axis of the ocular side extending the anterior part of the body,[2] suggesting the availability of ocular side otolith for reading, especially for the older fish. For this reason, only the ocular side otoliths were used for analysis. After being submerged in water for several hours, all ocular side otoliths were ground with fine (#600) sand paper so that the polished edge passed through the nucleus of otolith. The polished otoliths were mounted on glass slides coated with immersion oil against a black background to improve optical quality. The otoliths were then viewed at ×20 magnification under Nikon Profile Projection, and the otolith radius to the anterior margin and the ring radius to each translucent margin were measured to the nearest 5 μm along the longest axis from the nucleus of the otolith to the anterior margin (Fig. 2). These measurements were made at least twice on all otoliths by the same person. The time of annulus formation was determined by seasonal difference in percentage occurrence of otoliths with translucent edges.

However, the sample collected on September 6, 1990, contained a marked small sized two ring group, and fish with three rings or more were also smaller than other samples in total length. So, these fish (24 male, 29 female) were excluded from the calculation of growth curves.

Results

Time of Annulus Formation

As shown in Fig. 3, the percentage occurrence of otoliths with translucent edge was low (male: 30.0%; female: 16.7%) in September, and reached the maximum in November for males and in December for females. Opaque zones of both male and female began to form in

*3 Prefectural Government of Aomori: "*Koikishigen Baiyokanri Suishinjigyo Hokokusho*", Aomori Pref., Aomori, 1991, p. 51.

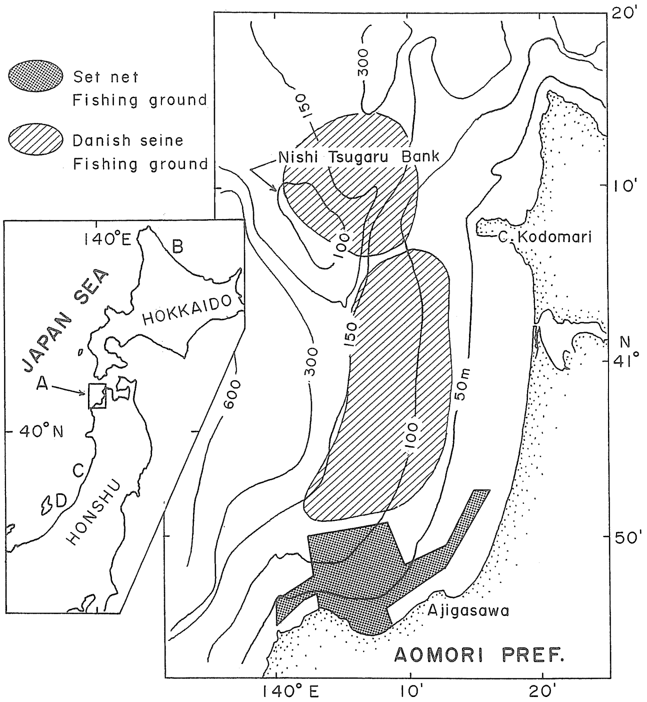


Fig. 1. Map showing sampling area (shaded and striped parts) and contours of depth (m) in the coastal waters of western Aomori Prefecture.
A: this study area, B: Esashi region, C: Yamagata region, D: Niigata region.

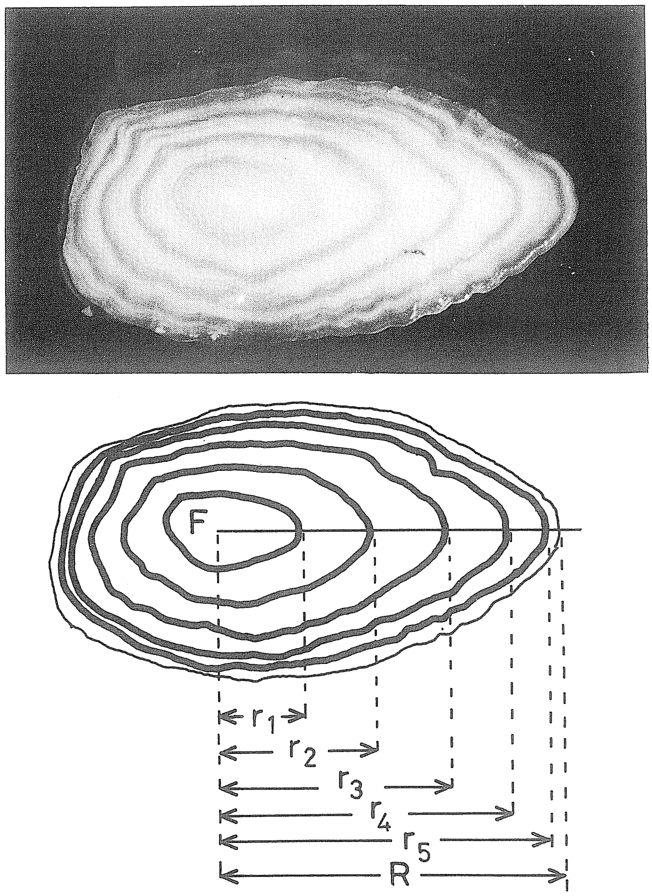


Fig. 2. Ocular side otolith of brown sole with five annuli (female, 280 mm in total length).
F: focus; R: otolith radius; $r_1 \sim r_5$: annual ring radii.

December, and the percentage occurrence of otoliths with translucent edges dropped remarkably after February. In April, all otoliths from females had opaque edges and the majority of otoliths from males had opaque edges in May. These results show that the annulus (outer margin of translucent zone) of the otolith is formed chiefly between February and March, though some difference between the two sexes was observed.

In this study area, it was reported that a large number of spent brown sole were found in April.[7] Kawasaki *et al.*[8] showed that the type of maturation and oviposition of brown sole was the bimode-split-batch spawning and the oviposition of each fish continued over one month. Accordingly, it seems likely that the spawning of brown sole in this study area begins in March, indicating the time of annulus formation of otolith approximately coincides with the beginning of spawning season.

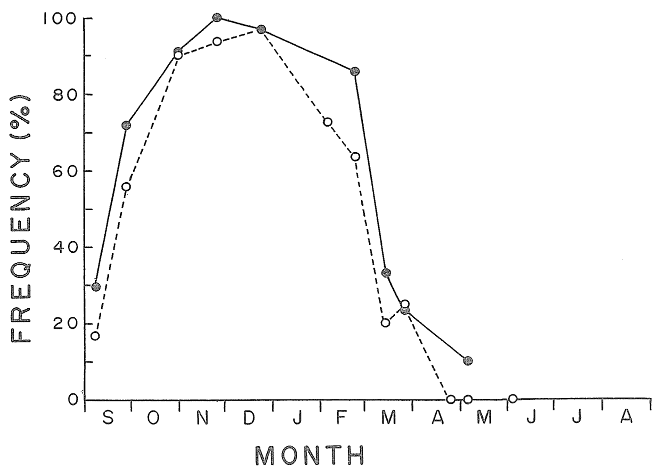


Fig. 3. Percentage occurrences of otolith with translucent edge in male (solid circles) and female (open circles) brown sole.
Samples less than nine otoliths are not shown.

Growth Curves

Plots of the relationship between otolith radius (R) and total length of fish (TL) are shown in Fig. 4. These were approximately linear and the least-squares equations were as follows:

Male:

$$TL=62.96R-3.22,\ r^2=0.83,\ p<0.001,\ n=370$$

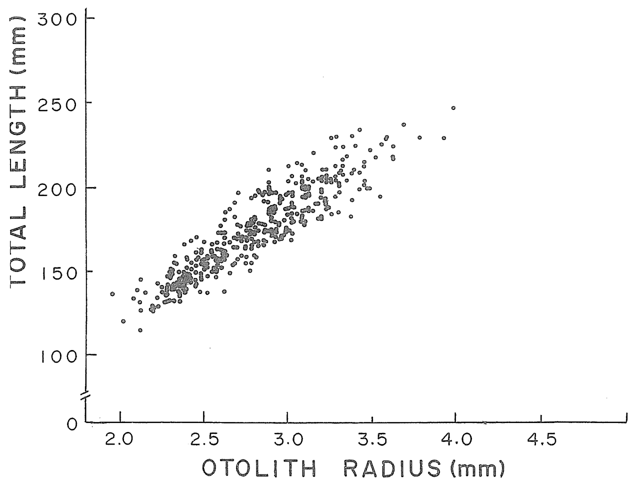
Female:

$$TL=67.65R-15.12,\ r^2=0.89,\ p<0.001,\ n=478.$$

The mean radii of each successive otolith ring at each estimated age are shown in Table 1. This data shows that Lee's or reverse-Lee's phenomenon is not present. The mean total lengths (TL_t) back-calculated from otolith readings at each estimated age are shown in Table 2. The von Bertalanffy growth curves[9] computed using back-calculated lengths were as follows:

Male:

$$TL_t=255.2(1-\exp^{-0.463(t-0.267)})$$



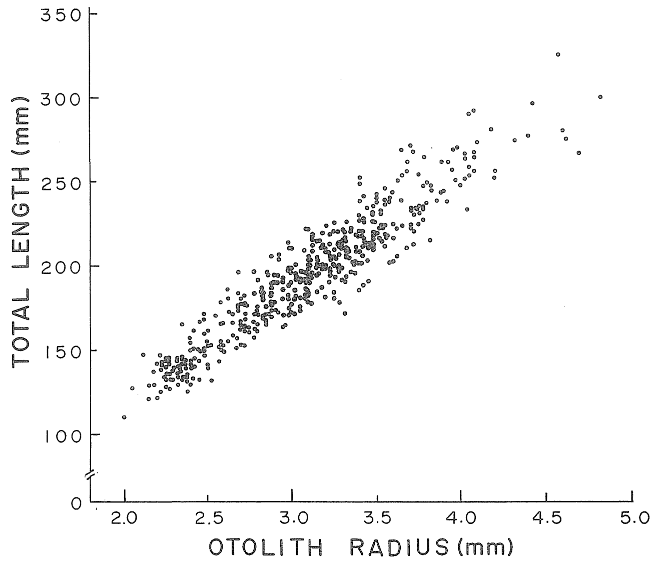


Fig. 4. Relationships between otolith radius and total length for male (upper) and female (lower) brown sole.

Female:

$$TL_t = 350.2(1 - \exp^{-0.308(t-0.300)})$$

Table 2. Mean back-calculated total lengths (Tl_t, mm) and total lengths (TL_t, mm) calculated from von Bertalanffy equations at the time of each annulus formation

t	Male		Female	
	Tl_t	TL_t	Tl_t	TL_t
1	73.4(59.3)	73.4(59.3)	67.8(54.4)	67.9(54.5)
2	140.4(117.0)	140.7(117.3)	143.0(119.2)	142.7(119.0)
3	183.6(154.2)	183.1(153.8)	198.2(166.8)	197.7(166.4)
4	209.7(176.7)	209.8(176.8)	237.0(200.3)	238.1(201.2)
5	—	—	268.2(227.2)	267.8(226.8)

Figures in parentheses are standard lengths (SL) converted using an equation: $SL = 0.862TL - 4.017$ ($r^2 = 0.99$).

where TL_t is the total length (mm) at age t (in years). The total lengths (TL_t) at each estimated age calculated from the above equation are also shown in Table 2. The observed and calculated values agree very well. There is little difference in the growth rate between the two sexes until the 2nd annulus formation, however, thereafter females showed a higher growth rate than males at each age (Table 2).

Variation in Growth among Individual Fish

Total length distributions of the 1988 year-class collected from September 1989 to September 1990 are shown in Fig. 5. There were large variations in total length among individual fish on the whole. This fact was remarkable, especially in the female sample taken in September 1990, showing a distinct bimodal distribution. Although the length of the small-sized group was significantly larger than that of the 1989 year-class in the same catch (chi-square test, male: $p < 0.01$, female: $p < 0.05$), this difference was not so large. The existence of these two different size groups could be also demonstrated in the growth pattern of otoliths, that is, the plots of ring radii to otolith radii for the female 1988 year-class taken in September 1990 hardly overlapped between the two groups (Fig. 6).

Discussion

Growth rates of brown sole in different regions of the

Table 1. Mean ring radii (±SD) for each age group of brown sole

Ring groups	N	Ring radii (mm)				
		r_1	r_2	r_3	r_4	r_5
Male						
1	90	1.36±0.19				
2	225	1.18±0.16	2.30±0.23			
3	47	1.09±0.15	2.16±0.24	2.92±0.21		
4	8	1.30±0.24	2.46±0.23	3.22±0.27	3.38±0.25	
Weighted mean	370	1.22±0.19	2.28±0.24	2.97±0.24	3.38±0.25	
Female						
1	103	1.38±0.19				
2	251	1.19±0.18	2.37±0.27			
3	98	1.14±0.17	2.24±0.27	3.15±0.28		
4	20	1.28±0.24	2.39±0.46	3.18±0.43	3.69±0.37	
5	6	1.23±0.12	2.22±0.16	3.13±0.14	3.85±0.13	4.19±0.21
Weighted mean	478	1.23±0.20	2.34±0.28	3.15±0.30	3.73±0.34	4.19±0.21

n: number of otoliths used.

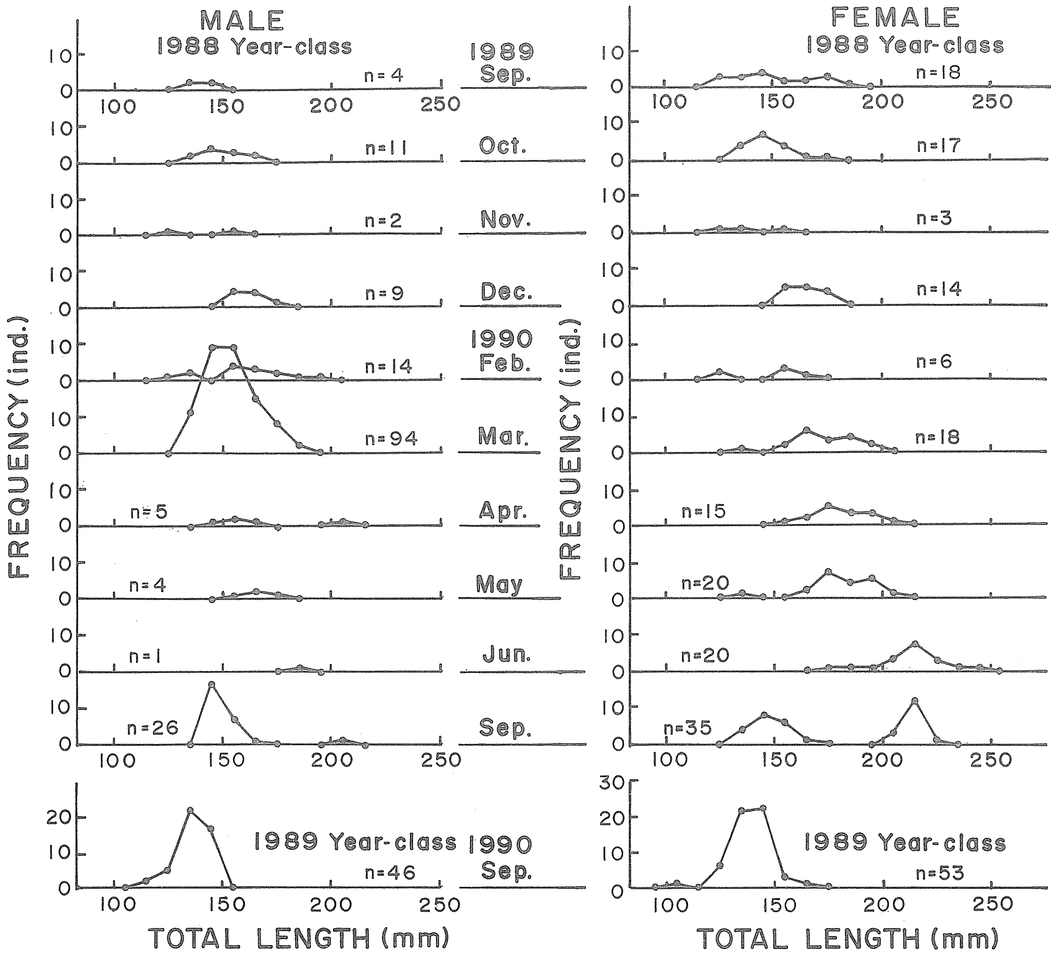


Fig. 5. Length frequency distributions for the 1988 year-class of brown sole collected from September 1989 to September 1990. Data for the 1989 year-class collected in September 1990 are also shown. n: number of fish examined.

Japan have been previously reviewed by Kato.[6] We discuss geographical variations in growth rates of the populations from the Hokkaido to the northern Japan Sea.

In the coastal waters of western Aomori Prefecture, the time of annulus formation in the otolith of brown sole was associated with the spawning season. A similar fact was known from the populations in the Niigata and Esashi regions.[2,3] Therefore, it is possible to compare the growth rates at each age among the above three areas. Growth curves for females from each area are shown in Fig. 7. For reference, the growth curve for the population in the Yamagata region[10] is also shown, though the data is based on the length frequency distribution in summer. Because in the previous papers standard length (SL) was used, the values were converted to total length using the above-mentioned equation (Table 2).

As can be seen in Fig. 7, brown sole in this study area showed as rapid a growth rate as those in the Esashi region, while the growth rate for the Niigata region was very low. Although a precise comparison is difficult, the growth rate for the Yamagata region,[10] which is situated between the Aomori and the Niigata regions, seems to lie between the above two areas.

Thus, in the northern Japan Sea there is a tendency that the growth rate of brown sole in the north is higher in length at comparable ages. Kitagawa *et al.*[11] stated that the growth rate of the Japanese flounder *Paralichthys olivaceus* around Japan is higher in the south as a rule and gave the following as possible factors affecting it: (1) the growth period of young-of-the-year is contracted in the north, where the spawning season occurs later, and (2) the period of tardy growth is longer in the north for all age groups because of low water temperature. Brown sole is superior to cold resistance but is inferior to heat resistance, as compared with the Japanese flounder.[12,13] It is known that brown sole in the Niigata region exhibits a behavior to escape the warm water after June.[14] Considering these facts, the bottom temperature seems to be an important factor to explain the geographical variation in growth of brown sole in the northern Japan Sea coast. There is no appreciable difference in spawning season between the Aomori and the Niigata regions. Otherwise, Pitt[15] stated that the growth rate of American plaice *Hippoglossoides platessoides* in the Northwest Atlantic was probably related to water temperature and food supply. Brown sole consume chiefly polychaete annelids,[16,17] however there is no available data to compare the food abundance in the Niigata and the Aomori regions.

The sample collected on September 6, 1990 contained a marked small-sized two ring group (Fig. 6), which were caught around the Nishi Tsugaru Bank. Although it is considered that the slow growing group is small in abundance, their presence also indicates the geographical variation in growth of brown sole. To confirm the cause affecting the

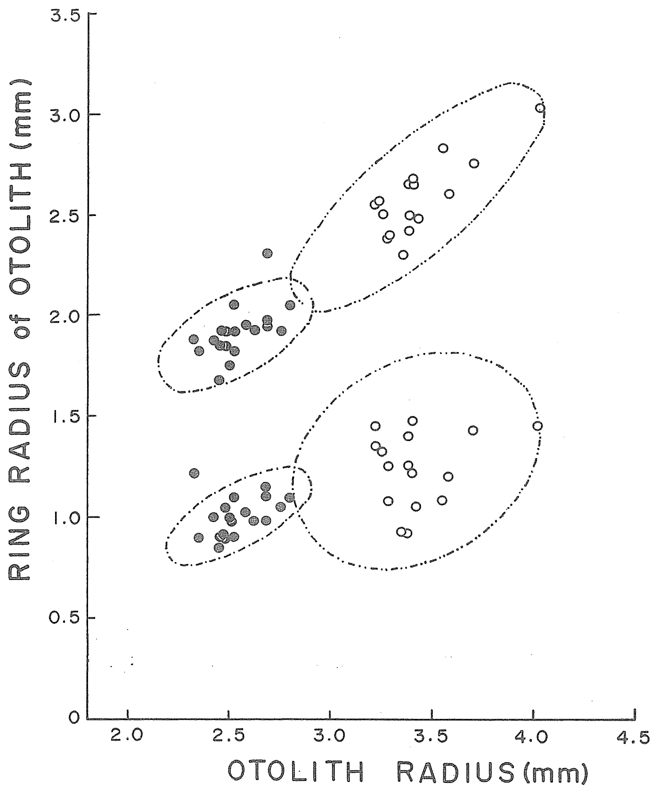


Fig. 6. Rejection ellipses for relationships between otolith radius and ring radius ($r_1 \sim r_2$) for two-year-old female brown sole collected in September 1990.

Closed and open circles represent slow and fast growing groups, respectively.

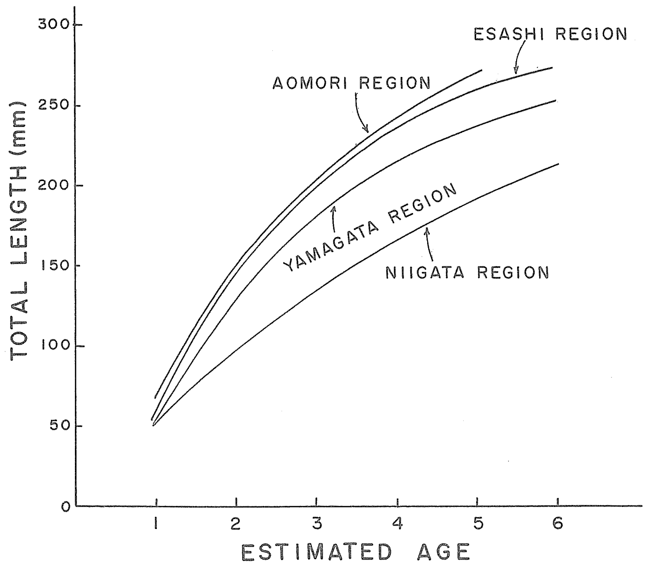


Fig. 7. Comparison of female brown sole growth curve for this study area with those for Niigata region given by Wada,[2] for Esashi region by Nishiuchi,[3] and for Yamagata region by Sando and Hida.[10]

geographical variation in growth of this species, the information on feeding and detailed temperature data are necessary.

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