Age and Growth of the Cardinalfish *Apogon lineatus* in Tokyo Bay, Japan

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Age and growth of the cardinal fish *Apogon lineatus* in Tokyo Bay were estimated from right sagittal otoliths of 556 fish. Examination of the outer margins of the otoliths showed that the translucent zone was formed once a year, and can be used as an annulus, with its formation completed at the beginning of the spawning season. Growth of fish, expressed by the von Bertalanffy growth equation, was $L_t = 86.6[1 - \exp\{-1.12(t+0.01)\}]$ for males, and $L_t = 118.5[1 - \exp\{-0.37(t+1.03)\}]$ for females, where L_t is total length in mm and t is age in years. Growth of males and females differed. Females were larger than males at each estimated age. Most fish examined were ages 1 and 2, although the oldest fish were 3 years old for both sexes.

Key words: Tokyo Bay, *Apogon lineatus*, age and growth, otolith

The cardinal fish *Apogon lineatus* inhabits sandy or muddy bottoms from coastal inlet to a depth of 100 m, from Uchiura Bay in Hokkaido, Japan to the South China Sea and the Indo-West Pacific.¹⁾ In Tokyo Bay, this species is one of the major components of the fish fauna,²⁾ and many are taken as bycatch in bottom trawl fisheries which target mantis shrimp, mud dab and conger eel.

This species is well known for the peculiar habit of mouthbrooding by males. There is, however, insufficient information available on the life history of the species, because it is rarely targeted by commercial fisheries. The only studies on age and growth of *A. lineatus* are by Omori and Takahashi,³⁾ and Yamada,⁴⁾ who analyzed monthly changes in body length. In this study, we attempted to clarify age and growth of *A. lineatus* in Tokyo Bay using otoliths.

Materials and Methods

Fish were collected from May 1996 to February 1998 by commercial bottom trawling in Tokyo Bay. A map of the study site, and description of fishing gear were given by Yamaguchi *et al.*⁵⁾ A total of 564 specimens (male=260, female=304) were examined. Most of the collected specimens were kept frozen for later measurements, while some were immediately measured after we returned to the laboratory. Total length of fish was measured to the nearest mm. Size distribution of the collected specimens was showed in Table 1.

Sagittal otoliths were removed from specimens and kept in glass vials. Some of the otoliths, especially the larger ones, were ground with a whetstone until the focus could be seen clearly. The otoliths were placed in a watch glass containing glycerine. They were examined with a binocular microscope using transmitted and reflected light against a black background, and the otolith radius and ring radii were measured to 0.01 mm with a built-in measuring device. The otolith radius and ring radii were measured from focus to the posterior distal margin of the

Table 1. Size distribution of specimens

Total length (mm)	Number of specimens		
	male	female	Total
31–40	1	0	1
41–50	3	3	6
51–60	20	8	28
61–70	37	23	60
71–80	90	68	158
81–90	68	134	202
91–100	38	56	94
101–110	3	10	13
111–120	0	2	2
Total	260	304	564

Fig. 1. Otolith of *Apogon lineatus*, male, 85 mm in total length collected in July.

R, otolith radius (223 mm); r1-r2, annual ring radii 1-2; F, focus.

otolith, and to the outer margins of the translucent zones, respectively. (Fig. 1). Since there were no differences in size and ring formation between right and left otoliths,

only right otoliths were used for measurements.

The period of annulus formation was determined by monthly changes in percentage occurrence of otoliths with opaque margins. The von Bertalanffy growth equation was estimated using Akamine's program⁶⁾ which implements Marquardt's algorithm for nonlinear least squares parameter estimation.

Results

Of 564 otoliths examined 556 (98.6%) were readable, the remaining 8 otoliths had obscure rings. Monthly changes in percentage occurrence of otoliths with an opaque margin are shown in Fig. 2. The formation of the translucent zone began in August and was completed between March and June. The completion of the period of translucent zone formation coincides with the beginning of the spawning season of *A. lineatus* in Tokyo Bay. These data indicate that the translucent zone is formed once a year and it can be used as an annual mark (annulus) for age determination.

Fig. 2. Monthly changes in percentage occurrence of otoliths with an opaque margin in *Apogon lineatus*.

Numbers represent total number of otoliths read each month.

The relationships between otolith radius and total length are shown in Fig. 3. The equations are as follows:

$$\text{male } TL = 37.7R^{1.000} \quad (r^2 = 0.841, n = 255),$$

$$\text{female } TL = 41.9R^{0.874} \quad (r^2 = 0.804, n = 301),$$

where TL is total length in mm and R is otolith radius in mm. Because analysis of covariance showed a significant difference between males and females ($P < 0.05$), these data were treated separately for sexes. The mean radii of each successive otolith ring at each estimated age for males and females are shown in Table 2. These data show Lee's phenomenon, the mean radius of each ring decreasing with age, in both sexes. Therefore, following Uehara and Shimizu,⁷⁾ we used the mean radii of the most recent ring at each estimated age for back-calculating fish length (Table 2).

The von Bertalanffy growth equations derived from the back-calculated length were as follows:

Table 2. Mean otolith ring radii ($\pm$ SD) at estimated age for males and females *Apogon lineatus*

Estimated age (year)	N	Male Mean otolith ring radii (mm)		
		r1	r2	r3
1	165	1.56 $\pm$ 0.21		
2	65	1.45 $\pm$ 0.16	2.06 $\pm$ 0.18	
3	8	1.26 $\pm$ 0.06	1.84 $\pm$ 0.14	2.22 $\pm$ 0.11
Back-calculated total length (mm)		58.8	77.6	83.7

Estimated age (year)	N	Female Mean otolith ring radii (mm)		
		r1	r2	r3
1	180	1.60 $\pm$ 0.21		
2	99	1.45 $\pm$ 0.20	2.11 $\pm$ 0.19	
3	4	1.39 $\pm$ 0.20	2.05 $\pm$ 0.16	2.47 $\pm$ 0.12
Back-calculated total length (mm)		63.1	80.4	92.3

Fig. 3. Relationships between otolith radius (R) and total length (TL) for male and female *Apogon lineatus*.

Fig. 4. The von Bertalanffy growth curves for male and female *Apogon lineatus*.

The closed and opened circles are the back-calculated total length at estimated age for males and females, respectively.

$$\text{male } L_t = 86.6[1 - \exp\{-1.12(t + 0.01)\}],$$

$$\text{female } L_t = 118.5[1 - \exp\{-0.37(t + 1.03)\}],$$

where t is age in years and L_t is total length in mm at age t . Females are larger than males at each age (Fig. 4).

The maximum age was 3 years old for both sexes. Total length for each age estimated by the von Bertalanffy equation is for males, 58.6 mm at age 1, 77.4 mm at age 2, 83.6 mm at age 3, and for females 62.5 mm at age 1, 79.8 mm at age 2, 91.8 mm at age 3. The observed maximum total length was 103 mm for males and 112 mm for females.

Discussion

In this study we used otoliths for aging *A. lineatus*. The boundaries between translucent and opaque zones were clearly defined, and 98.6% of otoliths examined were readable. Few studies have used annual ring readings to examine age and growth of Apogonidae. Suzuki and Ueno⁸⁾ used scales for aging *A. cyanosoma* in Suruga Bay. We also attempted to use scales for aging *A. lineatus*, but found that scales had obscure annuli and thus were less ageable than otoliths.

Beckman and Wilson⁹⁾ suggested that opaque zones on otoliths of 60–70% of 94 fish species inhabiting the temperate zone in the Northern Hemisphere (Lat. 23–45°N) are formed between spring and early summer. However, in this study we found that the opaque zone on otoliths of *A. lineatus* was formed during a longer period, from spring to autumn. Beckman and Wilson⁹⁾ also reported on the relationship between breeding seasons and periods of opaque zone formation in otoliths. We also observed that opaque zone of otoliths in *A. lineatus* was formed almost during the breeding season.

Differences in growth between males and females were evident in our study. Females were larger than males at each estimated age. In Apogonidae males cannot take ordi-

nary food during mouthbrooding,¹⁰⁾ which may account for the smaller size of males.

We compared our mean back-calculated lengths with Omori and Takahashi data³⁾ for *A. lineatus* from Yuya Bay, Yamaguchi Prefecture. Our length at age 1 was much less than that of fish from Yuya Bay (male: 58.8 vs. 69 mm, female: 63.1 vs. 82 mm). The maximum ages of *A. lineatus* from Tokyo Bay were the oldest in the previous studies. Yamada,⁴⁾ and Omori and Takahashi³⁾ reported the maximum age was 2 years old for both sexes. The difference with our values is undoubtedly due to differences in methods of determining age.

Yamaguchi *et al.*¹¹⁾ in their investigation of geographic variations in growth of the starspotted dogfish *Mustelus manazo*, found that age and growth of *M. manazo* in Tokyo Bay were different from those of other regions. Tokyo Bay is a closed bay and has peculiar characteristics as compared to the other bays. Differences in age and growth of *A. lineatus* in Tokyo Bay from those of other regions may be caused by a peculiar characteristics in Tokyo Bay (e.g. water temperature and food availability) or the differences in life history of this species, and further study is necessary.

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