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Age and Growth of *Sillago aeolus* in Okinawa Island, Japan

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In a study of the age and growth of *Sillago aeolus*, a total of 414 fish were collected from December 2000 to March 2002, around Okinawa Island. Ages of 403 specimens were determined by otoliths. Monthly changes in the percentage of otoliths with an opaque zone in the outer margin indicated that an opaque ring formed once a year, occurring between February and May. The rings can therefore be defined as annual rings. Ages of females were estimated to be 0+ to 4+, while those of males were 0+ to 2+. The von Bertalanffy growth curves were well fitted to age-standard length data of males and females, as follows:

Male: $L_t = 209.6\,[1 - \exp\{-0.70\,(t + 0.58)\}]$.

Female: $L_t = 297.7\,[1 - \exp\{-0.42\,(t + 0.61)\}]$.

Keywords:
· Age,
· growth,
· Okinawa,
· otoliths,
· *Sillago aeolus*.

1. Introduction

A total of 31 *Sillago* species within the family Sillaginidae have been recorded in the marine and estuarine waters of the Indo-Pacific (McKay, 1992). Most of the species are tropical, but some are found in the temperate water of Southern Australia and Northern Asia. Five *Sillago* species are well distributed in Japan: *S. aeolus*, *S. sihama*, *S. macrolepis*, *S. japonica* and *S. parvisquamis*. Among them, *S. aeolus*, *S. sihama* and *S. macrolepis* are found in Okinawa Prefecture and the latter two species are found in mainland Japan (Sano and Mochizuki, 1984; Suzuki *et al*., 2001).

The spotted whiting *Sillago aeolus* is distributed from Singapore, Thailand, China, Hong Kong, Taiwan, the Philippines to Southern Japan areas, in waters of depth 0 to 60 m (McKay, 1992). It is a commercial fish in Southern Japan. Around Okinawa Island, most of the fish are caught by gill net for local consumption. This species is well known for its delicacy. Insufficient information is available on the life history of the species, however; Kato *et al*. (1996) described the morphological development and seasonal abundance of *S. aeolus* and *S. sihama* in the surf zone of the Philippines. Along with three other species, Sano and Mochizuki (1984) have identified the key characters of *S. aeolus*, and Ohta (unpublished data) has described its spawning season on the basis of the occurrence of larvae and juveniles in the surf zone of Okinawa Island.

Age and growth information is essential for a complete knowledge of the life history characteristics of a population, i.e. growth rates, age and size at sexual maturity, mortality rate, and average life span, etc. These data are in turn used in stock assessment models and ultimately in fishery management of (Newman and Dunk, 2002). To date, no study on the age and growth of *S. aeolus* has been performed using either scales or any hard tissues. The objective of this study was to clarify age, growth rate, size and age composition of *S. aeolus* using otoliths.

2. Materials and Methods

A total of 414 fish were collected from December 2000 to March 2002 around Okinawa Island, Southern Japan (Fig. 1). Of the specimens, 329 were caught by rod and line, while the rest were bought from fish markets. All fish were sexed by observation of the gonads, measured to the nearest 0.1 mm of standard length (SL), and weighed to the nearest 0.01 g. A total of 403 left sagittal otoliths were removed and embedded in resin, samples were cut into dorsal-ventral (transverse) sections of 600 μm in thickness (Fig. 2) with a diamond blade installed in a cutting machine (Buehler, ISOMET™ Low Speed Saw). Each sectioned otolith was placed on a glass mi-

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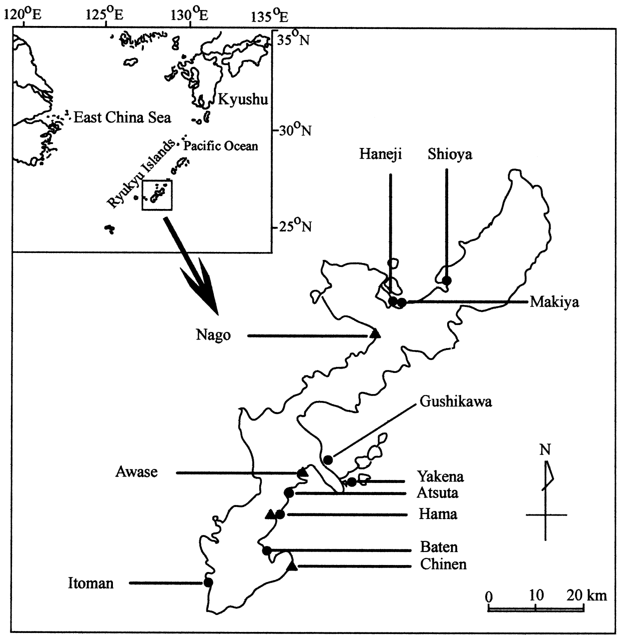

Fig. 1. Map showing sampling sites of *Sillago aeolus* caught by rod and line (●) bought at fish markets (▲) on Okinawa Island.

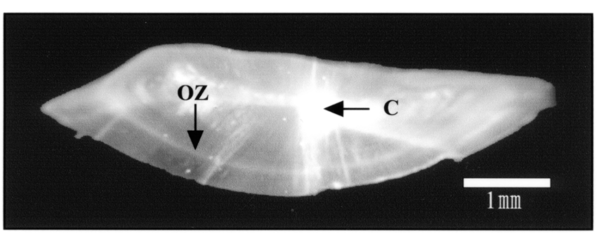

Fig. 2. Photograph of sectioned left sagitta (viewed under reflected light) of 1+ year old male (174.0 mm). OZ: Opaque zone; C: Core.

croscope slide, coated with clear nail polish, and examined under a binocular microscope using optical fiber light against a black background. In this study, the annual rings were defined as the outer margin of the opaque zone. In order to validate the annual periodicity of ring formation, the frequency occurrence of otoliths with an opaque margin was examined for each month.

The von Bertalanffy growth curves were fitted to the individual length-at-age data for females and males using Kaleida Graph software (Kaleida Graph®, version 3.5, Synergy software; USA). This software uses nonlinear regression to obtain parameter estimates for the selected growth model. The growth model is:

$$L_t = L_\infty[1 - \exp\{-k\ (t - t_0)\}]$$

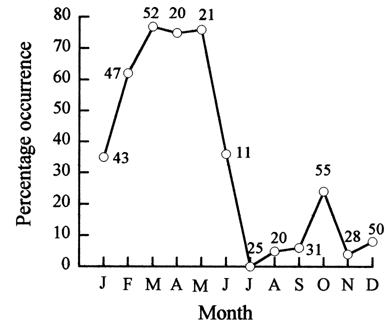

Fig. 3. Monthly changes in percentage of fish with otolith opaque margin of *Sillago aeolus*. Numbers beside plots show sample size.

where L_t is the length at age t, L_∞ is the asymptotic length predicted by the equation, k is the growth coefficient, and t_0 is the hypothetical starting time at which the fish would have zero length if it had grown according to the equation. The growth curve derived for the female was compared with that of male using a likelihood ratio test (Kimura, 1980).

3. Results

3.1 Time of otolith ring formation

Monthly changes in the percentage occurrence of otoliths with an opaque margin are shown in Fig. 3. The percentage of fish with opaque margins gradually increased from January, maintained high levels between February and May, and then gradually decreased until July. This seasonal change suggests that opaque ring formed once a year between February and May. The rings can therefore be defined as annual rings.

3.2 Length composition by ages

The length compositions of different age classes are shown in Fig. 4. The smallest cohort of fish which did not possess an opaque zone on their otoliths were caught in July and ranged from 59.3 to 119.6 mm SL. This cohort of fish were the results of spawning that occurred five months earlier (spawning period: Feb.–May, Habibur and Tachihara, unpublished data) and were therefore members of the 0+ age class. This cohort continued to grow in subsequent months. Large representatives of this 0+ age class were found in October and subsequently caught in all months through February. By this time, their lengths had reached 153.0 mm. By February, an opaque zone had become discernable at the edge of the otoliths of fish belonging to this cohort. The starting age was therefore assumed to be February. From March, otoliths possessed 1, 2, 3 and 4 opaque zones at their periphery and thus represented the 1+, 2+, 3+, and 4+ age classes, respectively.

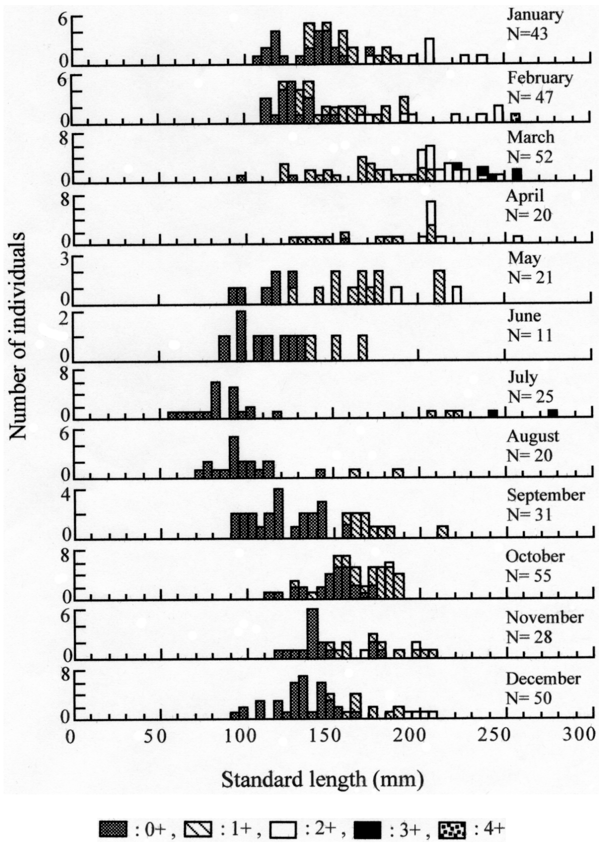

Fig. 4. Length composition by ages *Sillago aeolus*.

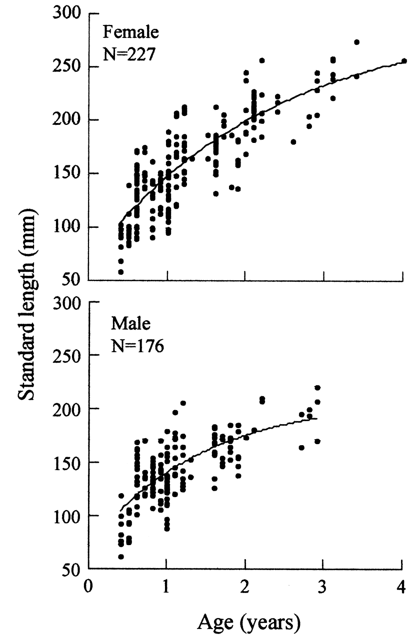

Fig. 5. Von Bertalanffy growth curve fitted to length at age data derived from sagittal otoliths of females (upper) and males (lower) for *Sillago aeolus*.

In March, the length ranges of *S. aeolus* whose otoliths possessed 1 and 2 opaque zones at their periphery ranged from 120.0 to 207.0 mm, and 181.0 to 247.0 mm. Fish > 3 yr old were occasionally caught during the study period. The oldest female and male were 4+ and 2+, respectively, while the maximum lengths were 275.0 mm for a 3+ female and 220.0 mm for a 2+ male.

3.3 Growth curve

The von Bertalanffy growth formula was computed for females and males separately using individual length-at-age data (Fig. 5). The growth curves showed a significant difference between two sexes (likelihood ratio test: $\chi^2 = 10.09$, df = 3, $P < 0.01$). The von Bertalanffy growth curves are as follows:

Female: $L_t = 297.7\ [1 - \exp\{-0.42\ (t + 0.61)\}]$ (r = 0.83).

Male: $L_t = 209.6\ [1 - \exp\{-0.70\ (t + 0.58)\}]$ (r = 0.72).

4. Discussion

This is the first report on age and growth of *Sillago aeolus* in Okinawa Island using otoliths as an age determinant marker. This study indicates differences between females and males, both in growth rate and maximum age, which is reflected in the fact that most of the larger specimens are females (see Fig. 5). The value of L_∞ of females was greater than that of males. The theoretical maximal length values ($L_\infty = 297.7$ for females and 209.6 for males) were close to the size of the largest fish examined and the growth coefficient values ($K = 0.42$ and 0.70 year^{-1} for females and males, respectively) indicated high attainment of maximum size. The asymptotic lengths and growth coefficient for the *Sillago* species in Japanese waters, which revealed variable growth patterns, are listed in Table 1. The growth coefficient (K) of *S. aeolus* was greater than *S. Japonica* for both males and females, but lower than female *S. parvisquamis* (Imoto *et al.*, 1997; Sulistiono *et al.*, 1999). The greater growth coefficient determined for this species might be caused by its rapid growth up to age 1+, at which time females and males will have reached their maximum standard length of 215.0 mm and 206.0 mm, respectively (Fig. 5). The females and males attained 72.6% and 98.2% of their asymptotic length, respectively, by age 1+. A similar phenomenon was observed for *S. burrus* in Australian waters where Hyndes *et al.* (1996) estimated a greater growth coefficient of *S. burrus*, and observed that this species attained almost 90% of its asymptotic length by the end of its first year. The rapid early growth enables this species (*S. aeolus*) rapidly to reach the size at which it typically becomes mature as our unpublished data showed that fe-

Table 1. Growth of *Sillago* species in Japanese waters.

Species	Male/Female	L_∞	*K*	Reference
Sillago aeolus	Male	209.6 (SL)	0.70	Present study
	Female	297.7 (SL)	0.42	
Sillago japonica	Male	341.98 (TL)	0.253	(Sulistiono *et al.*, 1999)
	Female	468.60 (TL)	0.174	
Sillago parvisquamis	Male	332.53 (TL)	0.577	(Imoto *et al.*, 1997)
	Female	288.61 (TL)	0.642	

males and males attained 60% and 91% maturity, respectively in the mentioned length at the end of their first year of life. The attainment of virtually large size by the end of the first year of life would also be of considerable advantage, since many individuals do not survive until the end of their second year of life. The differences in growth among *Sillago* species in different regions may be attributed to the difference in size of the individual sampled in each area. On the other hand, it is also possible that the variations in population parameters of the species of genus *Sillago* represent epigenetic responses (Bruton, 1990) to the different conditions (temperature and food) prevailing in different areas. In the present study the longevity of *S. aeolus* was found to be 4 years for females and 2 years for males. In comparison, in Indian waters *S. sihama* were observed with ages up to 4 years. The 1 to 3 year age groups were well represented, but older fish were scarce (Radhakrishnan, 1957). Sulistiono *et al.* (1999) estimated the longevity of *S. japonica* as up to 4 years at Tateyama Bay, Japan. In Australia, some whiting species (e.g. *S. vittata* and *S. burrus*) rarely exceeded 2 years of age, though a small number of the former species were caught between 4 and 7 years old, but several *S. schomburgkii* reached 4–7 years old (Hyndes *et al.*, 1996; Hyndes and Potter, 1997). However, the present study suggests that the majority of *S. aeolus* die before reaching 3 years old.

Most of the opaque ring/zones formed in *S. aeolus* in the spring season (Feb.–May), although a few individuals deposited opaque rings in the month of October. The ring formation between February and May was considered to be the annual ring. The formation of opaque zones on otoliths has been attributed to various factors, such as seasonal temperature, wet and dry season, feeding and reproductive cycles (Beckman and Wilson, 1995). Beckman and Wilson (1995) reported that opaque zones correspond with summer and spring growth, while translucent zones form during the winter season. Furthermore, otolith zone formation suggests complex control by endogenous and exogenous factors (Beckman and Wilson, 1995). From the observation of otolith edges in *S. aeolus*, the formation of an opaque zone was found to be correlated with spawning season (Feb.–May; Habibur and Tachihara, 2002; unpublished data) and it is thought that the spawning season might contribute the formation of an opaque ring. The ring formation of other *Sillago* species, i.e. *S. burrus*, *S. vittata*, and *S. schomburgkii*, was found in the summer season (spawning period) between November and December (Hyndes *et al.*, 1996; Hyndes and Potter, 1997) and for *S. japonica*, it occurred during the spring season between March and April (Sulistiono *et al.*, 1999). Therefore, ring formation (translucent/opaque) among *Sillago* species occurs differently either in the spring or summer season.

In conclusion, *S. aeolus* form growth rings on their otoliths on an annual basis. These rings can be used to determine the age of individual fish. Monitoring the age structure may be as indicator of the effect of exploitation, allowing the level of exploitation of this species to be monitored. Furthermore, the degree of survival of fish below the minimum legal size needs to be investigated and considered in future assessments.

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