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Age structure of Pacific saury *Cololabis saira* based on observations of the hyaline zones in the otolith and length frequency distributions

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ABSTRACT: The ages ($n = 11\,178$) and length frequency distributions ($n = 173\,300$) of Pacific saury *Cololabis saira* caught from September to November in 1989–2000 were examined. Most specimens were determined as either age 0 or 1 based on the number of annual rings in the otolith. The knob lengths (length from the tip of the lower jaw to the posterior end of the muscular knob on the caudal peduncle) at which 50% of the fish were age 1 ranged 277.8–304.7 mm. Analysis of length frequency distribution was also useful to divide the knob lengths of the two groups. The modal lengths of age 1 fish ranged 303.9–325.9 mm.

KEY WORDS: **age, *Cololabis saira*, hyaline zone, North Pacific, otolith, Pacific saury.**

INTRODUCTION

Pacific saury *Cololabis saira*, which is widely distributed in the north-western Pacific Ocean, is an important commercial pelagic fish in Japan. Pacific saury are mainly caught in the region from Krill Island to the Japanese coast from August to December using stick-held dip nets, with annual landings in Japan of 135 000–311 000 t over the last 20 years (1985–2004).[1] Body lengths of the fish caught in the main fishing season have been divided into small (200–240 mm), medium (240–290 mm) and large (>290 mm),[2] while Hotta[3] further separated fish of more than 320 mm into an extra-large-sized group. The abundance and modal length of each group change every year, although the causes of these fluctuations remain unknown. Because each length group is considered to be caused by differences in the ages or hatching periods, it is important to monitor the ages of these length groups and compare the lengths in different years among the same age groups. Recent studies on age determination of Pacific saury[4–8] based on analyses of the daily otolith growth increments have demonstrated that Pacific saury grow to a medium size within 1 year[8] and that their maximum lifespan is approximately 2 years.[5,6] Although the methods used could clarify the growth for each individual,[8] a correlation between each length group and age has not been clearly explained. Further, changes in modal length of the same age group in different year classes have not been investigated. It is too difficult to analyze a sufficient number of specimens based on daily otolith growth increments to demonstrate the cause of annual changes in modal length of the same age group in different year classes. Alternatively, hyaline zones in the otolith are formed from autumn to winter, and can easily be observed by light microscopy.[3,5,6,9,10,11] The main spawning season of Pacific saury is from September to June.[12] Therefore, fish that have no hyaline zone must have hatched in the previous spawning season (from September of the previous year to June of the current year),[8] while fish that have a hyaline zone must have hatched before June of the previous year.

Here a method is proposed for age determination of Pacific saury based on the presence or absence of a hyaline zone in the otolith. The age structure of Pacific saury from 1989 to 2000 is reported using this method. The length frequency distributions are analyzed as an alternative age determination method. Results obtained by two methods are compared and the validity of the sec-

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ond method is discussed. Finally, annual changes in the modal length of each age group are reported.

MATERIALS AND METHODS

Age determination

Fish with no hyaline zone in the otolith and those with hyaline zones are regarded as age 0 and age 1 fish, respectively. Otoliths with no hyaline zone were classified as type I, according to the criteria of Suyama and Sakurai.[11] Otoliths with hyaline zones were classified as type II (otolith enclosed by a broad translucent area along its outer edge), type III (otolith with one complete hyaline zone), and type IV (otolith with two hyaline zones). Fish with otoliths that did not belong to one of these four types were excluded from the age determination.

The difference between type II and type III otoliths was sometimes vague, although the hyaline zone of type II was much wider than that of type III. Specimens with type IV otolith were regarded as age 1, because a second hyaline zone is not always formed during winter.[11] Since the main formation period of hyaline zones is from October to February,[3,11] an incomplete hyaline zone was often observed along the margin of an otolith. These specimens were also excluded from this analysis.

The percentages of age 1 fish in each 5-mm length class and knob length were fitted to a logistic curve using the least squares method[13] through SOLVER in MS-Excel (Microsoft, Redmond, WA, USA). The knob length at which 50% of the fish were age 1 (L_{50}) was defined as the index of the boundary between the age 0 and age 1 fish.

The otoliths were collected from fish caught by fishery or research vessels in the north-western Pacific Ocean (33°40′–48°03′N, 136°00′–159°30′E). Most fish were collected from the main fishing ground, although some were caught in other areas by research vessels or small fishing boats using drift-gill nets. A total of 11 178 otoliths collected from 1989 to 2000, excluding 1994 and 1995, were examined (Table 1). The fish were measured for their knob length (the length from the tip of the lower jaw to the posterior end of the muscular knob on the caudal peduncle),[14] and the otoliths were then extracted, washed, dried, embedded in polyester resin and observed by optical microscopy at a magnification of 40×.

Table 1 Numbers of Pacific saury specimens used to analyze age determinations and length frequency distributions from 1989 to 2000

Year		September	October	November	Total
1989	No. age	103	49	0	152
	No. length	10 813	4891	1730	17 434
1990	No. age	254	67	186	507
	No. length	15 894	5361	2069	23 324
1991	No. age	317	120	337	774
	No. length	7 477	4436	3106	15 019
1992	No. age	40	80	130	250
	No. length	9 255	5037	3212	17 504
1993	No. age	32	24	33	89
	No. length	8 248	6044	2641	16 933
1994	No. age	0	0	0	0
	No. length	8 265	9110	4703	22 078
1995	No. age	0	0	0	0
	No. length	7 827	5464	1514	14 805
1996	No. age	131	0	38	169
	No. length	4 033	5464	1400	10 897
1997	No. age	0	411	240	651
	No. length	3 686	5805	1625	11 116
1998	No. age	0	505	604	1 109
	No. length	3 103	4730	2688	10 521
1999	No. age	763	804	843	2 409
	No. length	3 980	4175	1325	9 480
2000	No. age	1 810	1192	876	3 878
	No. length	1 971	1185	1033	4 189

No. age, numbers of specimens used for age determinations; No. length, numbers of specimens used to analyze length frequency distributions.

Table 2 Percentages of age 0 and age 1 fish

Year	1989	1990	1991	1992	1993	1996	1997	1998	1999	2000
Percentage of age 0 fish with a type I	21.7	7.1	14.7	54.8	33.7	47.3	7.1	65.6	74.8	60.2
Percentage of age 1 fish with types II, III and IV	68.4	90.3	81.7	42.4	65.2	50.9	87.3	30.8	23.5	39.1
Percentage of fish excluded from age determination (other otolith types)	9.9	2.6	3.6	2.8	1.1	1.8	5.7	3.6	1.7	0.8
Total no. of fish	152	507	774	250	89	169	651	1109	2409	3878

Length frequency distributions

Length frequency data were derived from the Fishery Resource Conservation database (FRESCO1), which is an accumulation of data from commercial fishing (obtained using stick-held dip nets) and research vessels (obtained using stick-held dip and drift-gill nets) (Table 1). These data are regularly collected (at least once every 10 days) from commercial vessels in the north-western Pacific Ocean (34°43′N–47°46′, 140°46′E–156°50′). Since large-sized fish migrate southward earlier than medium- or small-sized fish,[15] the length frequency distributions of the fish caught by fishing boats would be upwardly biased at the beginning of the fishing season and downwardly biased at the end of the fishing season. Therefore, data collected in either August or December were excluded.

Data from fish less than 200 mm were also excluded since such fish occurred rarely. Thus, to analyze annual fluctuations in the length frequency distributions, data were restricted to those fish collected from September to November between 1989 and 2000 (=173 300 individuals).

The length frequency distributions were divided into two normal distributions, since the fish consisted of two age groups. The small and large normal distributions corresponded to age 0 and age 1 groups, respectively. Division of the length frequency distributions into the two normal distributions was carried out according to Aizawa and Takiguchi[16] using a least-squares method.

The intersection of these two normal distribution curves was defined as *Bs* (Fig. 1), which represented an alternative index of the boundary length between age 0 and age 1 fish.

RESULTS

Age determination

The ages of more than 90% of the individual fish were determined in each year. The percentage of fish that could not be age determined ranged 0.8–9.9% (Fig. 2, Table 2). The proportions of age 0 and age 1 fish fluctuated every year. For example, age 0 fish varied from 7.1–74.8%, while age 1 fish varied from 23.5–90.3% (Table 2). The length L_{50} also fluctuated interannually, ranging 277.8–304.7 mm. The average of L_{50} from 1989 to 2000 was 292.4 mm (Table 3).

Otolith types in age 1 fish

Among the three otolith types in age 1 fish, type III otoliths were dominant. In 1996, 95.3% of age 1 fish contained this type of otolith (Table 4). Type II and IV otoliths represented minor proportions of age 1 fish. Specifically, type II and IV otoliths ranged 2.3–23.6%, and 0.4–14.2%, respectively. Both types appeared at high rates in comparatively large-sized classes, mainly in fish of more than 320 mm in 1989, 1991 and 1992 (Fig. 2).

Analysis of length frequency distributions

During the observation period in the present study, except for 1996, the modal length of the large-sized group ranged 303.9–325.9 mm, while that of the medium-sized group ranged 260.6–288.5 mm. The length frequencies were divided into two groups in all years, except for 1996 (Fig. 2). In 1996, the two normal distributions overlapped, such that the length distribution appeared to be one normal distribution. The intersection between the normal distribution curves of large- and medium-sized fish (*Bs*) varied from 280.2 mm (in 1991) to 308.2 mm (in 2000), with an average of 290.1 mm (Table 3).

Relationship between otolith type and length frequency distributions

The relationship between L_{50} and *Bs* for each year was plotted (Fig. 3). Linear regression analysis between the two values quantified the slope as

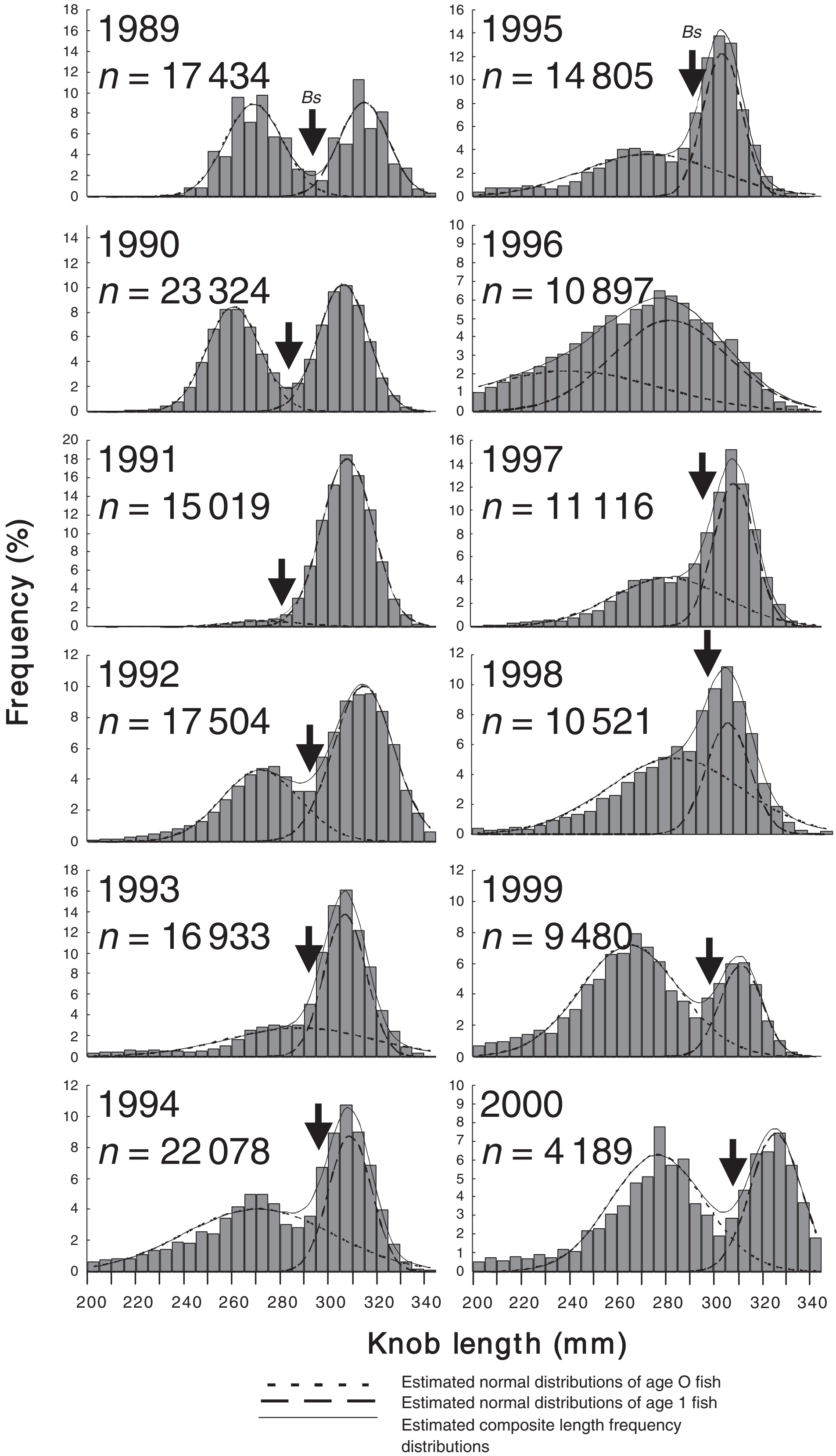

Fig. 1 Length frequency distributions of Pacific saury collected from September to November in 1989–2000. The distributions are separated into two normal distributions. Arrows indicate the intersection of the normal distribution curves (*Bs*).

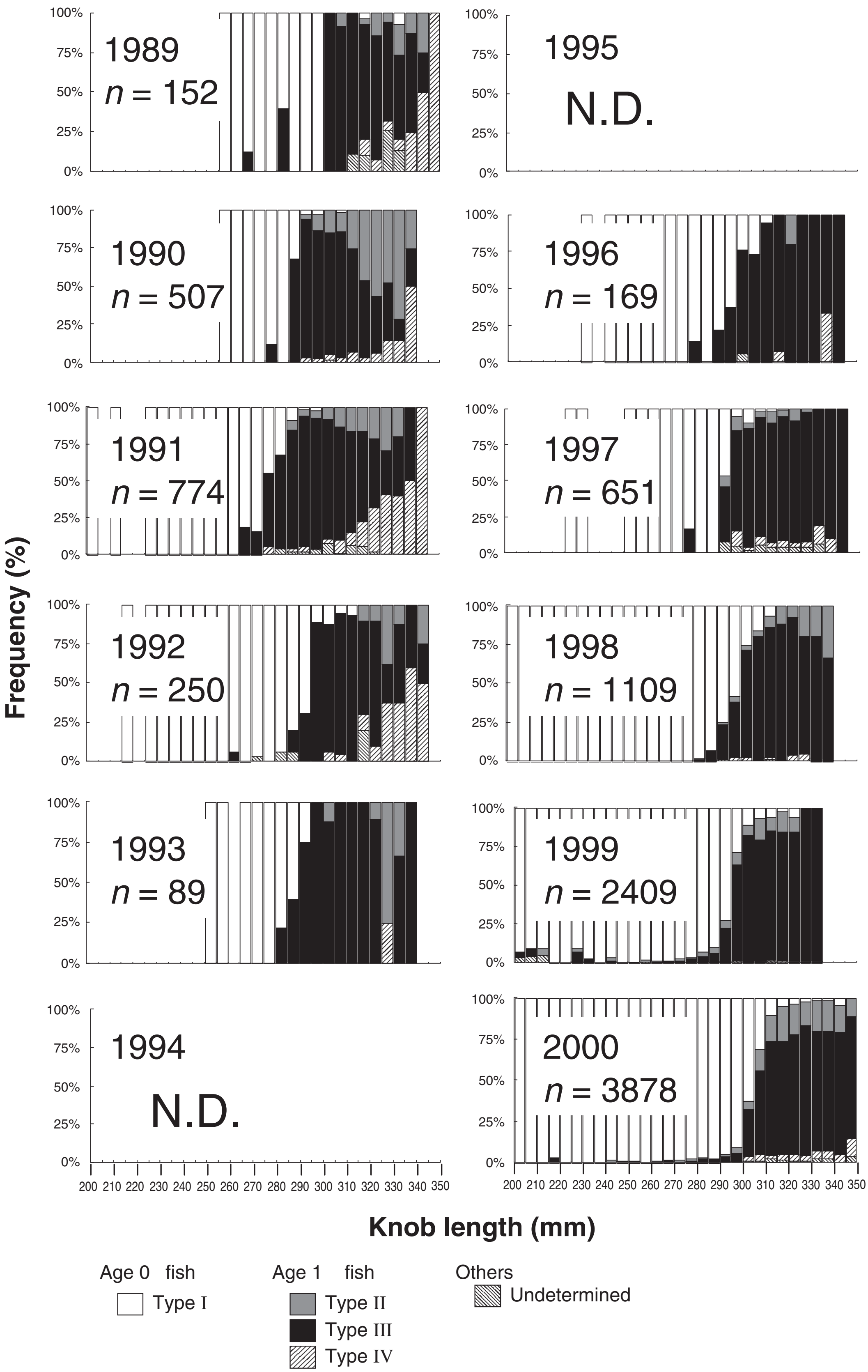

Fig. 2 Frequency of each otolith type for Pacific saury from 1989 to 2000.

Table 3 Analyses of length frequency distributions and knob lengths at which 50% of fish have a hyaline zone

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Otolith hyaline zone												
No. of fish	152	507	774	250	89	0	0	169	651	1 109	2409	3738
L_{50}†	293.4	286.4	277.8	293.8	288.4			294.3	291.7	298.5	295.1	304.7
α‡	–0.2	–0.6	–0.2	–0.4	–0.3			–0.2	–0.9	–0.2	–0.3	–0.3
β‡	44.8	168.4	58.8	121.2	84.1			58.8	259.6	63.6	87.1	83.5
L_{75}-L_{25}	14.4	3.7	10.4	5.3	7.5			11.0	2.5	10.3	7.4	8.0
Length frequency												
Total no. of samples	17 434	23 324	15 019	17 504	16 933	22 078	14 805	10 897	11 116	10 521	9480	4169
Age 0 group												
Estimated percentage of fish	53.6	47.1	4.5	37.4	41.8	61.7	51.0	40.8	48.6	67.7	74.8	61.5
Mean knob length	269.2	260.6	273.9	271.9	288.5	270.8	273.4	239.7	281.6	286.4	265.2	276.8
Standard deviation	11.9	11.1	14.3	16.2	30.3	30.6	27.8	37.4	23.2	26.8	20.8	19.6
Age 1 group												
Estimated percentage of fish	46.4	52.9	95.5	62.6	58.2	38.3	49.0	59.2	51.4	32.3	25.2	38.5
Mean knob length	315.0	306.3	308.0	314.8	307.1	309.2	303.9	281.9	308.9	308.0	311.4	325.9
Standard deviation	10.2	10.2	10.6	12.5	8.5	8.7	7.9	24.2	8.3	8.7	8.5	10.4
Bs§	293.8	283.9	280.2	292.6	291.8	296.2	290.6	250.3	295.6	299.3	298.7	308.2

L_{75} and L_{25}, estimated lengths at which 75% and 25% of the fish have one or two hyaline zones, respectively. L_{75}-L_{25}, L_{75} minus L_{25} (Fig. 1).
†Estimated length at which 50% of fish have a hyaline zone.
‡Parameters for the logistic percentage curves: percentage = $1/(1 + \exp(\alpha L + \beta))$. L: Knob length (Kimura[14]).
§Intersection between the estimated normal distribution curves of age 0 and age 1 groups.

Table 4 Percentages of each otolith type in age 1 fish

Year	1989	1990	1991	1992	1993	1996	1997	1998	1999	2000
Percentage of type II otoliths	9.6	23.6	12.5	6.6	10.3	2.3	6.0	7.9	14.0	19.0
Percentage of type III otoliths	79.8	71.6	76.4	79.2	87.9	95.3	89.4	90.6	85.7	76.8
Percentage of type IV otoliths	10.6	4.8	11.1	14.2	1.7	2.3	4.6	1.5	0.4	4.2
Total no. of age 1 fish	104	458	632	106	58	86	568	342	565	1515

Detailed classification of otolith types in Suyama and Sakurai.[11]

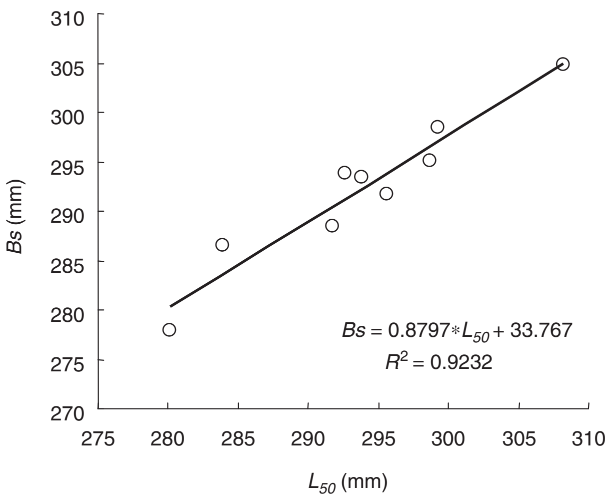

Fig. 3 Relationship between L_{50} and *Bs* from 1989 to 2000. L_{50} is the size of the boundary between age 0 and age 1 groups estimated from otoliths, while *Bs* is the size of the boundary estimated from length frequency distributions.

0.8797 ($R^2 = 0.9232$). Therefore, *Bs* correlated well with L_{50}. There did not appear to be a clear relationship between the rate of each otolith type and the modal length of age 1 fish. For example, in 2000, when the modal length of the age 1 fish was largest (324.8 mm), type III otoliths were dominant (76.8%) among these fish, while in 1990, when the ratio of type III otoliths was lowest, the modal length was similar at 306.3 mm (Fig. 3, Table 4).

DISCUSSION

Our results indicated that Pacific saury caught in the fishing season consisted of two age classes. Each age group showed a clear normal distribution. Age 0 fish are regarded as mainly having hatched during the previous spawning season, specifically from autumn of the previous year to spring of the current year,[8,12] while age 1 fish must have predominantly hatched from autumn 2 years previously to the spring of the previous year.

Since the boundary length between age 0 and 1 groups (L_{50}) fluctuated from year to year, it is necessary to investigate L_{50} in a given year. As the length of *Bs* was close to L_{50}, *Bs* could be used as a substitute for L_{50}, except for years in which the length frequency distributions do not show two clear normal distributions, such as 1996. However, the length frequency distributions of the fish caught by fishing boats may be biased within a fishing season. Therefore, *Bs* is only be used if L_{50} is not available.

Pacific saury caught during the fishing season have previously been divided into either three or four length groups.[2,3] The length of 290 mm that has been used to separate the large- and medium-sized groups was close to the average length of L_{50} in the present study. The large-sized group is considered to almost correspond to the age 1 fish group, while the medium- and small-sized groups almost correspond to the age 0 fish group.

Sugama[9,10] concluded that type I medium-sized fish become type II extra-large-sized fish the following year. Our results refute this conclusion because most of the extra-large-sized fish were type III. Although type IV otoliths possibly indicate the presence of an age 2 fish (the individuals that overwintered once again after the first hyaline zone had formed), we do not consider that all fish with type IV otoliths had survived for more than 2 years, since Suyama and Sakurai[11] pointed out the possibility that a second hyaline zone may form not only during the winter but also during other seasons. Further, although some otoliths possessed more than three hyaline zones, it is not believed that the ages of such fish were more than 3 years. Since the hyaline deposition appeared to become unstable after the formation of the first hyaline zone, it is concluded that the second and third hyaline zones could not reliably be used as annual rings.

The modal length of age 0 fish was estimated to range 239.7–288.5 mm in the present study. However, Sugama[9] and Hotta[3] estimated the length at which the hyaline zone started to form was 220–230 mm, and approximately 170 mm, respectively. These lengths indicate the lengths of age 0 fish. The length frequency distributions of age 0 fish caught by fishing boats may be larger than the real length frequency distributions because of size selectivity.

Our results revealed that Pacific saury consists of only two year-classes. An abundance of age 0 fish would indicate an abundance of age 1 fish in the subsequent year. If the exact abundance of age 0 fish can be determined, the abundance of age 1 fish can be predicted for the next year. Therefore, investigating the abundance of age 0 fish using methods that avoid size selection is now very important.

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