

GROWTH OF PACIFIC SAURY, *COLOLABIS SAIRA*, IN THE NORTHEASTERN AND NORTHWESTERN PACIFIC OCEAN¹

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ABSTRACT

Growth of the Pacific saury, *Cololabis saira*, from the northeastern and northwestern Pacific Ocean was studied using otolith growth increments. We found that growth of Pacific sauries from the western Pacific was higher than that from the eastern Pacific. Assuming that otolith growth increments are deposited daily, average growth rates from hatching up to 1 year old were 0.62 mm/d in the eastern and 0.85 mm/d in the western Pacific. Because the growth rate changes at around 100 mm, two curves were used to model the growth of Pacific saury in the western Pacific: one for fish up to 100 mm and the other for fish larger than 100 mm. Based on counts of daily increments, Pacific sauries may be short lived. The oldest specimen examined was only 14 months old.

The Pacific saury, *Cololabis saira* (Brevoort), is distributed throughout the North Pacific Ocean and is one of the most important commercial fishes in the northwestern Pacific. The average annual catch of Pacific saury in Japan has been approximately 200,000 t (metric tons) in the last 20 years (Statistics and Information Department, Japan 1985). The catch has varied by an order of magnitude in the last 20 years from a minimum of 63,000 t in 1969 to a maximum of 406,000 t in 1973. Fluctuation in stock size is a major factor in catch variability although economic factors such as fish price may also affect total landings. However, the causes of stock fluctuation in the western Pacific remain unknown. In the eastern Pacific, the Pacific saury has not been exploited but is recognized as a potential fishery resource (Ahlstrom 1968; Smith et al. 1970).

Investigations of the Pacific saury have mainly been devoted to such subjects as systematics, abundance, distribution, migration, and formation of fishing ground in relation to oceanographic conditions (e.g., Hubbs and Wisner 1980; Smith et al. 1970; Odate 1977; Fukushima 1979; Sablin and Pavlychev 1982; Gong 1984). Age determination and growth, however, remain controversial (Hatanaka 1955; Hotta 1960; Novikov 1960; Sunada 1974; Kim

and Park 1981), notwithstanding their critical importance for fish stock assessment.

The discovery of daily increments in the otoliths of fishes (Pannella 1971) has made it possible to estimate age and growth of larval and juvenile fishes accurately. Daily increments have been used to age many species of fishes (Jones 1986). Nishimura et al. (1985) reported the presence of growth increments in Pacific saury otoliths observed by scanning electron microscopy and suggested that it is possible to estimate age and growth of Pacific saury by using daily increments in the otolith. The purpose of this paper is to determine the age of Pacific sauries from the eastern and western North Pacific using daily increments and to compare the growth rates in these areas.

MATERIALS AND METHODS

We read otoliths of 75 Pacific sauries from the northeastern and 172 from the northwestern Pacific Ocean. Details of sampling and methods of reading otoliths are summarized in Table 1 and Figure 1. Additional samples from the western Pacific were used to determine the relation between otolith size and fish length. Fish from the eastern Pacific were fixed and preserved in 80% alcohol after capture, and those from the western Pacific were stored frozen and thawed when processed. Because specimens frequently have damaged upper jaws, knob length (the distance from the tip of the lower jaw to the posterior end of the muscular knob at the base of a caudal peduncle) is the standard measure of body size in Pacific saury. All body lengths in this paper are knob length.

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TABLE 1.—Collection records of saury samples from the eastern (# 1–10) and the western (# 11–22) North Pacific. N = Neuston net; G = Gill net; D = Dip net.

Sample	Date	Location		No.	Size range (Knl mm)	Gear	Microscope
		Lat.	Long.				
1	80 06 29	36°02'N	124°04'W	10	19.8–109.0	N	LM
2	80 06 29	36°07'N	123°55'W	10	19.8– 66.0	N	LM
3	80 06 29	36°07'N	123°45'W	10	15.3– 96.0	N	LM
4	81 10 26	46°36'N	127°49'W	5	47.8–235.0	N	LM
5	81 10 27	47°19'N	126°09'W	6	38.0–142.0	N	LM
6	81 10 28	47°20'N	124°30'W	12	23.9–216.0	N	LM
7	81 10 29	46°21'N	127°38'W	1	209.0	N	LM
8	81 10 30	46°38'N	125°54'W	14	20.6– 85.0	N	LM
9	81 11 01	45°21'N	127°38'W	4	27.0– 71.0	N	LM
10	81 11 02	45°38'N	124°51'W	3	70.0–206.0	N	LM
11	84 05 26	37°01'N	164°02'E	19	145.0–230.0	G	SEM
12	84 06 02	37°00'N	158°00'E	114	38.0–125.0	N	SEM
13	84 07 16	42°00'N	172°00'E	7	213.0–282.0	G	SEM
14	84 10 06	43°09'N	153°14'E	5	300.0–330.0	D	SEM
15	85 05 20	36°00'N	150°00'E	3	21.0– 69.5	N	LM
16	85 05 21	38°15'N	149°59'E	2	8.3– 12.5	N	LM
17	85 05 23	38°30'N	152°00'E	2	26.5– 45.5	N	LM
18	85 05 24	38°00'N	152°00'E	9	29.0– 85.0	N	LM
19	85 05 29	38°45'N	156°00'E	3	16.0– 33.5	N	LM
20	85 05 29	38°30'N	156°00'E	2	27.0– 33.0	N	LM
21	85 05 29	38°15'N	156°00'E	3	24.6– 65.0	N	LM
22	85 05 30	38°00'N	156°00'E	3	31.5– 68.5	N	LM

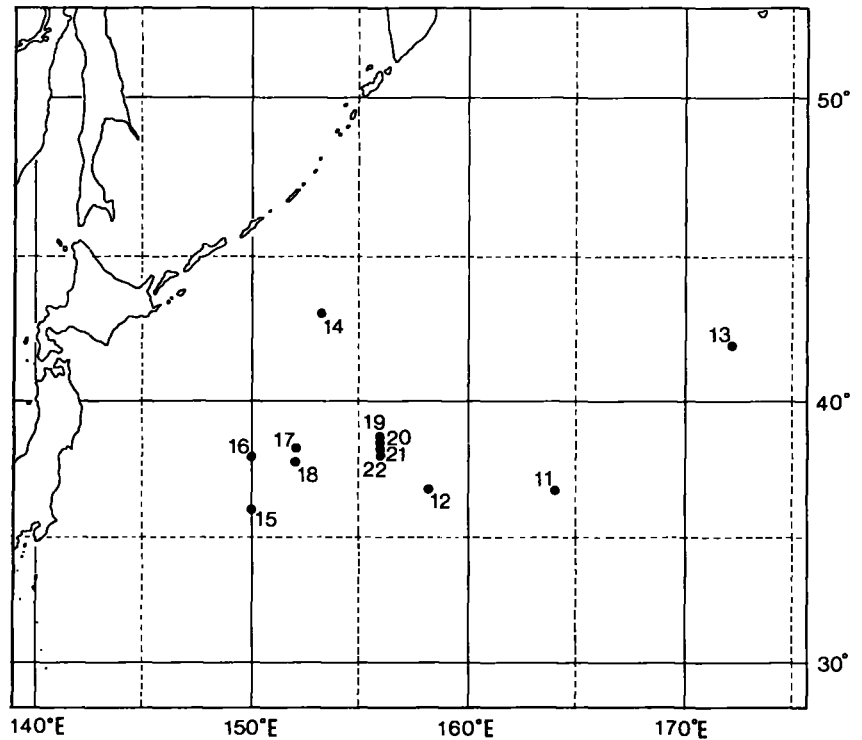
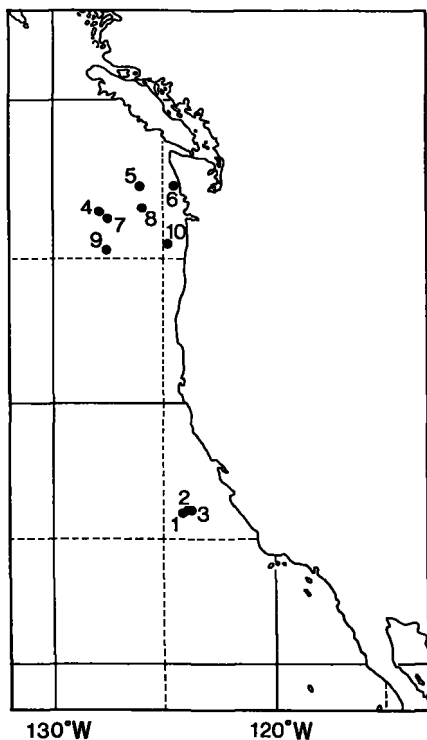


FIGURE 1.—Locations of Pacific saury collection in the North Pacific. Figures by

Sagittae were dissected out from fish and left to dry after removing tissues and membranes. We used a dissecting microscope with a polarizing filter to dissect otoliths from small larvae and juveniles. The otoliths were read either by light microscopy (LM) or by scanning electron microscopy (SEM). Otoliths that were to be read by LM were mounted in EUKITT⁵ after dissection. Otolith radius was measured from the focus to posterior margin and the increments were counted along the same transect using the otolith reading system, which was developed by the Southwest Fisheries Center of the National Marine Fisheries Service, NOAA, and which consists of a light microscope, a video monitor, a micro-computer, and a digitizer (Methot 1981).

For SEM, otoliths were mounted in epoxy or methacrylate resin. The otolith radius was measured from the focus to the posterior margin with an

⁵Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.



dots indicate sample numbers in Table 1.

optical comparator. The otoliths were ground oblique to the sagittal plane parallel to the long axis of the otolith in order to have a flat plane through the otolith nucleus. The polished surface was washed in xylene, using an ultrasonic washer, then dried and etched for 50 seconds with 0.2M EDTA-2Na (disodium ethylenediaminetetraacetic acid). The etched surface was coated with palladium platinum and observed under an SEM (JSM-25) at 15 kV.

The three authors of this paper read saury otoliths independently: the senior author read fish from the western Pacific up to 85 mm by LM, the second author read otoliths from the eastern Pacific by LM, and the third read otoliths from the western Pacific larger than 38 mm by SEM. To confirm that we were all interpreting the same structure as growth rings by SEM and LM, we compared 50 data points read by SEM and 14 points read by LM for western Pacific sauries between 38 and 85 mm. The distribution of increment number versus knob length was the same. We also checked for possible biases for the two readers using LM by having each read the same set of otoliths independently.

RESULTS

The nucleus of a Pacific saury sagitta is approximately 20 μm in diameter and is composed of four to six small dense bodies which appear to be assemblages of calcareous spherules (Fig. 2a). These dense bodies are separated from one another and each is surrounded by a small concentric ring.

We observed the nucleus areas of otoliths from Pacific sauries collected in the western Pacific in 1985 (sample # 15-22) and found that most of them had a distinct ring of about 27 μm in radius. Between the nucleus and this distinct ring, four (or five) indistinct growth rings were detected (Fig. 2b).

We measured knob lengths of 27 larval and juvenile Pacific sauries before freezing and after thawing, and found that the ratio of these two measurements was 0.997. There was virtually no shrinkage by freezing and thawing. Theilacker (1980) found that preservation of larval northern anchovy, *Engraulis mordax*, in 80% alcohol did not cause additional shrinkage of the body after net treatment. Thus, knob lengths after both 80% alcohol preservation and freezing are comparable to each other, and this measurement corresponds to the size after net treatment. Since shrinkage factors by net treatment are not known for the saury, lengths are uncorrected for net shrinkage.

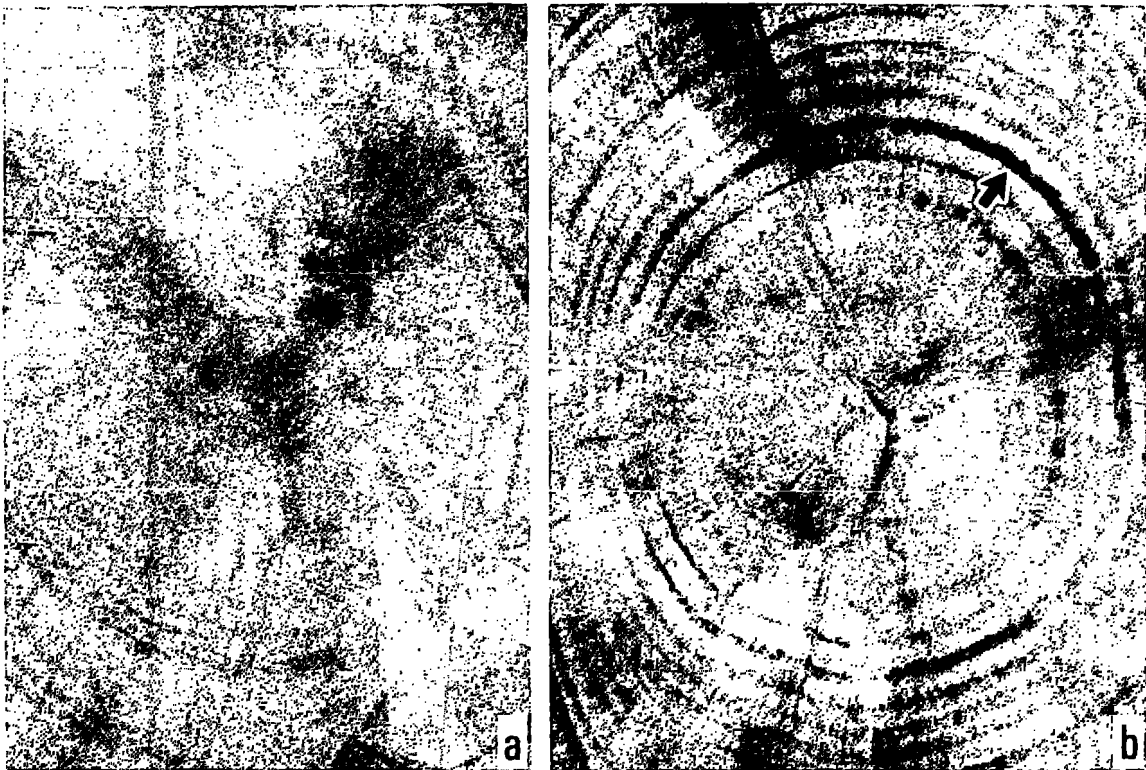


FIGURE 2.—Light micrographs of Pacific saury sagittae. a) Otolith nucleus composed of 5 or 6 separate dense bodies with surrounding cores. b) Assumed 4 embryonic and 1 hatching (arrow) rings.

The daily periodicity of growth increment formation in the Pacific saury has not been verified. For that reason we plotted the number of increments versus knob length instead of age versus length. We used the Laird-Gompertz equation to describe the relations of increment number and length as growth curves for both the eastern and western Pacific saury. Hatching size of artificially fertilized and incubated Pacific saury from the western Pacific was reported to be 7.19 mm in average live total length (Yusa 1960). From the drawing of a newly hatched larva in Yusa's paper, we estimated live knob length to be 6.60 mm. Shrinkage factors of northern anchovy in the size range from 6.00 to 7.99 mm were 0.88 for a 5-min net treatment and 0.85 for a 10-min net treatment (Theilacker 1980). Using these values, the capture size of a newly hatched larva of Pacific saury after a 5-min net treatment was estimated to be 5.95 mm and a 10-min treatment to be 5.61 mm. We fixed the hatching size from 5.85 to 5.95 mm in the growth curve, because the Pacific saury larvae at this size are in a more advanced develop-

mental stage and shrank less by net treatment than northern anchovy.

The resulting growth equation for the eastern Pacific saury was

$$KnL = 5.85 \exp((0.0427/0.115)(1 - e^{(-0.0115(I-5)}))$$

and the equation for the western Pacific saury was

$$KnL = 5.95 \exp((0.0504/0.0128)(1 - e^{(-0.0128(I-5)}))$$

where KnL is a knob length in mm and I is the total number of increments observed in an otolith. The term, $I - 5$, indicates that five increments were presumed to have been present at hatching. Data from the western Pacific saury appear to consist of two curves separated around 100 mm in KnL . Two Laird-Gompertz curves fit much better than one curve. The intersection of the two curves was at 114 increments and 100 mm. The growth equation for fish smaller than 100 mm was

$$KnL = 5.90 \exp((0.0865/0.0293)(1 - e^{(-0.0293(I-5)}))$$

and for fish larger than 100 mm KnL was

$$KnL = 3.01 \exp((0.0592/0.0126)(1 - e^{(-0.0126(I-5)}))$$

The estimated mean square error, 215.7, of the two curves was smaller than that for a single curve, 351.7. The two-curve model fits much better for the smaller size range up to 100 mm. The estimated mean square error of the two-curve model for this size range, 75.7, was much smaller than that of the one-curve model, 240.8.

The growth rate of Pacific saury in the eastern Pacific was slower than that in the western Pacific (Figs. 3, 4). The knob length of saury in the eastern Pacific would be about 75 mm at 100 rings, 170 mm at 200 rings, and 220 mm at 300 rings, whereas in the western Pacific knob length would be about 100 mm at 100 rings, 230 mm at 200 rings, and 300 mm at 300 rings. Assuming that the rings are formed daily, overall growth rates of the first one year of their life were 0.62 mm/d and 0.85 mm/d for

the eastern and western Pacific Ocean, respectively.

The largest specimen examined was 330 mm from the western Pacific, which had 328 increments, and the oldest fish, also from the western Pacific, which measured 320 mm, had only 418 increments. These fish would be classified as very large or large by Novikov's categories of fish size composition (Novikov 1960, 1973). The largest fish examined from the eastern Pacific was 235 mm and had 241 increments. Hughes (1974), however, reported larger fish from the eastern Pacific.

In Pacific saury from the western Pacific, the relation between otolith radius in μm (OR) and knob length in mm (KnL) was linear on logarithm-logarithm coordinates (Fig. 5). The equation computed by the geometric mean regression (Ricker 1973) was

$$\ln(OR) = 2.33 + 0.749 \ln(KnL) \quad (r = 0.979).$$

The otolith radius at hatching (5.9 mm KnL) calculated by this formula was $38.9 \mu\text{m}$, which was $12 \mu\text{m}$ larger than the radius of the presumed hatching ring.

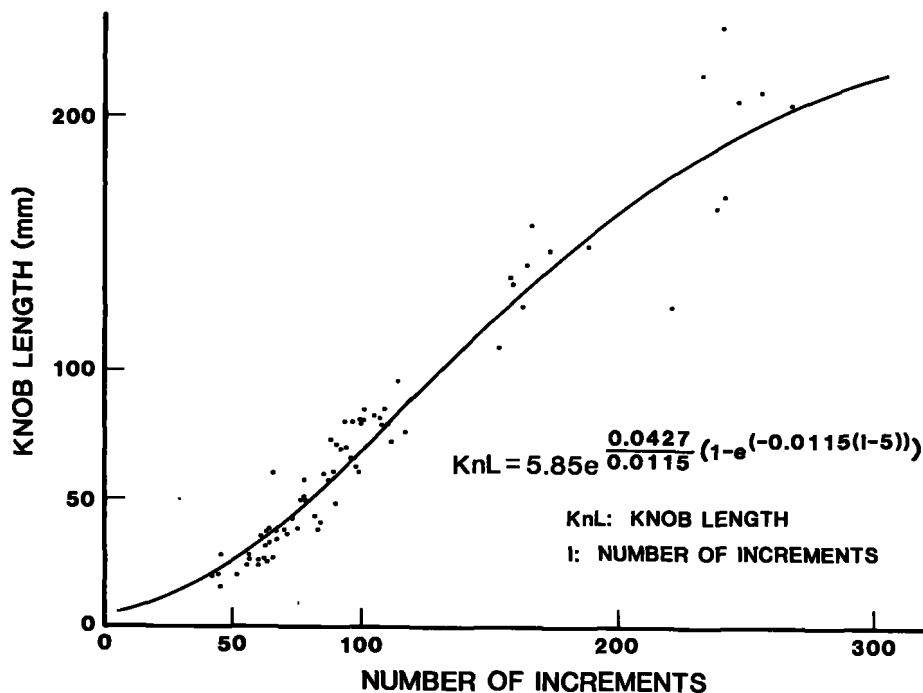


FIGURE 3.—Growth curve of the eastern Pacific saury.

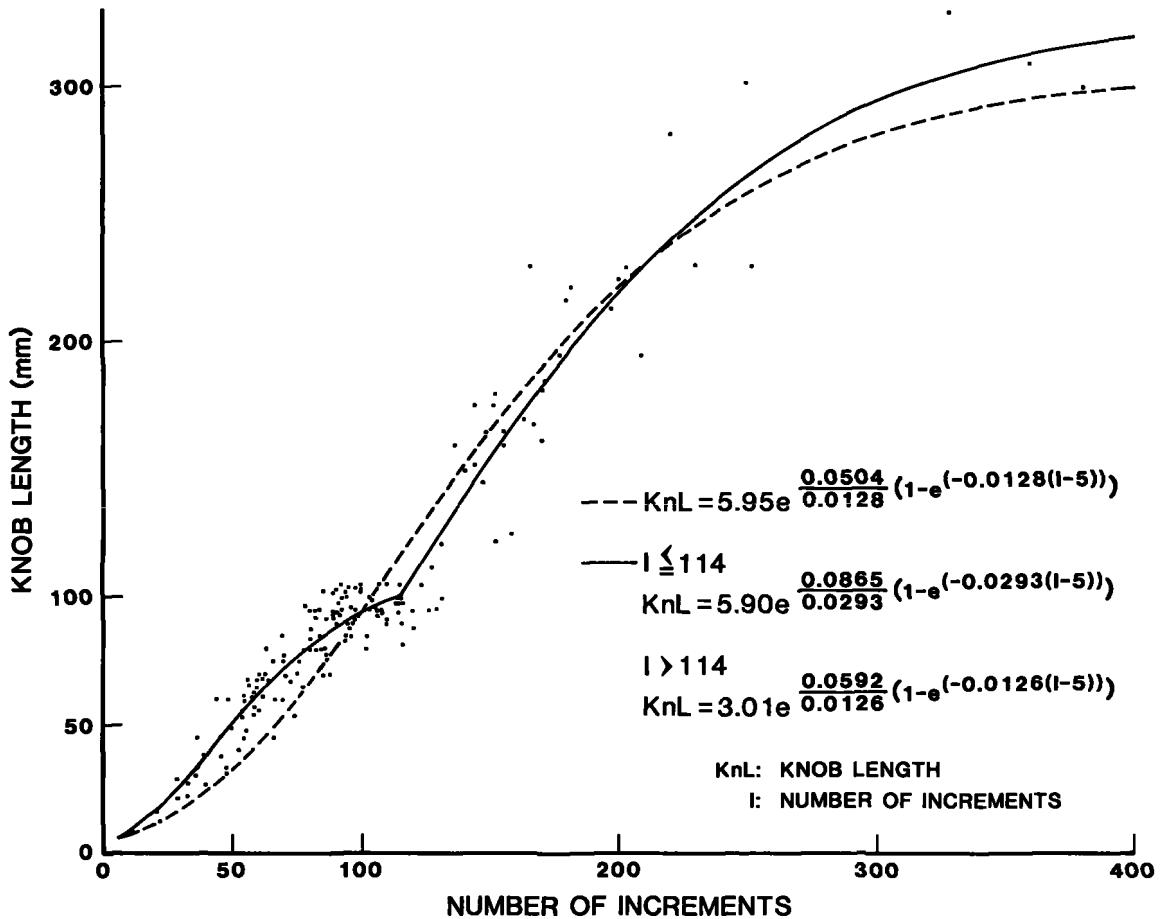


FIGURE 4.—Growth curve of the western Pacific saury.

DISCUSSION

The microstructure of otolith growth increments of the Pacific saury is similar to that of daily increments in some other fishes (Nishimura et al. 1985). Thus, the following discussion is based on the assumption that the increments are daily growth rings. A rearing experiment of larval sauries is under way in the senior author's laboratory to verify daily periodicity of the increment formation.

Formation of a few embryonic growth rings or a lamellar structure has been reported in California grunion, *Leuresthes tenuis*, (Brothers et al. 1976); mummichog, *Fundulus heteroclitus*, (Radtke and Dean 1982); and walleye pollock, *Theragra chalcogramma*, (Nishimura and Yamada 1984). Radtke and Dean (1982) mentioned that deposition of growth rings in the embryonic stage might be

related to a long incubation period. Pacific saury has a long incubation period—about 17 days under 13.5°–15.7°C (Yusa 1960). At this temperature, eye pigmentation begins 7 or 8 days before hatching, and pectoral fins show constant movement from 5 or 6 days before hatching (Yusa 1960). Notochord flexion occurs about midway through embryonic development at 14°–22°C (Uchida et al. 1958). Thus saury is more advanced at hatching than killifish based on the embryonic development of killifish reported by Armstrong and Child (1965). Observing the central area of otoliths, we found four faint rings and a dark ring immediately outside of those rings. We assumed therefore that the four faint rings are embryonic rings and the dark ring is the hatching ring. This assumption may be confirmed by examining otoliths of late embryos and newly hatched larvae of saury.

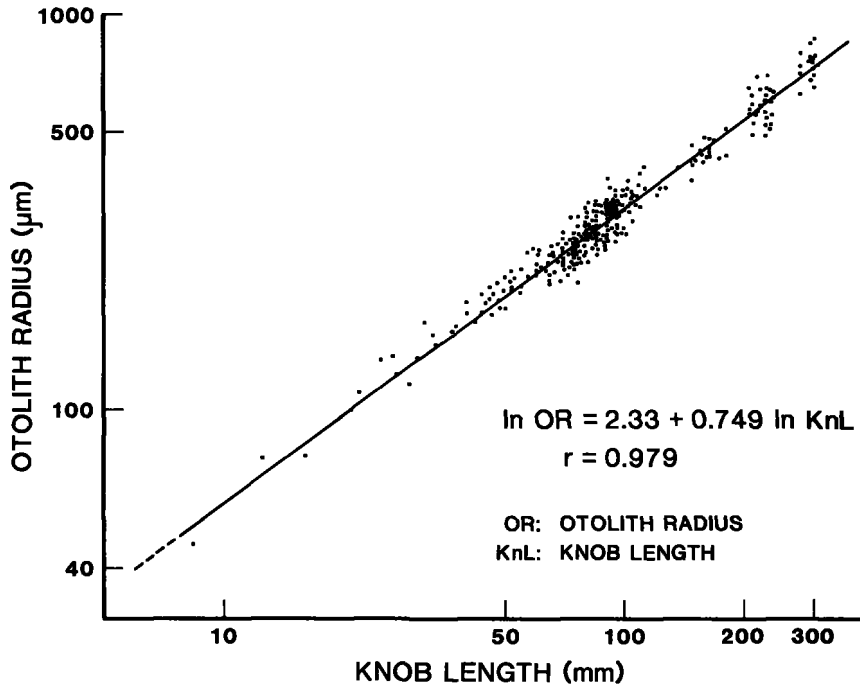


FIGURE 5.—Knob length and otolith radius relationship of the western Pacific saury.

Previous studies on age and growth of the Pacific saury have based on annuli on scales and/or otoliths. Sunada (1974) found five age groups in Pacific sauries off southern Oregon, California, and Baja California. Mean fork lengths of age groups were 171, 220, 246, 270, and 268 mm for age 0, 1, 2, 3, and 4, respectively. Hughes (1974) examined age composition of 5,248 sauries collected in waters off California up to Vancouver Island. He found spring- and autumn-born fish in his samples, but little difference was noted in growth rates between two groups. Approximate knob lengths of 1.0- to 5.0-year-old fish were 180, 230, 255, 290, 310 mm. The growth rates given in these two papers are not very much different. The saury grows at 0.5–0.6 mm/d up to 1 year old, which is almost equal to our growth rate in the eastern Pacific, 0.62 mm/d. Hatanaka (1955) found five age groups in the western population of the saury, 0–4 years old, and estimated mean body length of age groups to be 80, 160, 230, 265 mm for 1- to 4-year-old fish, respectively. Novikov (1960, 1973) divided sauries captured in autumn into five size groups, very small (<200 mm), small (201–240), medium (241–290), large (291–320), and very large (321+), and assigned the small, medium, and large

to 1-, 2-, and 3-year-old with maximum 5-year-old fish.

A different model of Pacific saury growth in the western Pacific was proposed by Hotta (1960) based upon a hypothesis of two subpopulations. He separated the saury into spring-spawning and autumn-spawning populations based upon the observations of fish size composition, scales, otoliths, and numbers of vertebrae. He assigned four ages of half year intervals, 1.0, 1.5, 2.0, 2.5 years old, to fish 210–240, 260–280, 290–300, and 310–330 mm, respectively. The growth rate up to 1 year was 0.6–0.7 mm/d. Kim and Park (1981) examined Pacific sauries from Korean waters and found four size groups of four different ages of half-year intervals as well. They presented two growth models for each of two subpopulations, spring and autumn spawning, based upon the von Bertalanffy equation. The sizes at ages were almost identical to those of Hotta (1960). However, the hypothesis of two saury subpopulations in the western Pacific is not supported by electrophoretic analyses of genetic separation (Numachi 1971; Hara et al. 1982).

The average growth rate of the western Pacific saury in this paper was 1.1 mm/d from 0 to 8 or

9 months old. It was still faster than Novikov's growth rate of the corresponding age period (0.83 mm/d), which was the highest rate of all the previous reports. The fish would become 316 mm in one year according to our model.

Support for the fast growth rate of Pacific saury presented in this paper in the western Pacific can be found in rearing experiments. Hotta (1958) reared young sauries caught by a set net. He reared them in a crawl and fed them minced anchovy and mackerel twice a day. Young sauries 116 mm in mean length became 172 mm in the rearing period after 72 days. The growth rate was 0.78 mm/d. The sauries fed three times a day grew 130–143% faster than the group fed twice a day. Thus growth rates of young sauries may be higher than 1.1 mm/d (0.78×1.4 mm/d) when food is readily available. Our growth rate of sauries in this size range was approximately 1.5 mm/d in the western Pacific. For Atlantic saury, *Scorpaenopsis scorpaenoides*, reared by Brownell (1983), the average growth rate of the larvae was 0.62 mm/d from hatching (7.5 mm SL) to 47-day old (36.8 mm SL). The growth rates of *Cololabis saira* in a corresponding period were 0.48 mm/d in the eastern Pacific and 1.0 mm/d in the western Pacific.

Our results indicate that the growth rate of Pacific saury in the western Pacific is much higher than in the eastern Pacific. This could be due to a difference in food availability between the two areas. However, mean zooplankton standing stock in 1951–66 was 34.8 g/m² in the California Current region in June (Smith and Eppley 1982), whereas that of Kuroshio water off southern Japan was 4.7 g/m² and of Oyashio area off northern Japan was 25.7 g/m² in May to July (Odate 1986). Thus, differences in zooplankton standing stock do not explain the difference in growth rates.

On the other hand, there seems to be a reasonable explanation for the reacceleration of growth rate at around 100 mm in the western Pacific saury. The western sauries hatch out mainly in offshore water of the Kuroshio Current (lat. 31–33°N) off Japan in winter. They migrate north to the Oyashio area (up to 46–50°N) where copepods are highly available. Young and adult sauries feed actively and gain fat. They are in the northward migration stage in early summer when they are about 100 mm, and are moving from poor Kuroshio water to rich Oyashio water (Fukushima 1979). High zooplankton standing stock in the Oyashio water and its derivatives might be responsible for the reacceleration of growth rate in fish older than 100 days.

The growth rates of Pacific saury in the western

Pacific may differ from year-to-year due to environmental factors and may result in changes in size composition of the fish. Between 1968 and 1972, mean knob length of exploited sauries in the western Pacific was 170–250 mm, whereas in the 1980's the major mode in the size composition was 290–310 mm (S. Kosaka⁶). This increase could have been due to an acceleration of growth rate or a shift of spawning season to early months or both in recent years. The high growth rate of western Pacific saury presented in this paper has come from specimens collected in 1984 and 1985. The growth rate in the late 1960's and early 1970's may have been lower than that presented in this paper. Investigation of the interannual variation in growth rates using daily increments would distinguish between these two hypotheses.

We used three different gears to collect Pacific saury samples in the western Pacific. Knob lengths of sauries collected were from 8.3 to 125 mm by ring net, 145 to 282 mm by gill net, and 300 to 330 mm by stick-held dip net. Sauries of 125–145 mm might not be available either to the ring net or to the gill net. Further, the ring net may select small juveniles of a cohort in the size range over 100 mm, and this may have produced the two growth curves. This problem needs to be examined further with data on gear selectivity.

We do not know how long Pacific sauries survive after becoming adult. The oldest specimen in our sample was about 14 months old after hatching (418 increments). The largest saury aged (330 mm), which had 328 growth rings, is close to the maximum size. Although the maximum known length of the Pacific saury was reported to be about 400 mm (Hubbs and Wisner 1980), the largest fish exploited in Japan is about 340 mm. Therefore, the lifespan of the Pacific saury is about one year in the western Pacific. Our results are more consistent with those of Kosaka (1979) who found two age groups (0 and 1 year) than those (Sablin 1979) who found three age groups (0, 1, and 2 years).

In Japan, fishing efforts of the Pacific saury is regulated by fishing season as well as by the number of fishing boats. The fishing season starts in mid-August. Pacific sauries hatched in the main spawning season are about 250 days old at this time of year (approximately 270 mm) and are growing at the rate of 0.8 mm/d. Thus a 2-wk postponement at the beginning of fishing season would result in an 11 mm (10–15 g body weight) increase of average fish

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length. The biomass and yield of Pacific saury need to be reestimated based on faster growth rates presented here.

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