STOCK COMPOSITION, GROWTH, MORTALITY, AND AVAILABILITY OF PACIFIC SAURY, *COLOLABIS SAIRA*, OF THE NORTHEASTERN PACIFIC OCEAN

STEVEN E. HUGHES[1]

ABSTRACT

Recent international interest in the Pacific saury *(Cololabis saira)* resource of the northeastern Pacific Ocean prompted studies to determine the stock's composition, structure, growth, mortality, and availability.

During August-September 1969-71, data were obtained from more than 5,000 fish sampled from 19 individual schools captured between southern California and Vancouver Island, B.C. Length and age frequency distributions indicate fish grow to 340 mm in length during their 6-year lifespan. Larger fish apparently migrate farthest north and consequently age at full recruitment off Washington is III or IV, and II off Oregon. Spawning is extended over most of the year and the stock is believed homogeneous. First maturity appears to be reached during the second year. Numbers of males and females were nearly equal until age IV when females began to predominate. Length-weight regressions are presented by sex. Bertalanffy growth parameters were calculated: $K = 0.42$, $L_\infty = 342$ mm, and $t_0 = -0.72$ years. The total instantaneous mortality coefficient was estimated at 1.25-2.20.

Data on distribution and availability suggest a viable domestic fishery on this species is unlikely.

In 1969, an investigation of the distribution, availability, and biology of Pacific saury, *Cololabis saira*, in the northeastern Pacific Ocean was begun by our laboratory. This study was a direct result of a tenfold decrease in combined Japanese and Soviet landings of the species in the northwestern Pacific Ocean since 1958. Unusually high market demand created international interest in the unexploited stock in the eatern Pacific Ocean.

Initial studies were concerned primarily with the development of sampling and harvesting gears (Ellis and Hughes, 1971). This paper contains results of research on the biology and availability of saury, except for parasite studies which were treated separately (Hughes, 1973). The purpose of the paper is to provide initial information on stock composition, growth, and mortality and to supplement previous studies of distribution and abundance. Data were obtained during research vessel surveys, conducted primarily during August and September 1969 off the California coast, and during August and September 1970 and 1971 off the Washington and Oregon coasts.

STATUS OF KNOWLEDGE

Parin (1960) reported that the Pacific saury inhabits the northern Pacific pelagic zone and has a continuous range from Asia to North America. Sokolovskii (1969) inferred from studies of parasites and biological and morphometric characteristics of the species that there exist within its total range, stocks distinguishable from one another—western (Asian), central (Aleutian), and eastern (American)—that there is no clear boundary between these stocks, and that there are rather wide zones of mixture of the stocks. The eastern stock ranges from Baja California to the Gulf of Alaska (Ahlstrom and Casey, 1956; Clemens and Wilby, 1961). Novikov and Kulikov (1966) found that in the eastern Pacific Ocean, saury occupied an extensive coastal region 50-70 miles wide between lat. 41° and 48°N during August-October, but that major concentrations were irregularly distributed. Their survey indicated the most dense aggregations occurred off southern Oregon during August, October,

[1] Northwest Fisheries Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Manuscript accepted July 1973.

and November in water temperatures of 12.5 to 13.5°C. Data obtained from night-light station observations off California indicated that in the California Cooperative Oceanic Fisheries Investigations area saury occurred most frequently in waters north of San Francisco in a band 40-120 miles offshore (Smith, Ahlstrom, and Casey, 1970). Peak availability occurred during November. Results of egg surveys suggested peak spawning activity occurs off California during April, May, and June and that the standing stock in the eastern North Pacific Ocean was at least 450,000 to 500,000 tons (Ahlstrom, 1968; Smith et al., 1970).

METHODS

The method of finding schools of Pacific saury was similar to procedures employed by commercial Japanese saury vessels. The Japanese technique has been reviewed by Inoue and Hughes (1971). The Japanese use artificial lights during hours of darkness to visually locate schools near the surface and to attract the fish alongside the vessel for eventual capture. Sonar was also used to assist in detecting concentrations during 1970 and 1971. Our surveys were generally restricted to areas where surface water temperatures were between 13° and 17°C. Typically, they were conducted along a zig-zag track designed to cross boundaries between warm and cold water masses. Once detected and concentrated under the vessel's alluring lights, the total weight of each school was derived by estimating the percentage of the school captured, weighing our catch, and then computing the weight of the remaining fish.

During 1969, surveying was confined to waters off California and fishing was conducted with a Japanese-style boke-ami (Andreev, 1962). Operations were conducted off the Washington and Oregon coasts in 1970 and extended to include waters off Vancouver Island, B.C., during 1971. During those periods fishing was conducted with a small purse seine designed for capturing saury (Ellis and Hughes, 1971).

Table 1 summarizes times and locations where fishing was conducted and samples retained for biological studies. Catches were randomly subsampled aboard ship. All samples collected were returned to the laboratory for processing. Samples taken in 1969 were iced, whereas those collected in 1970 and 1971 were frozen. Only length frequency data were taken from the 1969 samples. Biological data from individual fish obtained during 1970 and 1971 included knob length[2] measured to the nearest millimeter, body weight to the nearest gram, sex, and maturity. Scales were removed for later examination.

Sex determination of fish measuring less than 230 mm was generally difficult. When gross examination of gonads proved inadequate, samples were further subsampled—the gonads cross-sectioned and examined for the presence of a lumen under 10× binocular microscopes.

Age was determined from plastic impressions of scales (Clutter and Whitesel, 1956) examined with a microprojector device (Mosher, 1950). Age determination of Pacific saury has long been a point of contention between Soviet and Japanese scientists working in the western Pacific (Kotova, 1958; Hotta, 1960). Details of assessment criteria by which ages were determined for this report have been documented by Mosher.[3]

TABLE 1.—Fishing areas and number of Pacific saury collected, 1969-1971.

Date	Coastal area	Location		Sample size
		W Long	N Lat	
Aug 1969	Calif.	124°03′	37°49′	220
Aug 1969	Calif.	124°03′	37°51′	222
Aug 1969	Calif.	124°03′	37°53′	143
Aug 1969	Calif.	123°59′	37°55′	52
Aug 1969	Calif.	123°48′	37°58′	31
Sept 1969	Calif.	122°23′	36°10′	160
Sept 1970	Oreg.	125°50′	45°03′	299
Sept 1970	Oreg.	125°11′	44°33′	300
Sept 1970	Oreg.	125°08′	44°30′	300
Sept 1970	Wash.	126°02′	47°43′	284
Sept 1970	Wash.	125°58′	47°41′	192
Sept 1970	Wash.	126°00′	47°39′	191
*July 1971	Calif.	120°00′	33°00′	98
Aug 1971	Van. Isl.	127°06′	49°16′	105
Aug 1971	Wash.	126°04′	48°21′	512
Sept 1971	Oreg.	125°01′	44°01′	506
Sept 1971	Oreg.	124°59′	43°55′	508
Sept 1971	Oreg.	125°00′	43°54′	508
Sept 1971	Oreg.	125°02′	44°02′	268
Sept 1971	Oreg.	125°04′	43°58′	419
			Total	5,248

* Sample captured with variable mesh gillnet. This sample used only in the growth analysis.

[2] Knob length (Kimura, 1956)—the distance between the tip of the lower jaw and the posterior end of the muscular knob on the caudal base—has been accepted internationally as the unit of length measurement for saury.

[3] K. H. Mosher. Age determination of eastern Pacific saury using scales. Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Northwest Fish. Center, Seattle, Wash. Unpubl. manuscr.

Preliminary scale studies indicated that the samples might be of two races of fish with different growth patterns—those with a wide zone of initial growth (distance between the focus and first annulus) and those with a much narrower zone of initial growth. Similar growth patterns have been detected by Japanese scientists on scales of fish of the western stock of Pacific saury and interpreted as distinct spring- and autumn-born "subpopulations" (Hotta, 1960). Accordingly, fish were classified as being either spring-born, autumn-born, or intermediate type by examining the initial growth zone of the scale. Length-weight regressions and von Bertalanffy growth in length parameters were determined for fish of the spring- and autumn-born scale types and compared statistically. In addition, electrophoretic techniques (Utter, Hodgins, and Johnson, 1972) were employed to test for significant inter-area heterogeneity as well as heterogeneity of fish with spring- and autumn-born scale features.

STOCK COMPOSITION

Temporal and spacial variations in length, age, sex, and maturity are treated in this section. In analyzing the sex ratio and age frequency data, fish of the spring- and autumn-born scale types were treated separately.

Size and Age Composition

There was a trend toward increasing length and average age with increasing latitude. Mean lengths in the California, Oregon, and Washington-Vancouver Island areas were 201 mm, 238 mm, and 277 mm, respectively (Figure 1). Length frequency histograms (Figure 2) show there was an absence of fish <160 mm off Washington-Vancouver Island which were represented off Oregon and relatively abundant off California. Conversely, fish >300 mm were absent off California, represented off Oregon, and relatively abundant off Washington-Vancouver Island.

Samples taken off California exhibited an unusual quadra-modal length-frequency distribution believed to be a sampling artifact rather than fluctuation in year-class strength. [Three of six schools sampled were schooled by size (Figure 1) which produced the minimum length mode at 165 mm and the maximum length mode at 270 mm.]

More symmetrical length distributions were produced from the three schools sampled in 1970 and five schools sampled in 1971 off Oregon. Lengths ranged from 159 mm to 293 mm in 1970 and 158 to 330 mm in 1971. Length distributions for both years are similar, being moderately skewed to the right with a mode at 210 mm in 1970 and 235 mm in 1971.

The three schools sampled off Washington in 1970 and two schools off Washington-Vancouver Island in 1971 showed more variation between years than the Oregon samples. A bimodal distribution was more apparent in 1971, modes at 245 and 305 mm, than the moderately asymmetrical distribution in 1970 with mode at 260 mm. Lengths ranged from 160 to 334 mm in 1970, and 161 to 340 mm in 1971. The upper limit of this latter range may exceed the previously known maximum length of the species in the eastern North Pacific Ocean. Clemens and Wilby (1961) reported lengths to 14 inches (356 mm); however, it is unclear whether this is standard or total length. The two saury measuring 340 mm knob length were ripe females measuring 363 and 364 mm in total length and weighing 180 and 190 grams respectively.

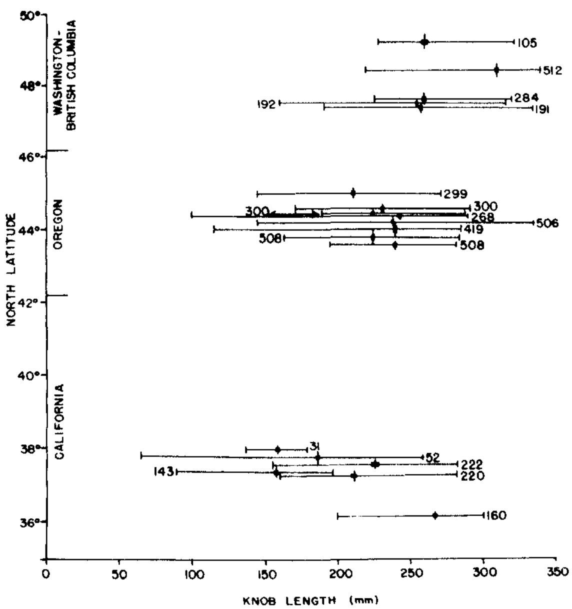

FIGURE 1.—Lengths (mean, range and S.D. of mean) of eastern Pacific saury plotted against latitude of capture. Numbers indicate sample size per school.

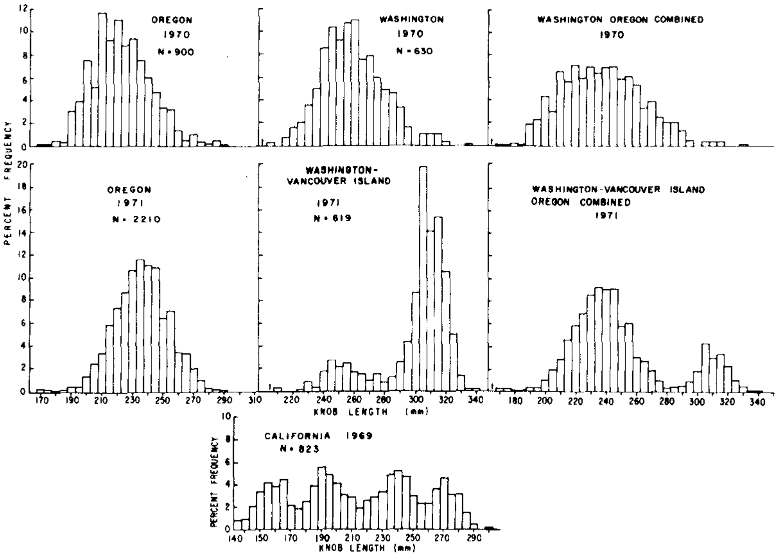

FIGURE 2.—Length frequency distributions of eastern Pacific saury captured off the Pacific coast of North America during August-September 1970-71.

Figure 2 also shows length-frequency distributions for combined Washington-Oregon samples in 1970 and Washington-Vancouver Island samples in 1971. A bimodal distribution is not apparent in 1970 but is distinct in 1971. Little variation in modes is noted between years.

Age frequency was determined from the 13 saury schools sampled off the Oregon-Washington-Vancouver Island coasts during 1970-71. Figure 3 histograms indicate the percentage of age groups by area, year, and areas combined within year.

Variations in age composition by latitude followed the expected trend established by size composition. Oregon fish were predominantly 1- and 2-year-olds while Washington-Vancouver Island fish were predominantly 2-, 3-, 4-, and 5-year-olds. Age composition of Oregon samples indicated little variation between 1970 and 1971 with age groups 1 and 2 representing 89% of the 1970 fish and 92% of the 1971 fish. In contrast, Washington fish showed considerable variation between years. In 1970, 93% of the fish were 2- and 3-year-olds while 54% were 4-year-olds in 1971. Sampling deficiencies probably account for the decline in the relative abundance of the 1968 year class between 1970 (2-year-old fish) and 1971 (3-year-olds). Fish aged as 6-year-olds were represented in 1970 and 1971 Washington samples, but it appears few fish survive beyond the age of 5.

Fish of the spring-born scale type consistently dominated all schools sampled (Figure 4) and also dominated most age groups. The greatest variation occurred at Oregon latitudes where fish of the autumn-born scale type comprised 27% of the 1970 samples and 12% in 1971. Washington samples were comprised of 21% autumn-born type in 1970 and 22% in 1971.

Sex Ratio and Maturity

The sex ratio was examined by age group for variation between area, year, and scale type.

Area differences in age composition and difficulties in determining sex of young fish hampered some comparisons; however, numbers of males and females were about equal through age 3 with females becoming predominant at age 4 and beyond. For more meaningful analysis, ages 1-3 and 4-6 were pooled for each area-year category. The sex ratio of saury of autumn- and spring-born scale types were next examined and found so similar that statistical treatment was unnecessary. Sex ratios of area-year-age group categories are presented in Table 2. While the sex ratio was age-dependent, sex composition differences in 1-3 year-olds of Washington vs Oregon catches in both 1970 and 1971 and 4-6 year-olds of Washington vs Oregon catches in 1971 were nonsignificant (0.05 level).

Size and age at first maturity could not be

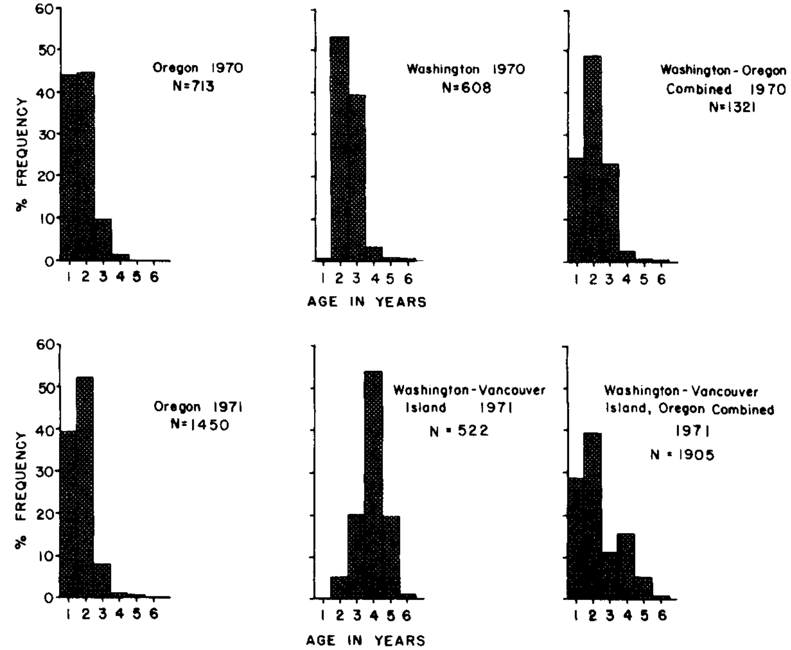

FIGURE 3.—Age frequency distributions of eastern Pacific saury captured off the Pacific coast of North American during August-September 1970-71.

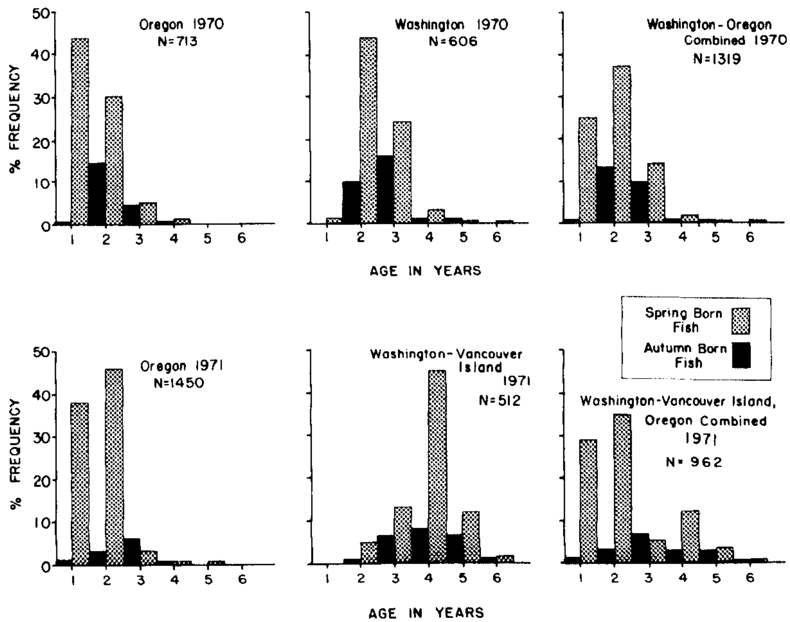

FIGURE 4.—Age frequency distributions of eastern Pacific saury showing age groups separated into spring- and autumn-born fish.

TABLE 2.—Sex ratios of age groups sampled in areas off the Pacific coast, 1970-1971.

Year-area category	Age group	Total no. fish examined	No. fish used for sex ratio	Sex ratio (% males)
1970				
Wash.	1-3	578	253	49.4
Oreg.	1-3	702	143	43.4
Wash.	4-6	28	26	30.8
Oreg.	4-6	10	10	0.0
1971				
Wash.-B.C.	1-3	179	100	54.0
Oreg.	1-3	1,365	1,024	56.1
Wash.-B.C.	4-6	391	388	37.6
Oreg.	4-6	8	6	33.3

directly determined from my samples since all but the very large fish were sexually inactive or immature upon collection. However, egg measurements obtained for ten 300-330 mm females collected off Washington in 1971 showed there were three distinct size groups of eggs: 0.1—0.4 mm, 0.8—1.5 mm, and the mature mode of 1.7—2.0 mm. Eleven smaller specimens collected off California by MacGregor[4] in March 1951 and 1954 ranged from 196 to 204 mm and contained eggs with a similar range (0.84—1.9 mm) indicating that saury are capable of reaching first maturity at lengths near 200 mm. Such fish would probably range from 1.1 to 1.4 yrs. old (Table 3).

Eighteen of the 19 schools sampled were composed principally of apparently mature fish in a resting state. The remaining school was predominantly 4-year-olds with females outnumbering males 1 to 0.73, and 96% of these were in spawning condition. Fish displaying both spring-born and fall-born growth patterns of scales were found in this school.

LENGTH-WEIGHT RELATION

The length-weight relation of saury captured in 1970 and 1971 was determined by fitting the logarithmic form of the equation $W = qL^d$, where W is weight in grams and L is knob length in millimeters, to mean emperical weights in each 5-mm length interval.

Separate relationships were determined for each hypothesized race and area-year category by sex. Using an analysis of covariance (Dixon and Massey, 1969), no significant difference in the L-W relation was detected between years, areas, or scale type, but there was a significant difference (0.05 level) between males and females.

A total of 1,170 males and 1,642 females representing immature, mature resting, and ripe saury were included in the length-weight regressions presented in Figure 5. The equation for males was $W = 3.293 \times 10^{-6} L^{3.050}$ and for females $W = 2.077 \times 10^{-6} L^{3.132}$. Females were slightly lighter than males at lengths <225 mm and heavier than males at lengths >280 mm.

GROWTH

Interpretation of growth was complicated because of the possible racial aspect and extended spawning season. Growth was determined for sexes combined because of the high probability of error in determining the sex of young fish. It was assumed that growth in length is asymptotic and that the von Bertalanffy (1938) growth equation adequately represents such growth.

Following methods of Stevens (1951), average lengths (observed and calculated from weight at age) were fitted to the equation $l t = L_\infty [1 - e^{-K(t-t_0)}]$.

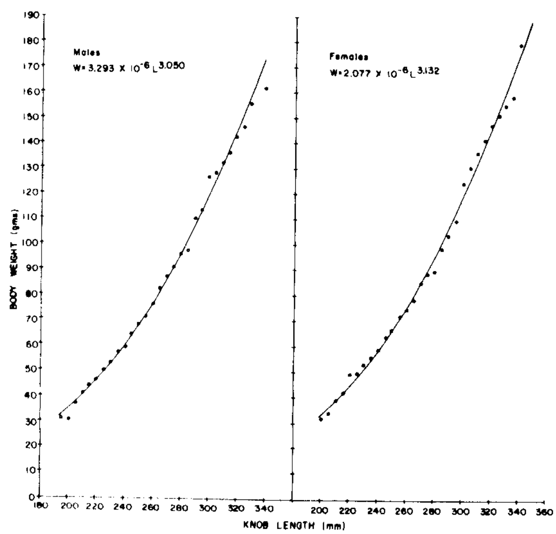

FIGURE 5.—Length-weight relation of male and female saury. The curve is fitted to mean-observed weight per 5-mm length interval.

[4] J. MacGregor, Fishery Biologist, Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Southwest Fish. Center, La Jolla, Calif., personal commun.

TABLE 3.—Average observed length at age, lengths calculated from weight at age and estimated von Bertalanffy growth parameters of hypothesized spring- and autumn-born fish.

Spring born fish			Autumn born fish		
Age (years)	Average observed length at age (mm)	Length calculated from weight at age[1] (mm)	Age (years)	Average observed length at age (mm)	Length calculated from weight at age[2] (mm)
1.10	183.9	182.5	0.75	142.8	151.2
1.40	219.0	223.6	1.00	178.7	182.1
2.40	245.5	249.3	2.00	232.1	235.8
3.40	268.8	272.7	3.00	256.8	260.6
4.40	308.6	312.5	4.00	297.0	303.0
5.40	319.8	321.4	5.00	314.5	316.8
6.40	319.9	323.0			
	L_∞ = 351.43	L_∞ = 360.23		L_∞ = 353.45	L_∞ = 348.50
	K = 0.34	K = 0.36		K = 0.38	K = 0.38
	t_0 = −1.19	t_0 = −0.83		t_0 = −0.72	t_0 = −1.02

[1] $W = 1.497 \times 10^{-6} L^{3.189}$
[2] $W = 1.809 \times 10^{-6} L^{3.155}$

Growth was first compared between fish of the autumn- and spring-born scale type. Table 3 summarizes the respective sets of length at age data and presents growth parameters. Little difference is noted between respective sets of length at age data for the two groups of fish. Although there is no consistent advantage in using lengths derived from weights at age, it should be noted that estimated t_0 values are sensitive to the method chosen. Regardless of method, no significant differences in growth parameters L_∞ and e^{-K} existed between fish of spring- and autumn-born scale types. Their graphic similarity is shown in Figure 6 where observed lengths at age and fitted curves are presented. Lack of significant differences in growth patterns between fish of spring- and autumn-born type suggested that respective data sets be pooled and that a single growth curve be presented (Figure 7). The resulting estimated parameters were L_∞ = 342.36, K = 0.41, and t_0 = −0.72. The calculated L_∞ is close to the maximum observed length of 340 mm. The estimated age at 95% growth completion was 6.5 years.

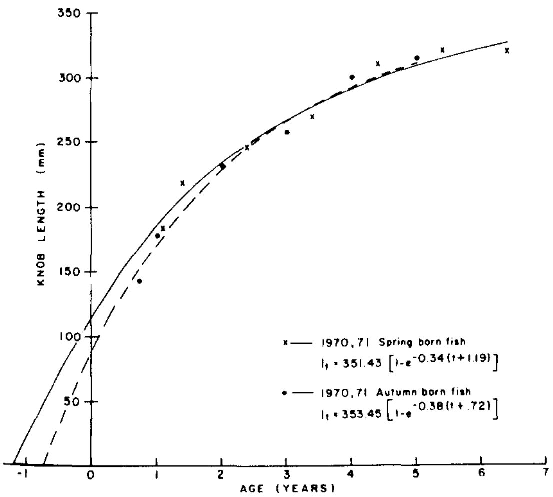

FIGURE 6.—Average observed length at age and fitted growth curves of spring- and autumn-born saury captured in offshore waters from southern California north to Vancouver, British Columbia 1970-71.

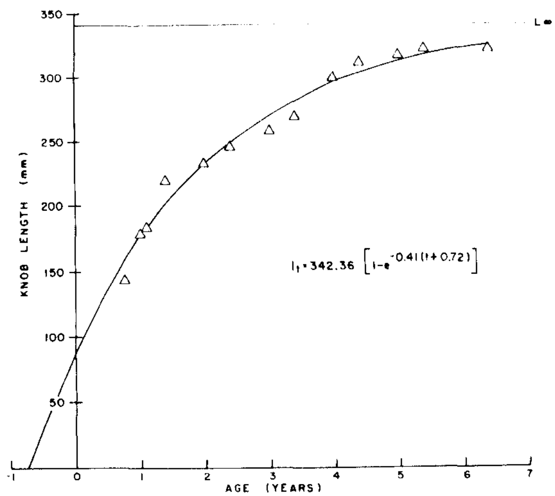

FIGURE 7.—Average observed length at age and fitted growth curve of eastern Pacific saury after pooling data from spring- and autumn-born fish.

MORTALITY

There are several limitations to the data used for estimating natural mortality: (1) Sampling was conducted during a period of apparent migration which caused the stock along the Pacific coast to become stratified in size and age composition, (2) sampling was limited and not conducted throughout the stock's entire geographical range, and (3) age frequency data indicate possible variations in annual recruitment and/or survival rate. Thus, one or more basic assumptions underlying traditional mortality models are violated to some degree. Realizing the above limitations and considering this an initial study of the adult stock, I have generated a range of estimates using several independent techniques.

A catch curve analysis (Robson and Chapman, 1961) was applied to the 1970 data since equal sampling occurred off Washington and Oregon, the only areas sampled, during that period.

Age	Coded age	No. of fish in catch
II	0	$N_0 = 644$
III	1	$N_1 = 313$
IV	2	$N_2 = 32$
V	3	$N_3 = 7$
VI	4	$N_4 = 1$
		$n = 997$

Annual survival rate estimate:

$$\hat{S} = .2876$$
$$\text{Var}(s) = 0.00017$$
$$\text{SE}(s) = 0.013$$
$$95\%\ \text{CI}(s) = .2876 + 2(0.013)$$
$$= (.2616, .3136)$$

When the above data were converted to a total annual instantaneous mortality rate, $Z = 1.25$ and 95% CI, $Z = (1.16, 1.34)$.

The raw age data were also converted to natural log form and treated by simple linear regression. The result was a significant linear relationship with $Z = 1.67$ and 95% CI, $Z = (1.41, 1.93)$.

Beverton and Holt's (1956) formula using length frequency data was also applied to the 1970 data. While this technique was designed primarily for exploited populations, its use generated another independent estimate and enabled the use of substantial numbers of fish which could not be aged.

The Beverton and Holt formula $Z = \dfrac{K(L_\infty - L)}{(L - L_r)}$ where L is the average length of the fish in the catch that are as large as, or larger than, the first fully recruited length L_r, estimated $Z = 1.41$ when $L_\infty = 342$ mm, $K = 0.41$, $L = 248$ mm, and $L_r = 220$ mm.

Survival rates were generated for each of the four area-year categories by subjecting respective sets of age frequency data to Jackson's (1939) technique:

$$S = \frac{N_2 + N_3 + \cdots + N_r}{N_1 + N_2 + \cdots + N_r - 1}.$$

The analysis yielded the following estimates:

Oregon, 1970; $Z = 1.58$,
Oregon, 1971; $Z = 1.80$,
Washington, 1970; $Z = 2.20$,
Washington-Vancouver Island, 1971; $Z = 1.27$.

The seven individual estimates obtained indicate a possible range of Z from 1.25 to 2.20 and an overall average Z of 1.60.

AVAILABILITY OF FISHABLE CONCENTRATIONS

Fishable concentrations of saury (>¾ ton) were usually located in waters of 15°-17°C near areas of upwelling. Surface temperatures strongly influence distribution and migration patterns of western Pacific saury (Fukushima, 1956 and 1962) as they appear to in the eastern Pacific (Ellis and Hughes, 1971). All studies indicate sharp thermal fronts affect and often dictate patterns of migration and areas where temporary concentrations may form.

Throughout the surveys, high density areas capable of sustaining productive fishing operations were rarely encountered. Most encounters were single schools (1-3 tons) or loose aggregations of fish dispersed over large areas of surface waters. The average probability of locating at least one fishable concentration during a night's operation (averaging 8 hr of searching effort and 70 miles of tracklines) was about 0.3. The relative densities decreased slightly with increasing latitudes, but large saury, which are currently in greatest commercial demand, were more available in the northern portion of the study area.

Low availability has evidently hampered Japanese attempts to establish new fishing grounds in the eastern Pacific. Operations by about 15 Japanese saury vessels in 1970 and 19 vessels in 1971 met financial failure. Consequently, major fishery firms such as Nihon Suisan, Hoko Suisan, and Nichiro have reportedly abandoned attempts to exploit the eastern Pacific saury resource.[5]

DISCUSSION

It seems pertinent to propose some general hypotheses about the life history of the eastern Pacific saury based on information presented here and in papers by Ahlstrom and Casey (1956), Ahlstrom (1968), and Smith et al. (1970).

The coastal stratification of saury by size and age composition during at least August-September is probably due to a northerly migration by many adults from California waters. Sea surface temperatures and position of warm-cold fronts strongly influence migration patterns and rates of movement of saury in the western North Pacific Ocean (Fukushima, 1956, 1962). Several factors indicate a similar situation exists in the eastern Pacific Ocean. Our surveys indicated eastern Pacific saury display narrow limits of thermal preference and are found most often near areas of upwelling. Furthermore, there is an excellent correlation between the apparent spacial and temporal distribution of saury and average month-by-month sea-surface temperature data. Using Johnson's (1961) 12-year monthly means and a thermal preference range of 14.0° to 17.0°C, it is apparent that large quantities of saury would not begin a northerly migration from California waters before June. Migration into northern Oregon and Washington waters would not be expected to occur before July. Rapid warming during July and August produces a favorable temperature regime along the coasts of Washington, Vancouver Island, and into Queen Charlotte Sound. While temperature conditions remain favorable in September, seasonal cooling occurs off Vancouver Island and Washington during October and continues through Oregon and northern California waters in November. Thus, it appears that in addition to influencing the time and patterns of saury migration, temperature conditions could also restrict the bulk of the stock to oceanic areas between Baja California and Queen Charlotte Sound or the southern Gulf of Alaska.

From the data presented, the degree of migration appears to be dependent on size and age of fish, and many young adults and juveniles apparently remain in California waters throughout the year.

Fish exceeding 300 mm in length (primarily ages 4, 5, and 6) reach maturity during the migration in August and release their mature mode of eggs (1.8-2.0 mm) in late August or September. Since Hatanaka's (1956) work on maturity in the western North Pacific Ocean (three modes of eggs, 0.6, 1.1, and 1.9 mm) is in close agreement with this study, it seems reasonable that eastern Pacific saury release modes of eggs at about the same intervals—2 months between the first and middle mode. Thus, the second spawning of large fish would probably take place in October or November and the third spawning during the winter while off California. Younger adults, sexually inactive during August-September, probably mature and spawn during the following winter and spring while in more southerly waters, primarily off California. It is not known whether 2- and 3-year-old fish spawn more than one mode of eggs per year.

The above hypothesis would account for the reported low abundance of eggs in California waters during August-September (Smith et al., 1970) when most spawning saury occupy a northerly regime. The spawning of younger age groups coincides with peak egg abundance in California during April, May, and June. Such an extended spawning season would account for spring-born, autumn-born, and some intermediate growth patterns detected from scale samples, as well as the fact that three-quarters of the samples displayed the spring-born growth characteristic.

There seems to be little likelihood that spring- and fall-born fish constitute different races, since both types were observed spawning together in the same school. Furthermore, statistical comparisons of length-weight and

[5] J. H. Shohara (Compiler). 1972. 12 Japanese vessels licensed for distant-water saury fishing [Excerpted from Shin Suisan Shimbun Sokuho, July 18 and July 29, 1972]. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Foreign Fish. Inf. Release 72-27, p. 3. (Processed.)

growth parameters failed to disclose any significant differences between these groups. These results are in line with unpublished results of Utter whose biochemical gene frequency studies gave no indication of heterogeneity between spring-born and fall-born saury.[6] Biochemical techniques also indicated intra-area homogeneity of fish in waters between southern California and Vancouver Island. Additional samples would have been desirable for a more complete racial study; however, results of this initial study strongly suggest the eastern Pacific saury stock is basically represented by a single gene pool.

Growth, maturity, and mortality studies indicate that saury (1) display rapid growth during the first year of life, (2) are capable of attaining maturity during the second year, and (3) probably do not survive beyond 6 years of age. Results indicate the total mortality coefficient (Z) is between 1.25 and 2.20. Since fishing mortality has remained insignificant, Z would be a result of natural mortality (M), assuming migration during the sampling period has not significantly confounded the situation. Intuitively, it seems Z is a reasonable approximation of M since sampling was conducted over a wide geographical area during the middle of the migratory period. No previous estimates of natural mortality have been published for the eastern Pacific saury stock; however, Novikov (1969) reports natural mortality in the western Pacific to be about 50%. Converting to instantaneous mortality for direct comparison, his estimate would be about 0.70.

ACKNOWLEDGMENTS

Robert Larsen, Master of the research vessel *John N. Cobb*, and his entire crew rendered exceptional service and helpful suggestions during the field operations in 1970-71. I also thank George Hirschhorn of the Northwest Fisheries Center for valuable assistance in the growth studies.

LITERATURE CITED

AHLSTROM, E. H.
1968. An evaluation of the fishery resources available to California fishermen. Univ. Wash., Publ. Fish., New Ser. 4:65-80.

AHLSTROM, E. H., AND H. D. CASEY.
1956. Saury distribution and abundance, Pacific Coast, 1950-55. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 190, 69 p.

ANDREEV, N. N.
1962. Stick-held dip net for saury fishing. *In* N. N. Andreev, Spravochnik po orudiyam lova, setesnastnym materialam i promyslovomu snaryazheniyu (Handbook of fishing gear and its rigging). Pishchepromizdat, Moscow, p. 459-462. (Translated by Israel Program Sci. Transl., 1966, p. 418-420; available U.S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, Va. as TT 66-51046.)

BERTALANFFY, L. VON
1938. A quantitative theory of organic growth (Inquiries on growth laws. II.) Hum. Biol. 10:181-213.

BEVERTON, R. J. H., AND S. J. HOLT.
1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapp. P.-V. Réun. Cons. Perm. Int. Explor. Mer. 140, Part 1:67-83.

CLEMENS, W. A., AND G. V. WILBY.
1961. Fishes of the Pacific coast of Canada. 2d ed. Fish. Res. Board Can. Bull. 68, 443 p.

CLUTTER, R. I., AND L. E. WHITESEL.
1956. Collection and interpretation of sockeye salmon scales. Int. Pac. Salmon Fish. Comm., Bull. 9, 159 p.

DIXON, W. J., AND F. J. MASSEY, JR.
1969. Introduction to statistical analysis. 3d ed. McGraw-Hill, N.Y., 638 p.

ELLIS, I., AND S. E. HUGHES.
1971. Pacific saury—A progress report. Natl. Fisherman Yearb. Issue 1971 51(13):67-70, 75, 77, 84-85, 92.

FUKUSHIMA, S.
1956. On the size-composition of the Pacific saury, *Cololabis saira*, caught in the North-eastern Sea area of Japan. [In Jap., Engl. summ.] Bull. Tohoku Reg. Fish. Res. Lab. 7:12-36.

1962. On the relation between the pattern of the Kuroshio Current in spring and summer and the saury fishing conditions in fall. [In Jap., Engl. summ.] Bull. Tohoku Reg. Fish. Res. Lab. 21:21-37.

HATANAKA, M.
1956. Biological studies on the population of the saury, *Cololabis saira* (Brevoort). Part I. Reproduction and growth. Tohoku J. Agric. Res. 6:227-269.

HOTTA, H.
1960. On the analysis of the population of the saury (*Cololabis saira*) based on the scale and otolith characters, and their growth. [In Jap., Engl. summ.] Bull. Tohoku Reg. Fish. Res. Lab. 16:41-64.

HUGHES, S. E.
1973. Some metazoan parasites of the eastern Pacific saury, *Cololabis saira*. Fish. Bull., U.S. 71:943-953.

INOUE, M.S., AND S. HUGHES.
1971. Pacific saury (*Cololabis saira*): A review of stocks, harvesting techniques, processing methods and markets. Oreg. State Univ., Corvallis, Eng. Exp. Stn. Bull. 43, 102p.

[6] F. Utter, Biochemical Geneticist, Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Northwest Fish. Center, Seattle, Wash., personal commun.

JACKSON, C. H. N.
1939. The analysis of an animal population. J. Anim. Ecol. 8:238-246.

JOHNSON, J. H.
1961. Sea surface temperature monthly average and anomaly charts northeastern Pacific Ocean, 1947-58. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 385, 56 p.

KIMURA, K.
1956. The standard length of the Pacific saury, *Cololabis saira* (Brevoort). [In Jap., Engl. summ.] Bull. Tohoku Reg. Fish. Res. Lab. 7:1-11.

KOTOVA, L. I.
1958. O biologii razmnozheniya sairy v Yaponskom more (The biology of reproduction of the saury in the Sea of Japan). Rybn. Khoz. 34(10):6-10. (Transl. Natl. Mar. Fish. Serv., Foreign Fish (Transl.), Wash., D.C.)

MOSHER, K. H.
1950. Description of a projection device for use in age determination from fish scales. U.S. Fish Wildl. Serv., Fish. Bull. 51:405-407.

NOVIKOV, N. P., AND M. YU. KULIKOV.
1966. Perspektivnyi raion promysla sairy (Prospective region for saury fishing). Rybn. Khoz. 42(7):20-21. (Transl. Natl. Mar. Fish. Serv., Foreign Fish. (Transl.), Wash., D.C.)

NOVIKOV, YU. V.
1969. Zapasy sairy i regulirovanie ee promysla (Conditions of the saury stocks and the regulation of their fishery.) Tr. Vses. Nauchn.-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 67:190-200. (Transl., Natl. Mar. Fish. Serv., Foreign Fish. (Transl.), Wash., D.C.)

PARIN, N. V.
1960. Areal sairy (*Cololabis saira* Brev.—Scombresocidae, Pices) i znachenie okeanograficheskikh faktorov dlya ee rasprostraneniya (The range of the saury (*Cololabis saira* Brev.—Scombresocidae, Pisces) and effects of oceanographic features on its distribution). Dokl. Akad. Nauk SSSR New Ser. 130(3):649-652.

ROBSON, D. S., AND D. G. CHAPMAN.
1961. Catch curves and mortality rates. Trans. Am. Fish. Soc. 90:181-189.

SMITH, P. E., E. H. AHLSTROM, AND H. D. CASEY.
1970. The saury as a latent resource of the California Current. Calif. Coop. Oceanic Fish. Invest. Rep. 14:88-130.

SOKOLOVSKII, A. S.
1969. K voprosu o stadakh sairy v Tikhom okeane (Populations of saira in the Pacific Ocean). Izv. Tikhookean. Nauchn.-issled. Inst. Rybn. Khoz. Okeanogr. 68:203-208. (Transl., 1971, Fish Res. Board Can. Transl. Serv. 1614.)

STEVENS, W. L.
1951. Asymptotic regression. Biometrics 7:247-267.

UTTER, F. M., H. O. HODGINS, AND A. G. JOHNSON.
1972. Biochemical studies of genetic differences among species and stocks of fish. Int. North Pac. Fish. Comm., Annu. Rep. 1970:98-101.