THE EARLY LIFE HISTORY OF SKIPJACK TUNA, *Katsuwonus pelamis*, IN THE PACIFIC OCEAN

HOWARD O. YOSHIDA[1]

ABSTRACT

This study investigates the early life history of skipjack tuna, including the distribution, abundance, age, and growth. The study is based on 1,742 juvenile skipjack tuna that were found in the stomachs of 6,867 billfishes caught in Hawaiian waters and in the South Pacific by commercial longline boats. The smallest juvenile taken near Hawaii was 5.9 cm in standard length, and in the South Pacific 1.6 cm in standard length. Regressions describing the relations between the standard length and lengths of (1) the vertebral column, (2) the precaudal vertebrae, (3) caudal vertebrae, (4) the 1st-10th vertebrae, and (5) the 21st-30th vertebrae of juvenile skipjack tuna were determined. The regressions provided estimates of the standard length of fragmentary specimens. Juvenile skipjack tuna were widely distributed between lat 5° and 32° S, and long 137° W and the 180th meridian. North of the equator, the commercial longline boats fished close to the main Hawaiian Islands, and thus only a limited picture was obtained of the areal distribution of juvenile skipjack tuna. Juvenile skipjack tuna were found in almost all months in Hawaiian waters. They were most numerous in July and August. In the South Pacific, juveniles were also found in almost all months between lat 5° and 20° S. Peaks in the apparent abundance were evident in April and October in the area north of lat 10° S. Juvenile skipjack tuna appeared to be more numerous in the South Pacific than around Hawaii.

Length-frequency distributions of juvenile skipjack tuna from Hawaii showed well-defined modes, which progressed with time. The growth of the juveniles was estimated by using the modal lengths determined from the monthly length-frequency distributions. Skipjack tuna between 9 and 40 cm around Hawaii are estimated to grow 2.0 cm per month. One-year-old fish are estimated to be 31 cm in standard length.

In 1968, 70,746 metric tons of skipjack tuna, *Katsuwonus pelamis*, were landed in the eastern Pacific (Inter-American Tropical Tuna Commission, 1970) and 109,018 metric tons were landed in Japan (Japan. Fisheries Agency, Research Division, 1970). Because of its commercial importance much knowledge has been accumulated on the biology of the skipjack tuna. Information on early life history, however, is incomplete. Matsumoto (1958) described skipjack tuna larvae and their temporal and spatial distribution in the central Pacific. Ueyanagi (1969) reported on the distribution of larval skipjack tuna in the Pacific Ocean between 1960 and 1967, and Higgins (1967) summarized the distributional records of juvenile skipjack tuna in the Pacific.

The present study is based on immature skipjack tuna between 1.6 and 40 cm taken from the stomachs of billfishes near Hawaii and in the South Pacific. Included are observations on geographical and seasonal distribution, length-frequency distributions, and age and growth rates.

MATERIALS AND METHODS

The stomachs of 6,867 billfishes[2] were examined in this study. Those examined included 4,118 striped marlin, *Tetrapturus audax;* 1,606 blue marlin, *Makaira nigricans;* 383 shortbill spearfish, *T. angustirostris;* 216 sailfish, *Istiophorus platypterus;* 196 swordfish, *Xiphias gladius;* 171 black marlin, *M. indica;* and 177 billfishes that were not identified to species.

[1] National Marine Fisheries Service, Hawaii Area Fishery Research Center, Honolulu, Hawaii 96812.

[2] The term billfishes as used in this paper includes swordfish.

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Sixty-six percent of the stomachs came from billfishes captured near Hawaii between July 1962 and April 1966. These stomachs were used previously in an early life history study of albacore, *Thunnus alalunga* (Yoshida, 1968). Most of these billfishes were caught within 37 km (20 nautical miles) of the main islands. A few were caught as far as 740 km (400 nautical miles) from Oahu. Thirty-four percent of the stomachs came from billfishes caught in the South Pacific between lat 5° and 32° S, and between long 135° W and 179° E (Figure 1). These were caught on longline gear by boats operating out of American Samoa between January 1964 and July 1966. The fishery has been described by Otsu and Sumida (1968).

Arrangements were made with the crews of several boats to have billfish stomachs collected on the fishing voyages. Each cooperating crew was provided with a stainless steel tank, formaldehyde solution, labels, and collecting bags. The crew was paid 50 cents for each stomach.

In the laboratory at Honolulu, all tuna and tunalike specimens were sorted from the stomach contents and identified. Skipjack tuna were identified by skeletal characters (Godsil and Byers, 1944). Standard length was recorded for all intact specimens. Following a technique used earlier (Yoshida, 1968), a method was devised to estimate the standard length of fragmentary specimens. Relations were determined between the standard length and the length of: (1) the complete vertebral column (41 vertebrae), (2) the precaudal vertebrae (vertebrae 1-20), (3) the caudal vertebrae (vertebrae 21-41), (4) 1st-10th vertebrae, and (5) 21st-30th vertebrae, based on 77 intact juvenile skipjack tuna specimens from around Hawaii and the South Pacific. All the relations appeared to be linear and straight lines were fitted to the data by the method of least squares. Combining the samples from Hawaii and the South Pacific should not adversely affect the results. A plot of the data for all five relations did not indicate any differences between the North Pacific and South Pacific samples. A covariance analysis applied to the relation between the standard length and the length of the complete vertebral column for Hawaiian and South Pacific juvenile skipjack tuna confirmed the lack of significant differences between the samples. No significant differences were found in the regression coefficients ($F = 0.105$; df $= 1, 73$) and in the intercepts ($F = 0.053$; df $= 1, 74$). The regressions of the standard length on the various vertebral segments are presented in Table 1.

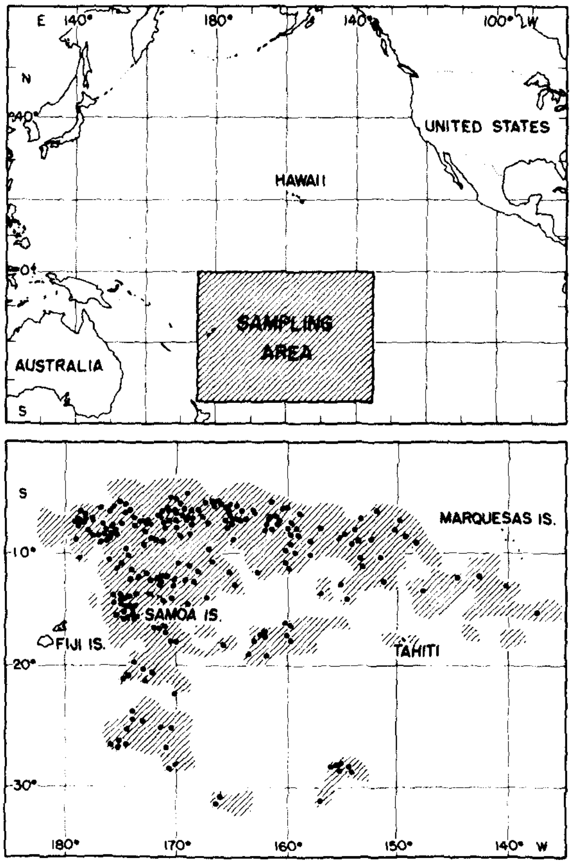

FIGURE 1.—The location of capture of billfishes (shaded area) and the distribution of juvenile skipjack tuna (dots) in the South Pacific.

The lengths of most of the specimens were estimated by using a suitable regression. For 22% of the specimens the relative position of the fragments could not be determined, and the regressions were not used. For these specimens the standard length was estimated by comparing the average length of the vertebrae in the fragment with the average length of the vertebrae of the specimens used to calculate the regressions.

TABLE 1.—Regressions describing the relations between the standard length and lengths of the vertebral column, precaudal vertebrae, caudal vertebrae, 1st-10th vertebrae, and 21st-30th vertebrae of juvenile skipjack tuna [l = standard length (cm), L = length of vertebral fragments (cm)].

Segment of vertebral column	Regression	Standard deviation from regression
Complete vertebral column	$l = 0.0693 + 1.2262L$	0.435
Precaudal vertebrae	$l = 0.6544 + 2.4926L$	0.439
Caudal vertebrae	$l = -0.4414 + 2.4196L$	0.445
1st-10th vertebrae	$l = 0.4280 + 5.2938L$	0.515
21st-30th vertebrae	$l = -0.2637 + 4.6942L$	0.595

DISTRIBUTION AND ABUNDANCE

Seasonal and areal coverage was spotty, but sampling was extensive enough to permit meaningful analysis for the present study. In the following sections I will discuss the distribution and the seasonal and annual apparent abundance of juvenile skipjack tuna in the South Pacific and near Hawaii.

AREAL DISTRIBUTION

Commercial longline boats engaged in collecting billfish stomachs in the South Pacific ranged over a wide area, and juvenile skipjack tuna, as indicated by their presence in billfish stomachs, also were widespread (Figure 1). Around Hawaii fishing was restricted to a relatively small area, and so a more limited picture was obtained of the areal distribution of juvenile skipjack tuna.

Skipjack tuna larvae are widely distributed in the Pacific Ocean (Matsumoto, 1966; Ueyanagi, 1969). Ueyanagi (1969) reports that larvae were taken across the entire South Pacific between the equator and lat 10° S. Also, west of long 140° W larvae were taken as far south as lat 32° S. My study shows that the distribution of juvenile skipjack tuna is similar to the distribution of the larvae. In the North Pacific, skipjack tuna larvae have been found around Hawaii and across the entire Pacific between the equator and lat 20° N. In the western North Pacific, between long 160° W and the Asian continent, larvae have been taken almost as far north as lat 35° N (Ueyanagi, 1969).

My study indicates that gaps in the distribution of juvenile skipjack tuna in the Pacific reflect a lack of sampling. Higgins (1967) has a somewhat similar viewpoint. It is likely that the juveniles are as widely distributed as larval skipjack tuna in the North Pacific.

The distribution of juvenile skipjack tuna in the South Pacific by quarters of the year (all years combined) is shown in Figure 2. This is only the apparent distribution, however, because it reflects the operations of Samoa-based vessels. These vessels primarily seek albacore, and therefore they fish the areas where albacore catch rates tend to be high. In the first half of the year, vessels generally operate north of lat 20° S, and in June or July they move as far south as lat 30° S before heading north again (Otsu and Sumida, 1968). Samples were available mostly from north of lat 20° S, and juvenile skipjack tuna were found throughout the sampling range. In the third and fourth quarters, samples were available from a wider area, and again juvenile skipjack tuna were taken from almost the entire area sampled. Although seasonal coverage was incomplete throughout the total area, synoptic sampling would probably produce juveniles in all seasons and throughout the total area.

SEASONAL APPARENT ABUNDANCE

Hawaii

Apparent abundance is expressed here as number of skipjack tuna per 100 billfish stomachs. The apparent abundance of juveniles around Hawaii, all years combined, is shown in Figure 3. The juveniles were more numerous during July, August, and September. A peak in abundance usually occurred in August. These observations confirm Matsumoto's (1966) conclusion that skipjack tuna in the Hawaiian Islands spawned during the summer. He showed that the abundance of larval skipjack tuna peaked in July.

The apparent abundance of juveniles in 1963, 1964, and 1965 offers interesting contrasts. For example, in August 1963 the apparent abundance peaked sharply to 100 juveniles per 100 bill-

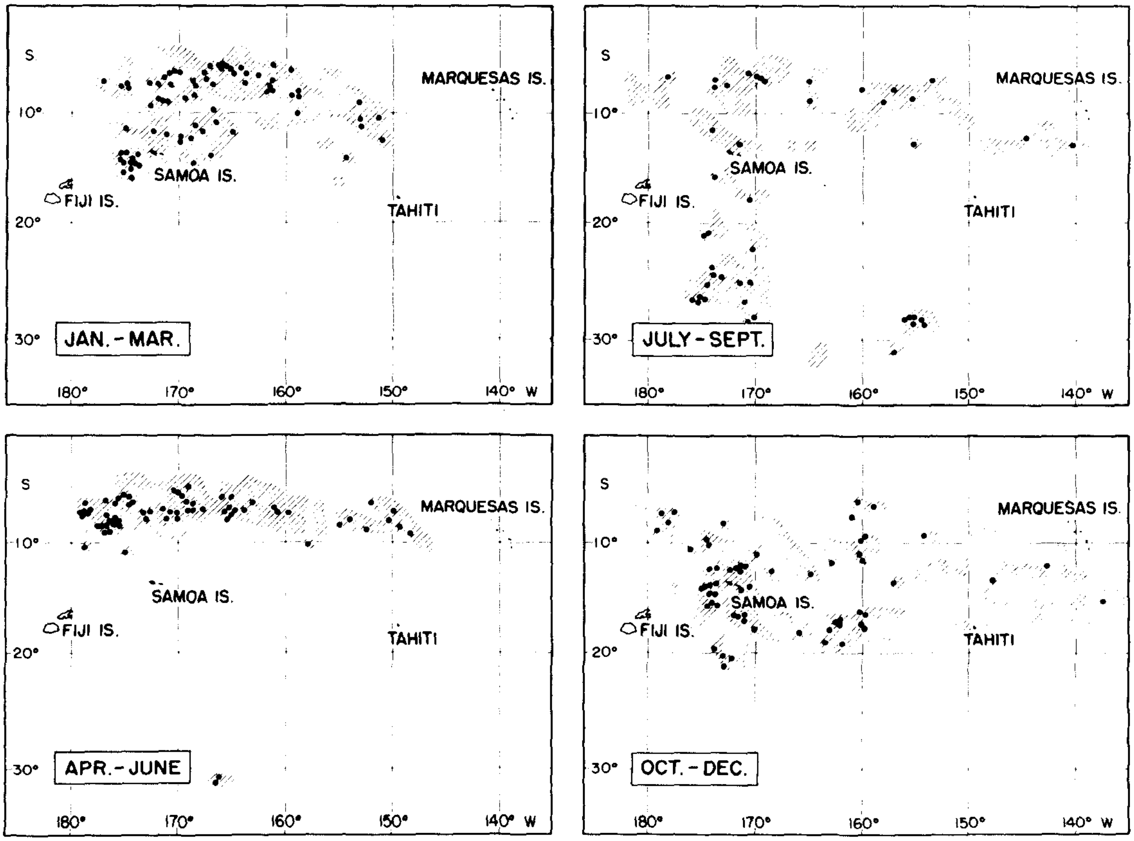

FIGURE 2.—Distribution of juvenile skipjack tuna (dots) by quarters of the year in the South Pacific. The shadings show the billfish sampling area.

fishes. Only small numbers were taken between January and June and between October and December. In 1964 and 1965 the summer peak in abundance was not so high; however, juveniles were more numerous in other months. The apparent abundance of juveniles was highest in 1964 when an average of 21.3 juveniles per 100 billfishes was taken. In 1965, an average of 19.1 juveniles was taken, and in 1963 the average was 12.4.

South Pacific

To examine the seasonal apparent abundance of juvenile skipjack tuna in the South Pacific, the area north of lat 10° S was considered separately from the area between lat 10° and 20° S (Figure 4). Because the coverage was poor in any one year, the data for all years were combined.

Juvenile skipjack tuna were taken throughout the year north of lat 10° S. Peaks in the apparent abundance were evident in April and October. Larvae have been taken throughout the year in the equatorial waters (lat 10° N to 10° S) of the central Pacific (Matsumoto, 1966). They were most numerous between April and July. Thus, the apparent abundance of the juveniles differs somewhat from that of the larvae in that a peak was absent in larval abundance in the latter half of the year. The difference in apparent abundance between the larvae and juveniles may not be real. The small number of stomachs collected in the latter half of the year may not have been adequate to reveal the true abundance of juveniles.

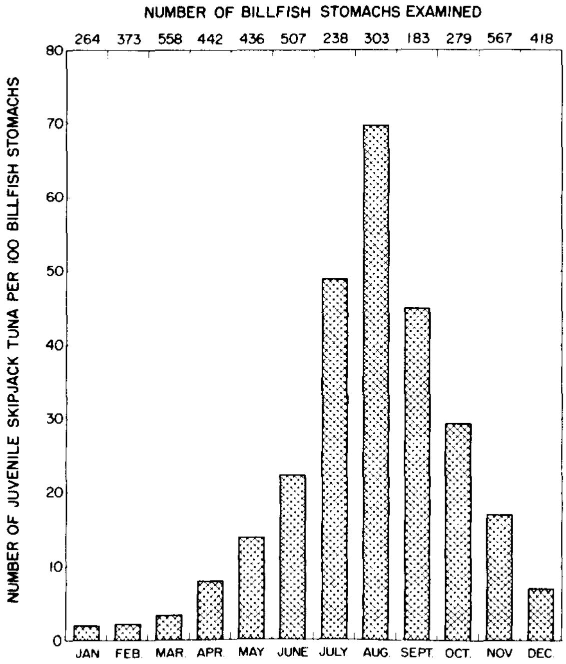

FIGURE 3.—Apparent abundance of juvenile skipjack tuna in Hawaiian waters, 1962-66.

Juveniles were taken in all months except July between lat 10° and 20° S. Here also the uneven sample sizes make the analysis of apparent abundance difficult. It appears, however, that juveniles were numerous from November to February. No comparable data on larval skipjack tuna in this area are available.

The apparent abundance of juvenile skipjack tuna was higher in 1964 than in 1965 in the South Pacific (Table 2). In 1964, juveniles were slightly more numerous north of lat 10° S than between lat 10° and 20° S. In 1965, however, juveniles were more numerous between lat 10° and 20° S than north of lat 10° S. Also they appeared to be more numerous in the South Pacific than near the Hawaiian Islands.

About 12% of the billfish stomachs from Hawaii contained one or more juvenile skipjack tuna, while 19% of the billfish stomachs from the South Pacific contained one or more juveniles. In both areas the largest number of juvenile skipjack tuna per stomach was 11; most of the stomachs from both areas had only one juvenile.

TABLE 2.—Annual apparent abundance of juvenile skipjack tuna in the central Pacific Ocean.

Year	Area	Number of billfishes	Number of juvenile skipjack tuna	Number of juveniles per 100 billfishes
1963	Hawaii	1,351	167	12.4
1964	Hawaii	1,608	342	21.3
	Equator-10° S	579	268	46.3
	10°-20° S	216	92	42.6
1965	Hawaii	1,008	193	19.1
	Equator-10° S	208	60	28.8
	10°-20° S	537	191	35.6

AGE AND GROWTH

The length-frequency distribution of juvenile skipjack tuna from Hawaii and the South Pacific is shown in Figure 5. Near Hawaii the smallest juvenile taken was 5.9 cm SL (standard

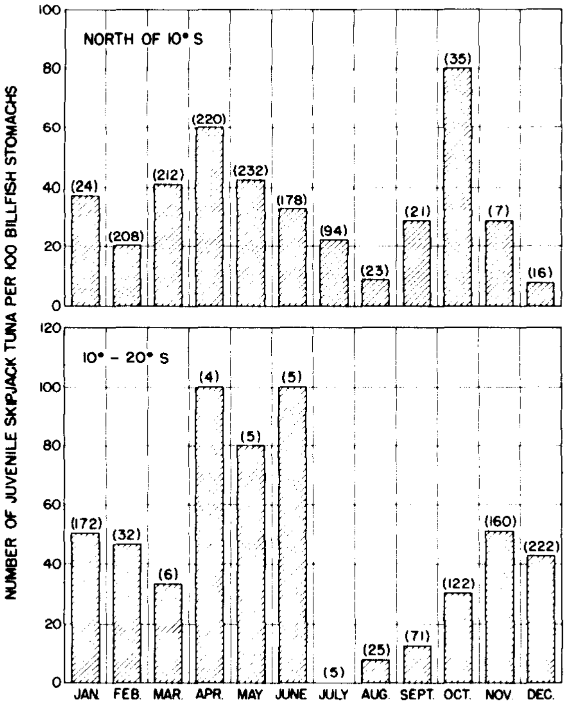

FIGURE 4.—Apparent abundance of juvenile skipjack tuna in the South Pacific. The figures in the parentheses are the number of billfish stomachs that were examined.

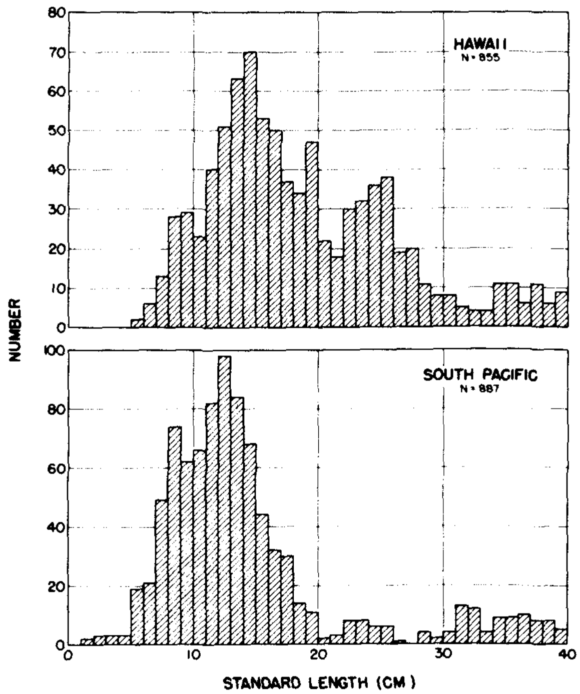

FIGURE 5.—Length-frequency distribution of juvenile skipjack tuna.

length). A prominent mode was located at the 14-14.9 cm size class, a lesser mode at 25-25.9 cm, and a relatively obscure mode was evident between 30 and 40 cm. The length frequencies of juvenile skipjack tuna from the South Pacific were similar to those from Hawaii. The smallest juvenile taken in the South Pacific was 1.6 cm SL. A prominent mode was evident at the 12-12.9 cm length class, a lesser mode between 20 and 30 cm, and a relatively obscure mode was apparent between 30 and 40 cm.

The monthly length-frequency distributions of the juveniles near Hawaii show well-defined modes in the summer and fall (Figure 6). Some of the length distributions have two or more well-defined modes. These modes probably represent progeny from two or more spawnings spaced more or less closely in time. An increase in size of the juveniles, as indicated by a progression of the modes, was evident in the monthly length distributions. In contrast, Higgins (1970) found that modal groups of juvenile skipjack tuna taken in midwater trawls did not show an increase in length with time.

Because the modal lengths increased with time, an attempt was made to describe the growth of the juveniles. To facilitate the designation of modes, the length data were smoothed by a moving average of three. Modes were not considered in samples that had fewer than 10 fish, nor in length groups containing fewer than 5 fish. The selected modes are given in Figure 7 and Table 3. Using the method of least squares, straight lines were fitted to groupings of modal points to represent the apparent growth of the juveniles. The slope of the lines for 1962, 1964-65, and 1965-66 indicates that juvenile skipjack tuna grow about 2.0 cm per month. The slope of the line for 1963-64 indicates a growth of 1.2 cm per month. These data suggest annual differences in the growth of the juveniles. I believe that an increment of 2 cm per month is the best estimate of the growth rate of juvenile skipjack tuna within the length range covered in this study. Rothschild (1967) used data from tag and recapture experiments and the von Bert-

TABLE 3.—Modes in the length-frequency distributions of juvenile skipjack tuna from Hawaii (from Figure 6).

Year	Month	Standard length (cm)		
1962	August	13.0	19.0	23.5
	September	20.0		
	October	27.0		
	November	22.0		
1963	June	13.5		
	July	13.5		
	August	9.5	15.5	
	September	15.5	22.0	
	November	23.5		
	December	24.0		
1964	April	30.0		
	May	19.0	25.0	
	June	15.5	25.5	
	July	8.5	13.5	
	August	11.0	18.5	
	September	12.5		
	October	14.5	23.5	
	November	23.5		
	December	25.0		
1965	April	35.5		
	May	12.5	26.5	
	June	9.5		
	July	15.5		
	August	10.5	14.5	18.5
	October	13.0	19.5	
	November	18.5		
1966	April	32.5		

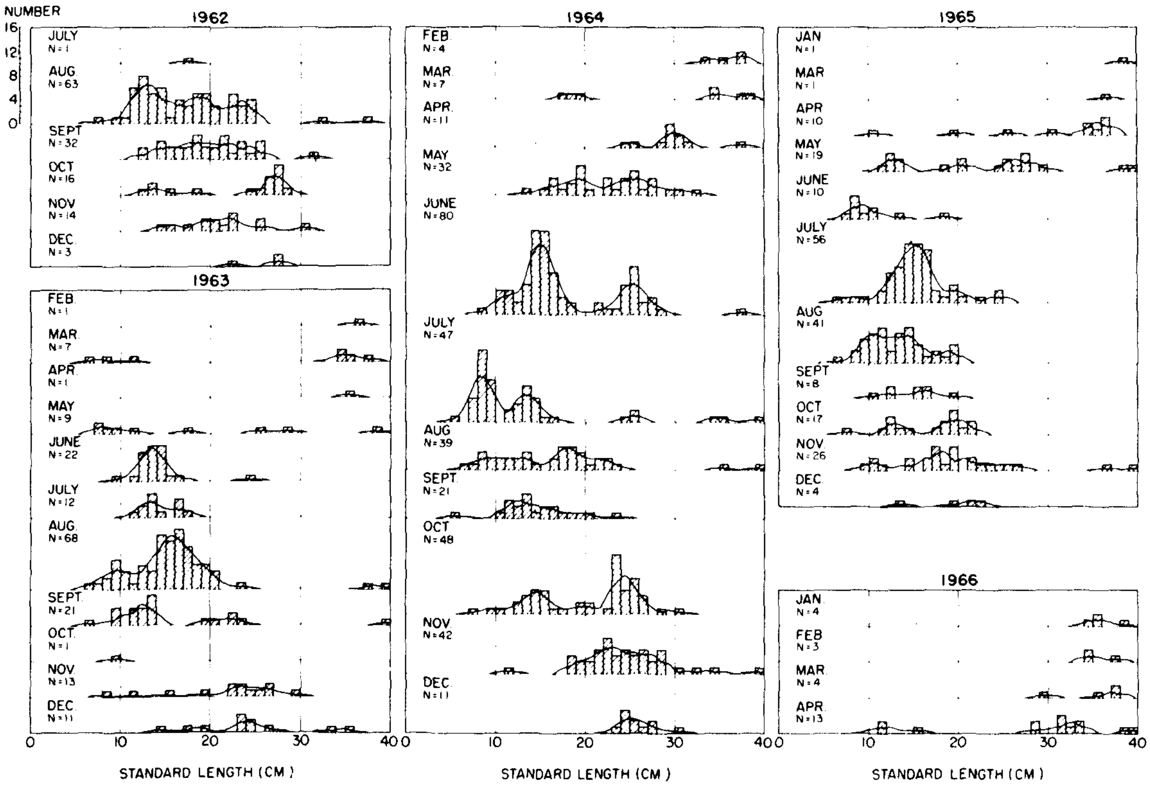

FIGURE 6.—Monthly length-frequency distribution of skipjack tuna from Hawaii.

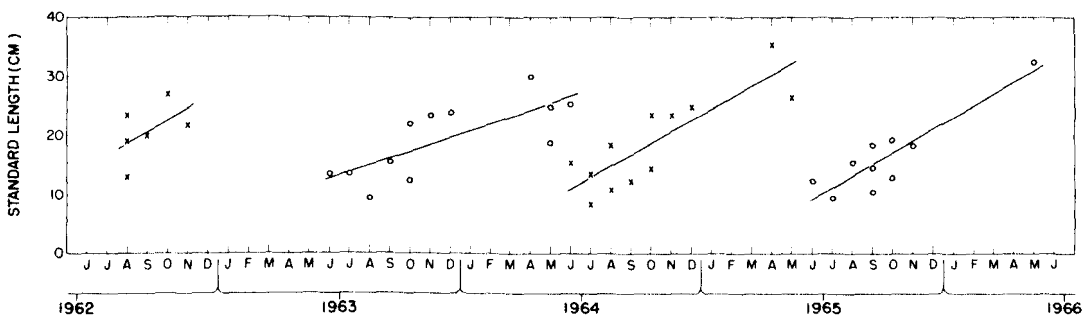

FIGURE 7.—Growth of juvenile skipjack tuna from Hawaii.

alanffy growth function to estimate skipjack tuna growth. He indicated that skipjack tuna between 44 and 72 cm grew about 16.6 cm per year or 1.4 cm per month. The deceleration in growth from 2.0 cm per month for skipjack tuna between 9 and 40 cm to 1.4 cm per month for fish between 44 and 72 cm is to be expected.

It is useful to determine the growth rate of skipjack tuna from hatching to 9 cm SL. These and other data may make it possible to estimate the age of skipjack tuna at various sizes. The growth rate of a related species, black skipjack, *Euthynnus lineatus,* between 17 and 75 mm SL has been determined (Clemens, 1956). In experiments conducted in shipboard aquaria Clemens showed that black skipjack grew 36.8 mm in 295 hr, which would be about 9 cm in a month. Houde and Richards (1969) reared larval little tunny, *E. alletteratus,* under laboratory conditions and reported similar growth rates. It was recently found that larval skipjack tuna have similar growth rates (personal communication, William J. Richards, Supervisory Zoologist, NMFS Tropical Atlantic Biological Laboratory, Miami, Fla. 33149, August 18, 1970). If larval skipjack tuna grow at the same rate (9 cm per month) for the first month and 2 cm per month for the next 11 months, then skipjack tuna 1 year old would be 31 cm SL.

Brock (1954) assumed that the modal sizes of fish between 40 and 50 cm FL (fork length) that appear in the Hawaiian skipjack tuna fishery during the summer represented 1-year-old fish. Forty to fifty centimeters for 1-year-old fish seems too high. Modal lengths typical of winter skipjack tuna in the Hawaiian fishery are 35, 50, and 70 cm FL (Rothschild, 1965). My data indicate that the 35-cm modal group that appears in the winter represents 1-year-old fish.

SPAWNING

In the Hawaiian area, juvenile skipjack tuna smaller than 10 cm were found during 7 months in 1963 and during 5 months in 1964 and 1965 (Figure 6). This suggests a protracted spawning season and nearly continuous recruitment of juveniles. The catch of larvae indicates that spawning begins in March, peaks in July, and declines sharply in September and October (Matsumoto, 1966).

The Hawaiian skipjack tuna fishery peaks in the summer when the bulk of the catch is composed of "season-size" fish larger than 60 cm (Rothschild, 1965). Larval and juvenile skipjack tuna also are most numerous during the summer, which suggests that the large fish spawn in Hawaiian waters. The presence of juveniles in the spring and fall, although in lesser numbers, indicates that spawning also takes place then. Rothschild (1965) has hypothesized that at least one subpopulation spawns in Hawaiian waters. The protracted spawning season may indicate that more than one subpopulation spawns here.

In the South Pacific between lat 5° and 20° S, the spawning season is more protracted than in Hawaiian waters. Juveniles smaller than 10 cm SL were taken in almost every month north of lat 10° S. Between lat 10° and 20° S they were taken in all months except March, April, June, and July (Figure 8); the reason for their absence in these months may be inadequacy of sampling. The area south of lat 20° S was somewhat different. Although sampling was sparse, the length-frequency distribution consistently showed few small juveniles, which indicates little or no spawning in this area.

The length-frequency distribution of juvenile skipjack tuna north of lat 10° S and between lat 10° and 20° S indicated a progression of modes (Figure 8). However, a plot of the modal lengths indicated no growth. The cause of this may be a protracted spawning season and inadequacy of samples. Also juveniles appear to migrate southward as they grow. Only small numbers of juveniles larger than 20 cm SL were taken north of lat 20° S, and most of the juveniles taken south of lat 20° S were larger than 20 cm SL.

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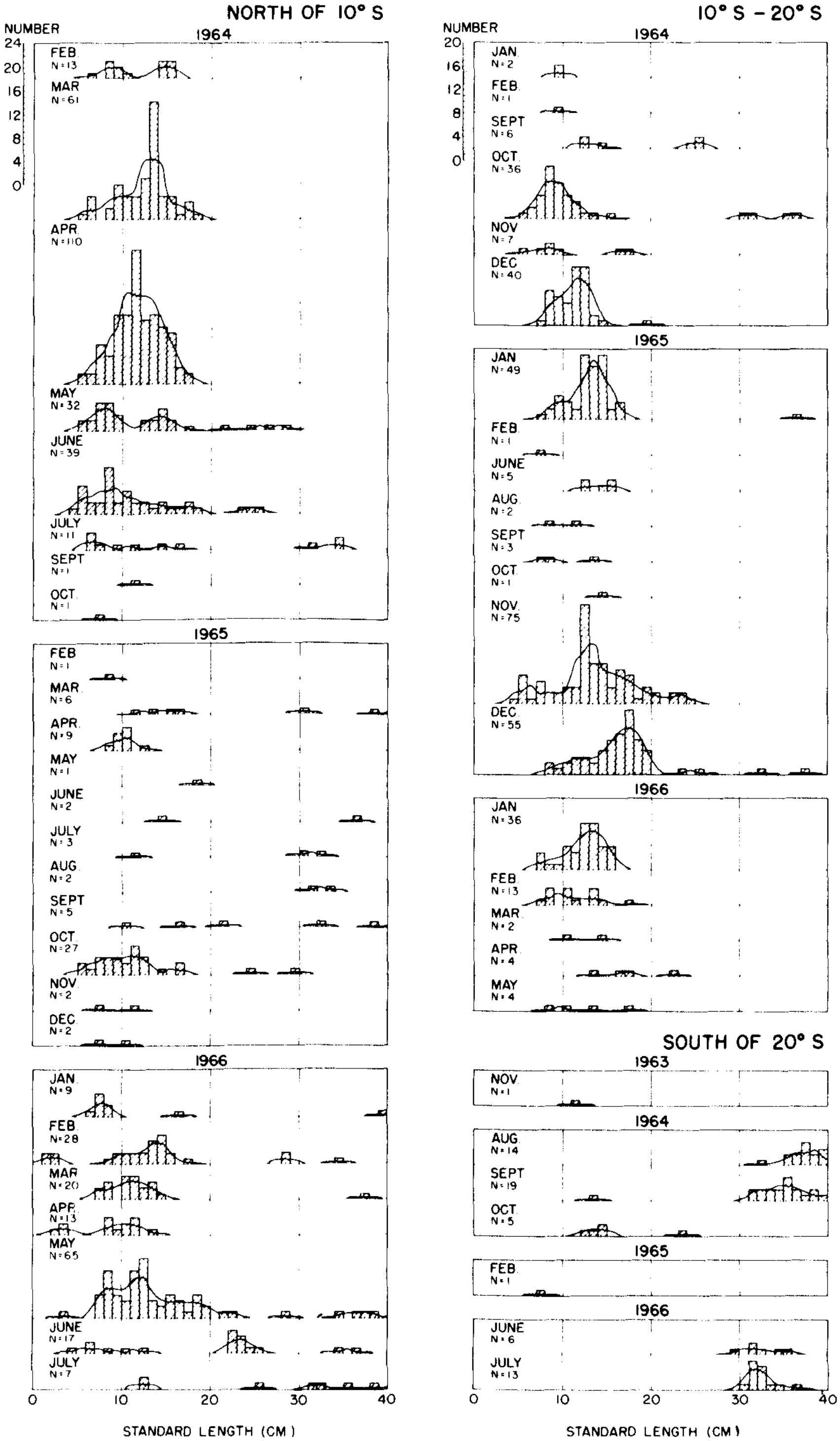

FIGURE 8.—Monthly length-frequency distribution of juvenile skipjack tuna north of lat 10° S, lat 10°-20° S, and south of lat 20° S in the South Pacific.

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