WP.10

DRAFT WORKING DOCUMENT

AGE AND GROWTH OF SKIPJACK TUNA, *KATSUWONUS PELAMIS*, YELLOWFIN TUNA, *THUNNUS ALBACARES*, AND ALBACORE, *THUNNUS ALALUNGA*, AS INDICATED BY DAILY GROWTH INCREMENTS OF SAGITTAE

James H. Uchiyama and Paul Struhsaker[1]

[1] Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812. This draft manuscript is a portion of a paper to be published in Fish. Bull., U.S.

INTRODUCTION

Pannella's recent reports (1971, 1974) provide circumstantial evidence that the smallest discernible growth increments in the sagittae (otoliths) of fishes are deposited daily. Recent studies provide direct evidence that these growth increments are a diel phenomenon in sagittae of temperate (Brothers, Mathews, and Lasker, in press) and tropical (Struhsaker and Uchiyama, in press) species of teleosts. In the latter study, the information gained from the reading of sagittae was utilized in the construction of a growth curve for the first 190 days after yolk-sac absorption of a short-lived engraulid. Here, similar growth curves are presented for skipjack tuna, _Katsuwonus pelamis_, to an age of about 3 yr and yellowfin tuna, _Thunnus albacares_, to about 2 yr from the central Pacific. Counts of sagittae from four young albacore, _T. alalunga_, from the eastern Pacific are also given. The results are discussed in relation to earlier age and growth studies of these species.

METHODS

Pertinent collection data and sagitta counts for all material utilized here are given in Appendix Tables 1-3. All tunas longer than 20 cm fork length (FL) are samples from commercial fisheries. Tunas smaller than 20 cm FL are from stomach contents of troll-caught skipjack tuna and regurgitations of a seabird, _Sula_ sp., after landing on the deck of a research vessel.

Juvenile skipjack tuna from stomach contents were identified by vertebral counts and skeletal characters given by Godsil and Byers (1944) and Gibbs and Collette (1967). In one case only the anterior portion of a juvenile skipjack tuna was collected: its standard length (SL) was determined from the length of the precaudal vertebrae using the equation given by Yoshida (1971).

The small (7.0 cm FL) yellowfin tuna specimen was tentatively identified on the basis of skeletal characters given by Matsumoto et al. (1972) and descriptions of Thunnus livers by Godsil and Byers (1944) and Gibbs and Collette (1967).

The caudal rays were missing from most of the tuna specimens collected from stomachs. Fork lengths were estimated by adding 3.5% of the standard lengths.

Heads of tuna specimens from which the sagittae were not immediately removed after collection were frozen or preserved in 75% isopropynol.

The sagittae of tunas lie close to the sagittal plane. In tunas less than 100 cm FL they are obtained by splitting or cutting the skull along the sagittal plane and teasing the otoliths from the semicircular canals. With experience, the cut can be made without damaging either of the sagittae. Sagittae were cleaned by teasing or brushing off the sacculus and nerve endings. Sagittae that were not mounted immediately were stored for periods of less than a year in either distilled water or 70% isopropynol.

After removal and cleaning, sagittae from tunas greater than about 45 cm FL were subjected to etching in a 1% solution of HCℓ for 3-5 min. After etching, each whole sagitta was then mounted in Euparal[2] and, in most cases, permitted to clear for 4 wk. Short lengths of monofilament line prevented contact of the otolith with the glass cover slip.

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

Each daily growth increment comprises a layer of protein (otolin) and a layer of aragonite (Degens, Deuser, and Haedrich 1969; Pannella 1971). The increments they form are usually about 4-5 micra wide, but this measurement may vary from 1-20 micra (Pannella 1974). On the basis of the aforementioned studies, we assume that the smallest observable growth increments of tuna sagittae are deposited daily.

Increments counts were made from the nucleus, day 1, to the rostrum, antirostrum and postrostrum (terminology of Messieh 1972) for most sagittae. For sagittae from fishes greater than about 60 cm FL, counts were made only to the rostrum and postrostrum. Specimens were examined at magnifications of 400-800 X. A microscope with a "zoom" feature was found to be very useful. Counts were made with the aid of a hand tally.

The technique that we utilized in counting increments in whole, mounted otoliths becomes progressively more difficult in direct relation to the size of the specimen. There is necessarily a certain amount of subjectivity involved and consistency of results is obtained only after a considerable amount of reading experience. Experience is best obtained by beginning with otoliths from young fishes and progressing through older age groups. The initial counts enable the counter to determine the best pathway to follow from the nucleus to the edge of the otolith. Eventually, counts for each measurement either converge on a value or repeated identical counts are obtained. The number of counts required to determine age is dependent on the readability of the otolith. We found that yellowfin tuna sagittae were the easiest to read and albacore the most difficult. Counts for skipjack tuna and yellowfin tuna otoliths were verified by a second reader.

The von Bertalanffy growth parameters were calculated by two computer programs, one by Patrick Tomlinson (Abramson 1971) and the other by Dixon (1973). The computer program BGC3 (Abramson 1971) was used to fit the von Bertalanffy model by the least squares method using all the central Pacific skipjack tuna age-length data. A second fit was made using age-length data of 21 of the 24 skipjack tuna measuring 42.5 cm (FL) or greater. (Note: Three points were determined after fitting.) Age-length data from all 14 yellowfin tuna were used to calculate the von Bertalanffy parameters by use of the computer program for asymptotic regression (BMDO6R) of the Biomedical Computer Programs (Dixon 1973).

RESULTS AND DISCUSSION

SKIPJACK TUNA

Fig. 1 Table 1 The age-length relation of the 51 skipjack tuna specimens from the central Pacific is plotted in Figure 1. Three stanzas of linear growth are apparent. Two sets of regression equations with both age and length as independent variables for the three stanzas are given in Table 1. The regression curve for the nine smallest skipjack tuna intercepts the ordinate at 0.577 mm and, by extrapolation, the regression equation for the second growth stanza at a length of 26.7 cm FL and an age of 5.4 mo (1 mo = 30.4 days). The second and third stanzas intersect at a length of 70.26 cm FL and an age of 23.4 mo.

Utilizing the applicable regression equations, the estimated fork lengths of central Pacific skipjack tuna for the following ages are: 0.5 yr: 28.0 cm; 1.0 yr: 42.6 cm; 1.5 yr: 57.2 cm; 2.0 yr: 71.0 cm; 2.5 yr: 76.3 cm; 3.0 yr: 81.6 cm. The estimated daily growth rates are 1.46 mm/day to a length of about 26.7 cm; 0.799 mm/day to about 70.26 cm; and 0.029 mm/day to greater than 80 cm.

Fig. 2 In order to facilitate comparison of our skipjack tuna growth estimates with those of earlier studies, von Bertalanffy growth parameters were obtained from 21 of the largest specimens. The resulting growth curve and data points are given in Figure 2, along with curves and parameters from other growth studies of central Pacific skipjack tuna populations. Because our data provide a direct estimate of a fork length of 42.6 cm at an age of 1 yr for central Pacific skipjack tuna, growth curves for all earlier studies for this region were recalculated and plotted from these coordinates. Brock's (1954) estimate was based on modal progressions for data obtained over a 5 yr period. Rothschild's (1967) estimate was based on corrected data from 35 long-term tag returns. Joseph and Calkins (1969) used Rothschild's uncorrected data to obtain other estimates of L_∞ and K. Skillman's (MS)[3] estimates are based on more than 356 tag returns obtained during a 2 yr period.

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[3]Skillman, R. A. Estimates of von Bertalanffy growth parameters for skipjack tuna, Katsuwonus pelamis, from capture-recapture experiments in the Hawaiian Islands. Manuscript in preparation. Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812.

Our estimates of skipjack tuna L_∞ (101.5 cm for 50 specimens and 92.9 cm for 21 specimens 42.5 cm FL or larger) for the central Pacific area are higher than the estimates by Brock (1954) and Rothschild (1967), but in good agreement with Skillman's estimates of 101.1 cm for males and 92.4 cm for males and females combined. Our K estimates of 0.5515 (50 specimens) and 0.7618 (21 large specimens are higher than those calculated by Skillman (MS, see footnote 3). Skillman's estimates of K are 0.3850 for males and 0.4741 for both males and females combined (Skillman, MS, see footnote 3).

YELLOWFIN TUNA

Plots of the 14 yellowfin tuna sagittae from the central

Fig. 3 Pacific (Appendix Table 2) are given in Figure 3. Linear growth

Table 2 is indicated for about the first 14 mo of life (Table 2). At about 14 mo the growth curve appears to begin either another linear growth phase or else the initial phase of asymptotic growth. A von Bertalanffy growth equation was successfully fitted to the data and the growth parameters obtained were: L_∞ = 173.4 cm; K = 0.3768, t_0 =-0.0367. Calculated fork length at various time intervals using the above parameters are as follows: 1 yr: 56.1 cm; 2 yr: 92.9 cm; 3 yr: 118.2 cm; 4 yr: 135.5 cm; 5 yr: 147.4 cm.

Using the otolith data, we derived age-length relations for yellowfin tuna as follows: 0.5 yr: 27 cm; 1.0 yr: 53 cm; 1.5 yr: 73 cm; 2.0 yr: 89.5 cm; 2.5 yr: 106.4 cm.

Our otolith data indicate daily growth rates of central Pacific yellowfin tuna to be 1.44 mm/day to a length of 64.5 cm and 0.88 mm/day between lengths of 64.5 and greater than 93 cm.

Our aging of yellowfin tuna by otoliths is, within the size range examined, in good agreement with most earlier studies for this species from the eastern and central Pacific Ocean. The results of aging by scales (Yabuta, Yukinawa, and Warashina 1960) and length-frequency mode progression (Hennemuth 1961) are given in Figure 3 for comparison. It has been suggested that growth of yellowfin tuna in the eastern Pacific between the lengths of 50 and 100 cm is linear (Inter-American Tropical Tuna Commission 1972, 1974).

Growth rates of 0.6 to 1.0 mm/day were also reported in the eastern Pacific (Inter-American Tropical Tuna Commission 1972, 1974).

ALBACORE

Age estimates were made on four albacore between 51.0 and 65.7 cm FL and the results are given in Appendix Table 3.

CONCLUSIONS

Growth information on a daily basis provides much greater insight into the growth patterns of teleost fishes than do traditional techniques. Linear growth has been demonstrated previously by this method for an endemic Hawaiian engraulid (Struhsaker and Uchiyama, in press). Data presented here demonstrate three stanzas of linear growth for skipjack tuna ranging in size from 3 to 80 cm FL. This study also shows yellowfin tuna to have at least one stanza of linear growth (7 to 64 cm FL).

Linear growth during at least part of the growth history has been previously suggested for yellowfin tuna (Inter-American Tropical Tuna Commission 1972, 1974) and skipjack tuna (Yoshida 1971).

It would appear that further investigation of the phenomenon of linear growth of fishes is warranted.

On the basis of present knowledge, it would seem that our assumption that the growth increments of tuna sagittae are deposited daily is warranted. This is supported by the relatively good agreement of our skipjack tuna and yellowfin tuna growth curves derived from otolith counts and previous studies utilizing other age estimation techniques.

Estimation of growth rates from daily growth increments of sagittae is subject to two possible sources of error. One potential source is that increments may not be deposited during some physiological activity such as reproduction. This is apparently the case for four species of boreal gadoids investigated by Pannella (1971). Another source is differential error during increment enumeration. If fewer rings are counted than actually exist, this, in addition to nondeposition of daily increments, would result in a much faster growth rate estimation (and a resulting high K value).

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Table 1.--Length-age and age-length regression equations of linear growth stages of skipjack tuna.

Stage 1 (3.6-16.03 cm FL)

Increments = 0.81385 + 6.065565 (fork length in centimeters)

Fork length (in centimeters) = 0.05770 + 0.160638 (increments)

Stage 2 (27-66.5 cm FL)

Increments = -164.78172 + 12.426894 (fork length in centimeters)

Fork length (in centimeters) = 13.38750 + 0.080110 (increments)

Stage 3 (70.1-80.3 cm FL)

Increments = -1637.49818393 + 33.434309 (fork length in centimeters)

Fork length (in centimeters) = 49.26771 +0.029571 (increments)

Table 2.--Length-age and age-length regression equations of linear growth stages of yellowfin tuna.

Stage 1 (7-61.3 cm FL)
Increments = -4.36260 + 6.934023 (fork length in centimeters)
Fork length (in centimeters) = 0.73284 + 0.143801 (increments)
Stage 2 (66.9-93.0 cm FL)
Increments = -288.35816 + 11.347093 (fork length in centimeters)
Fork length (in centimeters) = 25.50136 + 0.87983 (increments)

Figure 1.--Growth model of skipjack tuna, Katsuwonus pelamis, in the central Pacific as determined by otolith examinations.

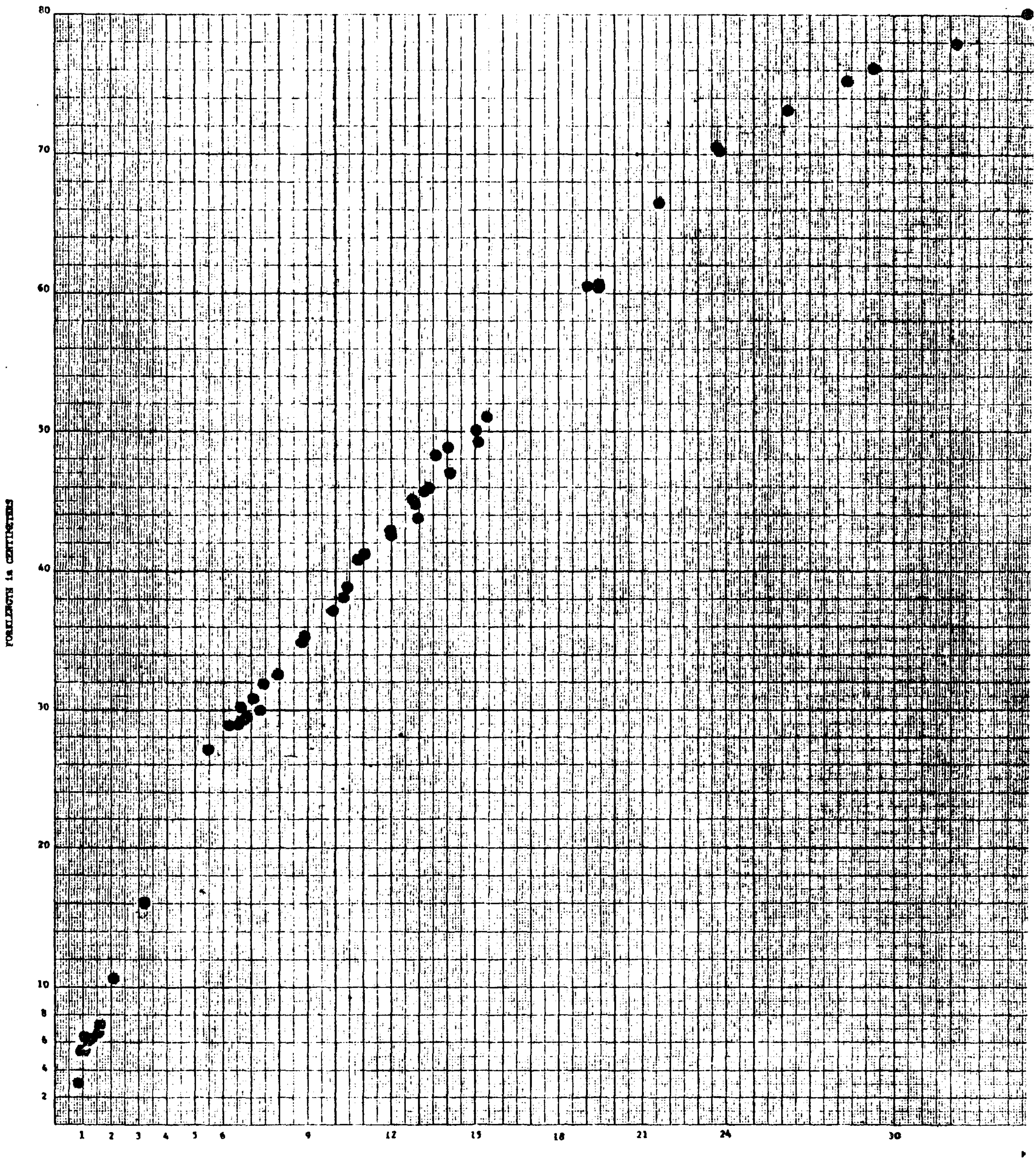
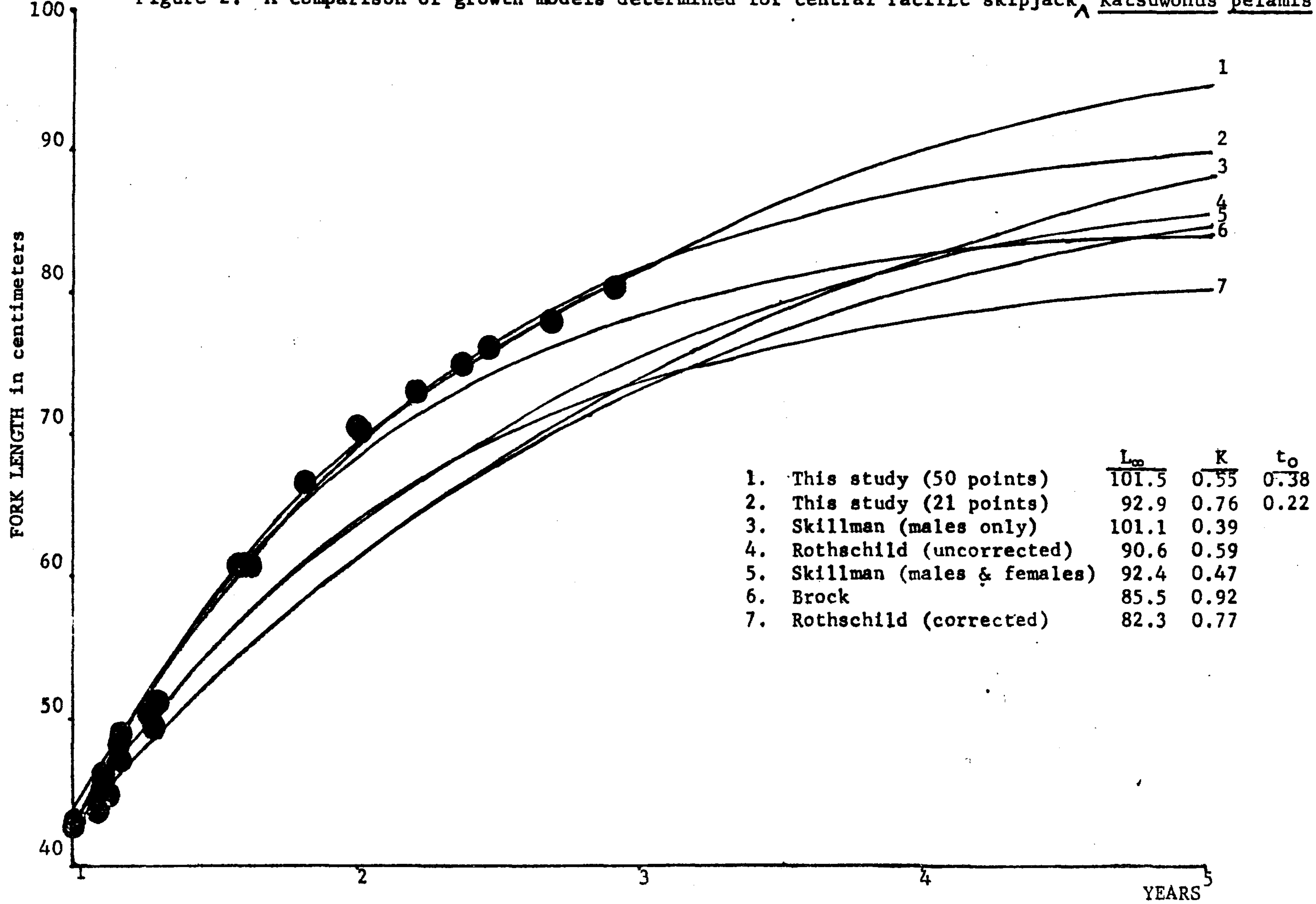


Figure 2. A comparison of growth models determined for central Pacific skipjack tuna, *Katsuwonus pelamis*.



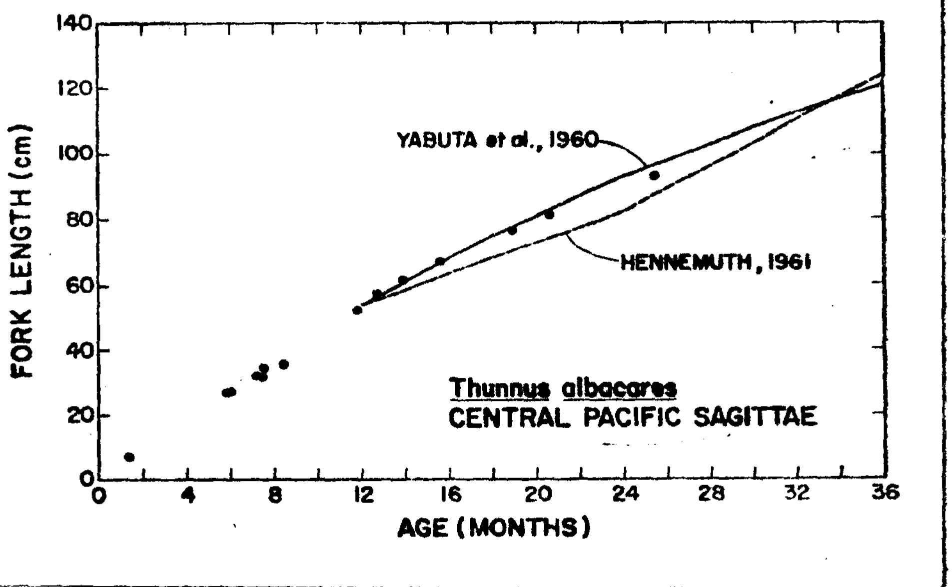


Figure 3.--Growth model of yellowfin tuna, Thunnus albacares in the central Pacific as determined by otolith examinations.

Appendix Table 1.--Age determinations of skipjack tuna from the central Pacific by otolith examinations.

Fork length	Sex[1]	Increments	Months	Years	Area of capture	Date of capture
cm						
[2]3.67	--	25	0.82	0.07	Christmas Island	Aug. 1972
5.322	--	27	0.89	0.07	do	Aug. 1972
[2]5.34	--	33	1.09	0.09	do	Aug. 1972
[2]6.09	--	36	1.18	0.10	do	Aug. 1972
[2]6.17	--	39	1.28	0.11	do	Aug. 1972
[2]6.31	--	36	1.18	0.10	do	Aug. 1972
[2]6.61	--	47	1.55	0.13	do	Aug. 1972
7.295	--	49	1.61	0.13	do	Aug. 1972
10.670	--	64	2.10	0.18	do	Aug. 1972
[2]16.03	--	98	3.22	0.27	do	Aug. 1972
27.0	--	167	5.49	0.46	Hawaii	14 Dec. 1972
28.9	--	190	6.25	0.52	do	14 Dec. 1972
28.9	--	200	6.58	0.55	do	13 Dec. 1972
29.3	--	205	6.74	0.56	do	13 Dec. 1972
29.5	--	209	6.88	0.57	do	14 Dec. 1972
29.9	--	224	7.37	0.61	do	14 Dec. 1972
30.2	--	202	6.64	0.55	do	13 Dec. 1972
30.9	--	209	6.88	0.57	do	13 Dec. 1972
31.9	--	227	7.47	0.62	do	13 Dec. 1972
32.5	--	241	7.93	0.66	do	13 Dec. 1972
34.8	--	268	8.82	0.73	do	14 Dec. 1972
35.3	--	270	8.88	0.74	do	14 Dec. 1972
37.2	--	301	9.90	0.82	do	13 Dec. 1972
38.1	--	315	10.36	0.86	do	Apr. 1972
38.8	--	318	10.46	0.87	do	Apr. 1972
40.8	--	330	10.86	0.90	do	8 Dec. 1972
41.2	--	337	11.09	0.92	do	8 Dec. 1972

Appendix Table 1.--Continued.

Fork length	Sex	Increments	Months	Years	Area of capture	Date of capture
42.5	--	366	12.04	1.00	Hawaii	12 Dec. 1972
42.8	--	363	11.94	0.99	do	7 Dec. 1972
43.8	F	393	12.93	1.08	do	Aug. 1972
44.8	--	392	12.89	1.07	do	9 Dec. 1972
45.2	--	389	12.80	1.07	do	8 Dec. 1972
45.7	--	402	13.22	1.10	do	8 Dec. 1972
45.9	F	408	13.42	1.12	do	7 Dec. 1972
47.0	--	430	14.14	1.18	do	9 Dec. 1972
48.2	--	413	13.59	1.13	do	9 Dec. 1972
48.7	--	426	14.01	1.17	do	8 Dec. 1972
49.3	F	467	15.36	1.28	Christmas Island	Feb. 1973
50.1	M	460	15.13	1.26	Hawaii	Aug. 1972
51.0	M	472	15.53	1.29	do	Aug. 1972
60.4	M	593	19.51	1.62	Christmas Island	18 Aug. 1972
60.5	M	581	19.11	1.59	do	18 Aug. 1972
60.5	M	592	19.47	1.62	do	18 Aug. 1972
66.5	M	660	21.71	1.81	do	7 Feb. 1973
70.1	F	724	23.82	1.98	Hawaii	4 July 1975
70.4	F	714	23.49	1.96	do	4 July 1975
73.2	M	800	26.32	2.19	do	Apr. 1973
75.2	M	865	28.45	2.37	do	Apr. 1973
76.1	M	891	29.30	2.44	do	4 Nov. 1974
77.8	M	979	32.20	2.68	do	4 Nov. 1974
80.3	F	1,054	34.67	2.88	do	4 Nov. 1974

[1]F = female; M = male.

[2]Converted from standard length.

Appendix Table 2.--Age determinations of yellowfin tuna from the central Pacific by otolith examinations.

Fork length	Sex[1]	Increments	Months	Years	Area of capture	Date of capture
cm						
7.0	--	44	1.45	0.12	Palmyra	Sep. 1972
26.7	--	176	5.79	0.48	Hawaii	20 Jan. 1974
27.7	--	181	5.95	0.49	do	17 Jan. 1974
32.0	--	225	7.40	0.61	do	20 Jan. 1974
32.1	--	220	7.23	0.60	do	20 Dec. 1973
34.3	--	228	7.50	0.62	do	21 Dec. 1972
35.8	--	255	8.39	0.69	do	20 Jan. 1974
52.1	M	359	11.81	0.98	Christmas Island	8 Feb. 1973
57.4	M	387	12.73	1.06	do	8 Feb. 1973
61.3	--	422	13.84	1.15	do	8 Feb. 1973
66.9	--	475	15.73	1.20	do	8 Feb. 1973
76.3	M	575	18.85	1.57	do	7 Feb. 1973
81.1	F	626	20.52	1.72	do	6 Feb. 1973
93.0	M	771	25.28	1.11	do	8 Feb. 1973

[1]M = male; F = female.

Appendix Table 3.--Age determinations of albacore from the eastern Pacific by otolith examinations.

Fork length	Increments	Months	Years	Area of capture		Date of capture
cm						
51.0	554	18.22	1.52	San Juan Seamount		8 Aug. 1974
52.0	590	19.41	1.62	do		8 Aug. 1974
62.9	735	24.18	2.01	46°15'N	125°W	29 Sep.-3 Oct. 1974
65.7	761	25.03	2.08	46°15'N	125°W	29 Sep.-3 Oct. 1974