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A COMPARATIVE STUDY ON THE AGE AND GROWTH OF YELLOWFIN TUNAS FROM THE PACIFIC AND ATLANTIC OCEANS*

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ABSTRACT

Scales from the body portion just below the sixth dorsal finlet, counted from behind, were selected for study on the age and growth of yellowfin tuna (*Thunnus albacares*) from the Pacific and Atlantic Oceans. There is a remarkable difference between the relationships of scale-radii and fork length in the case of specimens from the Pacific and Atlantic Oceans; and the asymptotic size as well as the sizes at time of ring-formation derived upon these regressions show much difference in values. The growth curve estimated for the Atlantic specimens is mostly followed by the progression of modal length of size composition data. The growth rate in the period prior to l_1 of the Atlantic yellowfin tuna seems to be much rapid than in the case of the Pacific yellowfin tuna, excepting in those cases where the duration needed for the formation of r_1 of the Atlantic specimens is longer than that of the Pacific specimens. The size of the Atlantic yellowfin tuna after l_1 is larger than that of the Pacific yellowfin tuna of same "age", supposing that the r_i we read for the Atlantic specimens corresponds to the r_i of the Pacific specimens.

I. INTRODUCTION

The age and growth studies by means of scale-reading was made on the yellowfin tuna from the Pacific and Atlantic Oceans, for the purpose of comparing the growth of the species from the two oceans.

A number of works have been carried out on the age and growth studies of yellowfin tuna from the Pacific Ocean (AIKAWA and KATO, 1938; MOORE, 1951; NOSE et al, 1955; NOSE et al, 1957; YABUTA and YUKINAWA, 1957 and 1959; HAYASHI, 1958; YABUTA et al, 1960; HENNEMUTH, 1961; and SHOMURA, 1966). Reviewing these reports, SHOMURA (1966) stated that the estimates of age and growth for the specimens from the various parts of the Pacific Ocean agree rather closely. On

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* This work has been undertaken in compliance with a request by **Far Seas Fisheries Research Laboratory** (former **Nankai Regional Fisheries Research Laboratory**); and it forms a part of the thesis by YANG submitted for the Ph. D. under the guidance of Professor Yoshio HIYAMA and Associate Professor Yukio NOSE, in the University of Tokyo.

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the yellowfin tuna in the Atlantic Ocean, however, very few papers concerning the age and growth of the species have been published. NAKAGOME (1963) reported that there is no difference between the size composition of male and female of yellowfin tuna from the waters off Ghana and the growth curve estimated from these size composition data agree well with that of YABUTA and YUKINAWA (1959) who derived it from the size composition data of yellowfin tuna caught in the Equatorial Pacific.

In 1964, NOSE, one of the authors in the present study, found in a preliminary study that the scale-size of yellowfin tuna from the Atlantic Ocean is smaller than that of the Pacific specimens. With this as a start and succeeded by YANG, the present study has been carried out. The results obtained substantiated, first, the above remarks, i.e., the relationships of scale-size and fork length show significant difference between the specimens from the two oceans. And hence the fish size at the time of ring-formation derived upon these relationships in one ocean is significantly different from the other ocean. The growth curve obtained for the Atlantic specimens has been investigated with the data of size composition.

II. ACKNOWLEDGEMENTS

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III. MATERIALS

Scales were collected from 210 Pacific specimens and 296 Atlantic specimens,

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together with the measurements on fork length of each specimen, drawn from the fish landed at the ports and fish markets in Japan from August, 1964 through September, 1965 (Table 1).

Table 1. The specimens of yellowfin tuna used for collecting of scales.

PACIFIC SPECIMENS

Sample number	Fishing date	Fishing ground	Sample size	Range of fork length
1	Feb.-March, 1965	3°-11° N, 170° E	35	1188-1355 mm
2	May, 1965	15° N, 130°-135° E	21	900-1005 mm
3	May, 1965	19° N, 113° E	54	1180-1370 mm
4	July, 1965	19°-21° N, 145° E	31	783- 983 mm
5	July, 1965	33° N, 144° E	34	598- 832 mm
6	Aug., 1965	16°-21° N, 124°-130° E	35	935-1392 mm
ATLANTIC SPECIMENS				
1	Aug., 1964	39.5° N, 61° W	32	1294-1513 mm
2	Aug., 1964	17° N, 83° W	23	826-1513 mm
3	Dec., 1964-Jan., 1965	2°-3° S, 3°-6° E	41	870-1450 mm
4	Apr., 1965	9° N, 23° W	55	700-1485 mm
5	Mar.-May, 1965	11°-12° N, 51°-52° W	30	980-1510 mm
6	Mar., 1965	0°-5° N, 38°-44° W	22	727-1520 mm
7	Sept., 1965	6° S, 4° E	18	1150-1493 mm
8	Sept.-Oct., 1965	7°-8° N, 14°-15° W	25	950-1490 mm
9	Nov., 1965	5°-6° S, 33°-34° W	20	1108-1550 mm
10	Aug.-Sept., 1965	10°-20° N, 20°-30° W	30	1040-1495 mm

Collection of scales and measurements for the Pacific specimens were made on those fishes in fresh or thawed condition, while the Atlantic specimens were all rigidly frozen.

The size composition data of the Atlantic yellowfin tuna used in this study were from the fishes caught by the long-line fishery boats, in the Atlantic Ocean from 1962 through 1965, operated by the Misaki Ship-owners Association and collected by Mr. NAKAGOME, Kanagawa Prefectural Fisheries Laboratory (Table 7 and Figure 11).

IV. METHOD

Scales were collected from the region of the body surface just below the sixth dorsal finlet, counted from behind. The selection of this body portion was based on a preliminary examination, as described in next section.

After soaking in water and removing the slime and adhering tissue, the collected sacles were dry-mounted between two glass-slides. Observations and measurements of scale-radius were made on the images enlarged by 20 times on a screen of projector, Nikon Model 6-C. Five scales per fish were read and measured on the ring-radii and scale-radii. The mean values for each specimen were calculated and used for analysis in the present study.

V. RESULTS

1. Scales from Various Body Portions

Selection of body portion was made in the following manner. Scales from 15 different body portions, as shown in Figure 1, of a Pacific and an Atlantic specimens were collected; and the coefficients of variations as well as the mean scale-radii of 16 scales were calculated for each body portion (Table 2). Then, considering the results obtained and examining the thickness, regularity of scale-shape, clearness of ridges and possibility of ringreading of the scales from each body portion, the region just below the sixth dorsal finlet was selected.

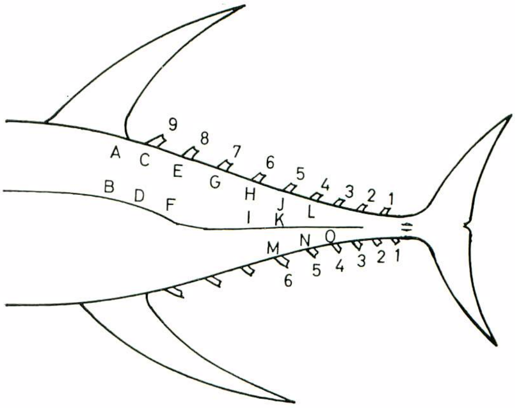

Fig. 1. The various body portions of yellowfin tuna from where scales were collected.

Table 2. The means of scale-radii and coefficients of variation of the scales collected from the various body portions of the yellowfin tuna. Body portions refer to Figure 1.
* means in mm, ** coefficients of variation in %.

PACIFIC SPECIMEN (115.0 cm)

Body portion	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Mean*	2.63	2.47	2.45	2.49	2.14	2.33	2.22	2.08	2.49	2.02	2.54	1.95	2.33	2.29	2.40
C. V.**	9.01	7.00	5.63	4.90	5.33	4.89	6.80	6.78	10.92	9.75	10.24	7.38	6.01	9.04	5.81

ATLANTIC SPECIMEN (113.8 cm)

Body portion	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Mean*	1.61	1.48	1.57	1.34	1.42	1.15	1.39	1.35	1.37	1.25	1.27	1.23	—	1.58	—
C. V.**	7.45	3.65	6.69	5.82	6.34	2.78	4.82	5.04	4.31	6.96	6.06	3.74	—	3.10	—

2. Variation of Scale-Radii Within and Between Fish

Stratified by fork length and number of rings on scale, the variances of scale-radii within and between fish were calculated. A part of the results are shown in Table 3. It is obvious that the variances within fish were almost independent of the fork length as well as the ring-number; but, the variances between fish are apparently greater in values for the specimens larger in size and numbers of rings.

Table 3. Variation of scale-radii within and between fish.
k: number of fish, n: number of scales measured per fish,
$\bar{R}$: mean of scale-radii, V_w: variance of scale radii within fish,
V_b: variance of scale-radii between fish,
$S_{\bar{R}}/(k-1)$: total variance, c: constant for the analysis of range.

(1). Fork length: 913–938 mm; Number of rings on scale: 3

Specimen No.	Scale-radii (in mm)					$\bar{R}$	Range
102	1.76	1.64	1.76	1.72	1.48	1.67	0.28
114	1.60	1.48	1.56	1.48	1.48	1.52	0.12
119	1.64	1.68	1.60	1.52	1.68	1.62	0.16
109	1.64	1.40	1.56	1.64	1.56	1.51	0.28
108	1.72	1.56	1.64	1.36	1.60	1.58	0.36
						$\Sigma\bar{R}$ = 7.91,	0.24
						$\Sigma\bar{R}^2$ = 12.51,	(mean)

n = 5, k = 5

$\sqrt{V_w}$ = mean range/c = 0.102 (mm)

$S_{\bar{R}}^2 = \Sigma\bar{R}^2 - (\Sigma\bar{R})^2/k = 0.0198$

$V_b = S_{\bar{R}}^2/(k-1) - V_w/n = 0.0029$, $\sqrt{V_b} = 0.054$ (mm)

(2). Fork length: 1180–1205 mm; Number of rings on scale: 4

Specimen No.	Scale-radii (in mm)					$\bar{R}$	Range
69	1.64	1.72	2.00	1.88	1.72	1.79	0.36
92	2.24	1.92	2.00	1.96	1.92	2.01	0.32
97	1.92	2.00	1.96	1.96	2.00	1.97	0.08
124	1.88	2.00	1.92	2.08	1.84	1.94	0.24
125	1.76	1.72	2.20	2.16	1.96	1.96	0.48
141	1.84	2.04	1.80	1.92	2.12	1.94	0.32
						$\Sigma\bar{R}$ = 11.62,	0.30
						$\Sigma\bar{R}^2$ = 22.52,	(mean)

n = 5, k = 6

$\sqrt{V_w}$ = mean range/c = 0.127 (mm)

$S_{\bar{R}}^2 = \Sigma\bar{R}^2 - (\Sigma\bar{R})^2/k = 0.0276$

$V_b = S_{\bar{R}}^2/(k-1) - V_w/n = 0.0023$, $\sqrt{V_b} = 0.048$ (mm)

3. Relationship Between Scale-Radii and Fork Length

The relationships between mean scale-radius and fork length were calculated, as shown in Figure 2 and 3, for the Pacific and Atlantic specimens respectively. Covariance analysis were, then, applied to test the significance of difference between the relationships of scale-radii on fork length of the specimens from the two oceans. As shown in Figure 4 and Table 4, the scale-radii of the Pacific specimens are apparently larger than that of the Atlantic specimens for the same fork length; and the difference in regression line, regression coefficient and adjusted mean are significant.

Table 3. ···continued.

(3). Fork length: 1230–1247 mm; Number of rings on scale: 4

Specimen No.	Scale-radii (in mm)					$\bar{R}$	Range
72	2.20	1.96	1.88	1.80	1.80	1.93	0.40
73	1.80	1.76	1.76	1.90	2.00	1.85	0.24
74	1.96	1.76	1.96	1.60	2.04	1.86	0.44
77	2.00	2.00	1.84	1.88	2.00	1.94	0.16
81	1.84	1.72	2.08	1.80	1.84	1.86	0.28
87	2.12	1.92	2.12	2.40	2.00	2.11	0.48
89	2.00	1.96	1.80	1.92	1.88	1.91	0.20
95	2.32	2.12	1.92	2.00	2.08	2.10	0.40
98	2.12	1.96	2.20	2.20	2.16	2.13	0.24
100	2.00	2.16	2.24	2.12	2.28	2.16	0.28
142	2.20	2.52	1.96	2.04	2.12	2.17	0.56

$\Sigma\bar{R}=22.02$, 0.33

n=5, k=11 $\Sigma\bar{R}^2=44.23$, (mean)

$\sqrt{V_w}$ = mean range/c = 0.143 (mm)

$S_{\bar{R}}^2=\Sigma\bar{R}^2-(\Sigma\bar{R})^2/k=0.1704$

$V_b=S_{\bar{R}}^2/(k-1)-V_w/n=0.0129$, $\sqrt{V_b}=0.114$ (mm)

(4). Fork length: 1250–1280 mm; Number of rings on scale: 5

Specimen No.	Scale-radii (in mm)					$\bar{R}$	Range
67	2.08	2.04	2.00	2.04	2.00	2.03	0.08
70	2.08	2.40	2.36	2.04	2.12	2.20	0.36
78	2.32	2.40	2.16	2.52	2.40	2.36	0.36
83	1.80	2.16	2.16	1.92	2.16	2.04	0.36
85	2.20	2.16	2.56	2.56	2.12	2.32	0.44
101	2.20	2.08	2.12	2.04	2.28	2.14	0.24
143	2.24	1.88	2.20	2.20	2.08	2.12	0.36

$\Sigma\bar{R}=15.22$, 0.31

n=5, k=7 $\Sigma\bar{R}^2=33.17$, (mean)

$\sqrt{V_w}$ = mean range/c = 0.134 (mm)

$S_{\bar{R}}^2=\Sigma\bar{R}^2-(\Sigma\bar{R})^2/k=0.099$

$V_b=S_{\bar{R}}^2/(k-1)-V_w/n=0.0128$, $\sqrt{V_b}=0.113$ (mm)

4. Rings on the Scale and Measurements of Ring-Radii

Thousands of scales have been examined and we could not found any difference between the scale characters of the specimens from the two oceans, in spite of the apparent difference in the size of scale-radii as described in the previous section; and it made us possible to examine the scales of the Pacific and Atlantic specimens in random order, for avoiding the possible effects of subjectivity in scale-reading and measuring. Ring counting and measuring were made based on the reports by those authors who had worked on the aging of yellowfin tuna, especially that of Nose et al (1955), Yabuta et al (1960).

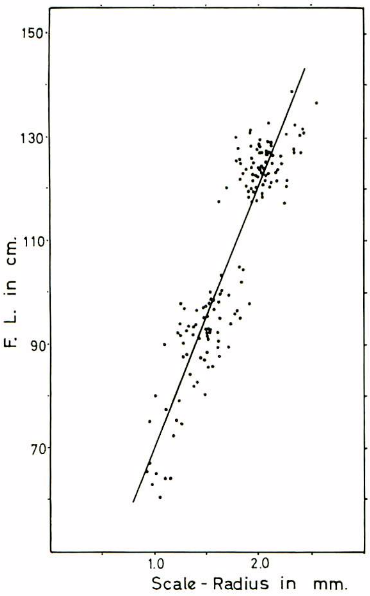

Fig. 2. Relationship between scale-radii and fork length of the Pacific yellowfin tuna.

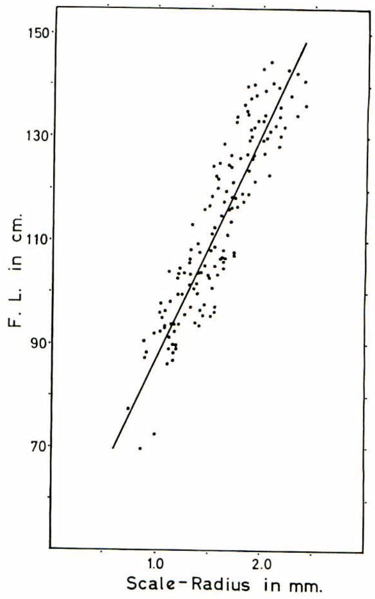

Fig. 3. Relationship between scale-radii and fork length of the Atlantic yellowfin tuna.

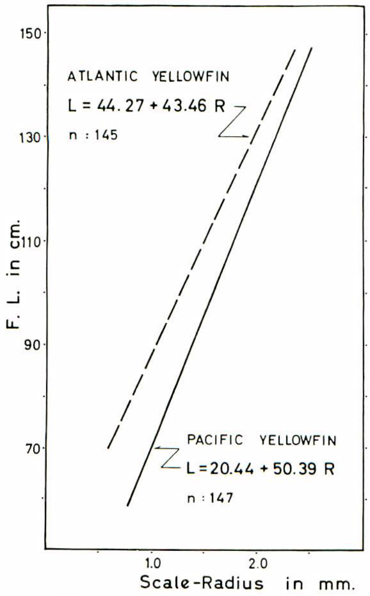

Fig. 4. Comparison of the relationship between scale-radius and fork length of the Pacific and Atlantic yellowfin tuna.

Bell (1962) stated that diagnosing of annuli (ring) necessitated considering several features, such as, crowding of circuli, discontinuous circuli, and transparent circuli areas as reported by Nose et al (1955). In the case of yellowfin tuna scales examined on the screen of a projector by transist light, we were convinced that most of the rings could be distinguished by crowding of circuli in the anterior part, i. e., the portion of the scale overlapped by the one in front, and by discontinuous circuli in the lateral parts of the scale.

Photographs of yellowfin tuna scales taken on the screen of a projector are shown in Figure 5, showing the rings and the measuring axis.

As mentioned already, five scales per each specimen were examined and measured; and the mean values were calculated for each specimen as the representative value of ring-radius (radii) used for analysis.

Table 4. Result of test for the difference of relationship between scale radius and fork length of Atlantic and Pacific tuna.

	Atlantic yellowfin	Pacific yellowfin
N	145	147
ΣX	233.84	251.75
ΣX^2	394.02	453.88
ΣY	16583.9	15692.6
ΣY^2	1938779.5	1744031.4
$\Sigma X \cdot Y$	27479.53	28021.58
$S_{(xx)}$	16.91	22.76
$S_{(yy)}$	42050.2	68808.97
$S_{(xy)}$	734.85	1146.67
r	0.8715	0.9163
b	43.46	50.39
a	44.27	20.44
$S_{y \cdot x}$	10116.2	11033.5
$V_{y \cdot x}$	70.7427	76.0934
$\sqrt{V_{y \cdot x}}$	8.411	8.723
V_b	4.1834	3.3433
$\sqrt{V_b}$	2.04	1.83

$F_0 = 1.0756$

$S_{y \cdot x(T)} = 32556.5$ $S_{y \cdot x(B)} = 21620.02$ $S_{y \cdot x(W)} = 21149.74$

$F_r = 77.7^{**}$ $F_b = 6.40^{*}$ $F_a = 146.2^{**}$

Note: X: scale radius in mm, Y: fork length in cm, b: regression coefficient, r: correlation coefficient, a: intercept, *: significant at 5% level, **: significant at 1% level. $\sqrt{V_{y \cdot x}}$: standard deviation from regression, $\sqrt{V_b}$: standard deviation of regression coefficient.

F_r, F_b and F_a are the variance ratios to test the significance of the regression line difference, regression coefficient difference and adjusted mean difference respectively.

5. Back-Calculation of the Size of Fish at the Time of Ring-Formation

The values of ring-radii obtained for each specimen were, first, stratified by number of rings; and then, the mean values of ring-radii for each ring group were calculated. As shown in Table 5, no obvious difference in the mean values could be seen for the identical ring-radii between ring groups; and so, the values of ring-radii were pooled for the identical ring and the grand mean values with its 95% confidence limits were derived for the Pacific and Atlantic specimens respectively.

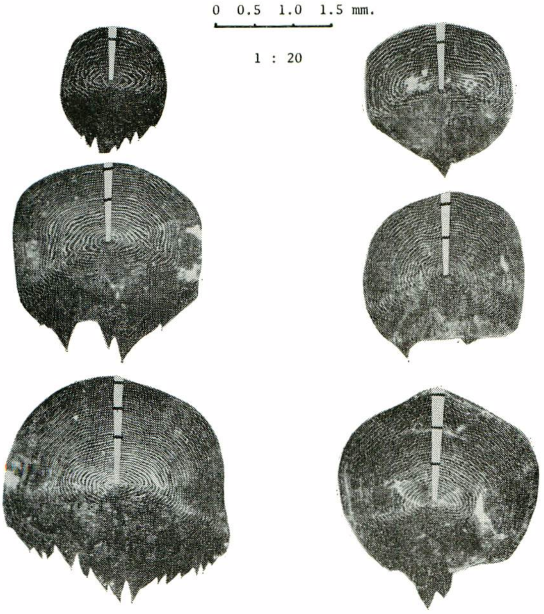

Fig. 5. Yellowfin tuna scales showing the rings and the measuring axis.

Based on the grand mean values of ring-radii obtained above, the fork length at the time of ring-formation, with 95% confidence limits, were derived upon the regression lines obtained in section V-3. The results are listed in Table 5 and shown also in Figure 6, for comparison.

The growth curve in Figure 6 were drawn by free hand. It is apparent from Figure 6 that the size at the time of ring-formation shows significant difference between the two oceans, for the same ring. The sizes at the time of ring-formation

Table 5. Mean ring-radii and the fork length at time of ring-formation; with 95% confidence limits.
$\bar{\bar{r}}$: mean ring-radii in mm; l_i: fork length in cm.

PACIFIC SPECIMENS

Ring group	No. of fish	$\bar{r}_1$	$\bar{r}_2$	$\bar{r}_3$	$\bar{r}_4$	$\bar{r}_5$	$\bar{r}_6$
I	6	0.541					
II	24	0.495	0.957				
III	41	0.511	0.974	1.369			
IV	51	0.503	0.975	1.400	1.761		
V	24	0.506	0.962	1.378	1.750	2.059	
VI	4	0.490	0.893	1.266	1.643	1.969	2.249
$\bar{\bar{r}}_i$		0.51 ±0.023	0.97 ±0.048	1.38 ±0.067	1.75 ±0.093	2.05 ±0.143	2.25 ±0.192
l_i:		45.9 ±4.62	69.2 ±3.08	90.0 ±2.03	108.7 ±1.97	123.5 ±3.52	133.6 ±8.94

ATLANTIC SPECIMENS

Ring group	No. of fish	$\bar{r}_1$	$\bar{r}_2$	$\bar{r}_3$	$\bar{r}_4$	$\bar{r}_5$	
I	3	0.515					
II	28	0.502	0.963				
III	67	0.500	0.955	1.365			
IV	35	0.502	0.968	1.392	1.737		
V	11	0.501	0.969	1.402	1.765	2.039	
$\bar{\bar{r}}_i$		0.50 ±0.017	0.96 ±0.051	1.38 ±0.092	1.74 ±0.110	2.04 ±0.113	
l_i:		66.1 ±4.74	86.0 ±3.01	104.1 ±1.92	120.0 ±3.58	132.9 ±6.34	

for the specimens from both oceans are, then, compared with that recorded by other authors. As shown in Table 6, the values we obtained for the Pacific specimens, agree quite well with those published by YABUTA et al (1960).

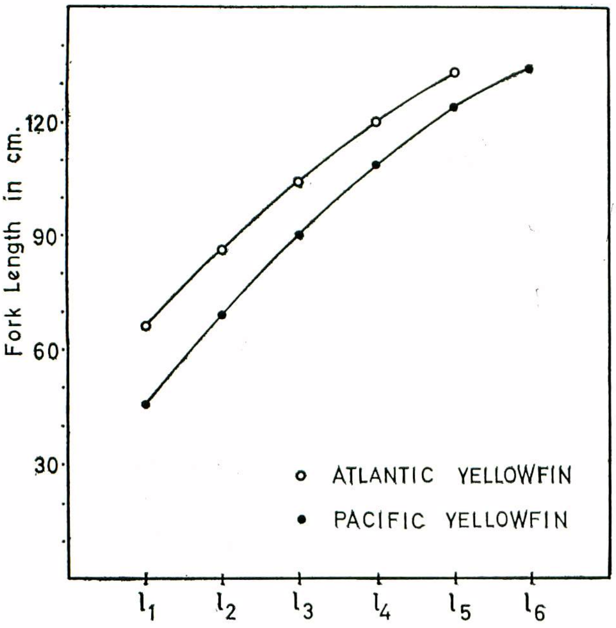

Fig. 6. The fork length at time of ring-formation and the growth curves for the Pacific and Atlantic yellowfin tuna.

6. Walford's Graphic Method and Estimation of Parameters of the Von Bertalanffy Growth Function

WALFORD's graphic method was applied to the size at the time of ring-formation estimated in the previous section, as shown in Figures 7 and 8. The values of l_∞ and K for the Pacific specimens were estimated as,

$$l_{i+1}=31.80+0.8731 l_i$$

$$l_\infty=195.2\ \text{cm}\ ;\ K=0.178$$

and for the Atlantic specimens as,

$$l_{i+1}=28.90+0.8703 l_i$$

$$l_\infty=222.8\ \text{cm}\ ;\ K=0.139$$

Table 6. The fork length at time of ring-formation, in cm, estimated by different authors.

Fork length	l_1	l_2	l_3	l_4	l_5	l_6	l_∞
Atlantic(present study)	66.1	86.1	104.1	120.0	132.9		222.8
Pacific (Present study)	45.9	69.2	90.0	108.7	123.5	133.6	195.2
Pacific* (Yabuta & Yukinawa)	54.3	74.7	92.7	108.2	120.8	131.0	190.1
Pacific** (Yabuta & Yukinawa)	51.0		100.0		125.0		
Pacific*** (Moore)	54		103		136		

* by scale reading,1960.
** by length frequency, 1959.
*** by weight frequency, 1951.

As shown above, there is no much difference between the K values of the specimens from the two oceans; while the asymptotic size for the Atlantic specimens is larger in value than that for the Pacific specimens. The t_0 values for the specimens from both oceans had not been estimated, because of lack of information about the spawning season of yellowfin tuna in the Atlantic

Ocean.

7. Time of Ring-Formation for the Atlantic Yellowfin Tuna

The (R-r_i) values of scales were calculated for the Atlantic specimens.

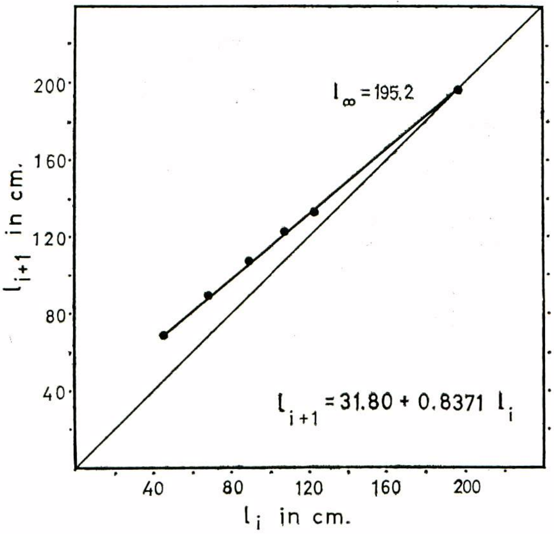

Fig. 7. Walford's graphic method for the Pacific specimens.

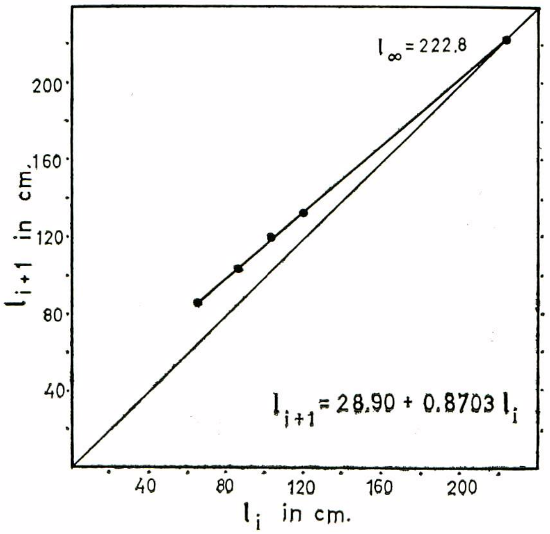

Fig. 8. Walford's graphic method for the Atlantic specimens.

The monthly frequency distributions of the values, stratified by ring number, are shown in Figure 9. Abrupt decrease in (R-r_i) values between March-April and between September-October, respectively, is apparent; and, a similar tendency is significant among the monthly frequency distributions of fork length stratified by ring number as shown in Figure 10.

According to YABUTA et al (1960), the scale-rings of the Pacific yellowfin tuna are formed twice a year, i. e., one in March-April and the other in September-October. So it can be considered that the time of ring-formation for the Atlantic yellowfin tuna is the same as that for the Pacific yellowfin tuna, viz., twice a year, one in March-April and the other in September-October.

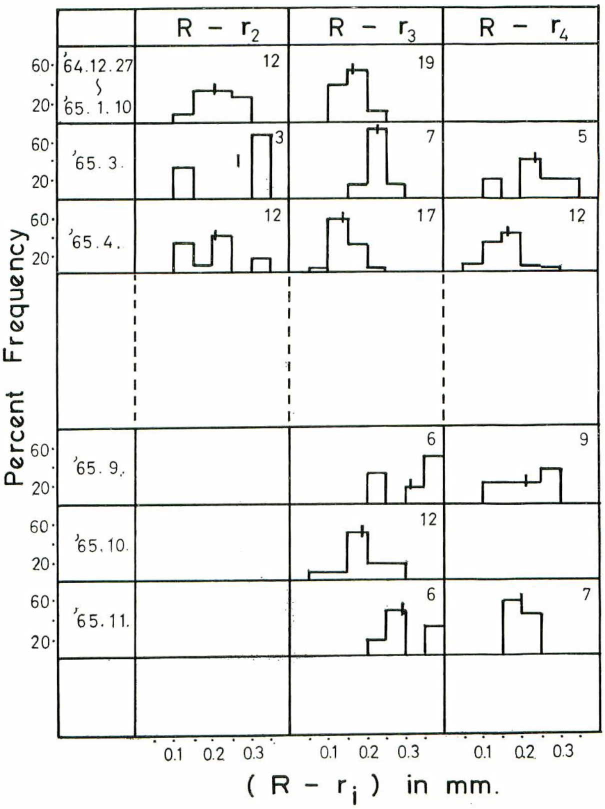

Fig. 9. Monthly variation of marginal growth on the scale of the Atlantic yellowfin tuna. Figure in the body of graph indicate the number of specimens.

8. Modal Length of Size Composition Data of the Atlantic Yellowfin Tuna

The growth curve for the Atlantic specimens was examined with the size composition data collected in the Atlantic Ocean (Table 7 and Figure 11), in the following manner.

Firstly, the three-class moving average was applied to the size composition data collected in 2 cm class-interval. Then, the frequency distribution in percentage was calculated, as shown in Figure 12. The modal length of each sample was picked up and plotted, and the monthly variation of modal length was examined with the growth curve drawn by connecting the sizes at the time of ring-formation. As shown in Figure 13, the growth curve estimated had not been thoroughly followed by the progression of modal length, yet we regarded it as an acceptable result, since the number of modes deviated from the growth curve were not many.

Table 7. The Atlantic yellowfin tuna samples with size composition data.

Sample number	Fishing date	Fishing ground	Sample size	Range of fork length	Name of boat
14	Nov., 1962	5°-10° S, 22°W	52	98-174 cm	18 AZUMAMARU
12	Nov., 1962	18°-19° S, 6-8° E	55	86-158 cm	17 AZUMAMARU
13	Nov., 1962	19°-20° S, 0°-1° E	94	108-166 cm	do.
15	Nov., 1962	15°-16° S, 14°-15°W	135	65-166 cm	21 AZUMAMARU
8	Feb., 1963	1°-3° S, 1°-6°W	609	70-180 cm	8 SEISHOMARU
10	Feb., 1963	8°-9° E, 6°-7° E	628	110-172 cm	17 AZUMAMARU
7	Feb., 1963	1°-2° N, 2°-8°W	364	110-170 cm	18 AZUMAMARU
5	May, 1963	7°-10° N, 28°-31°W	556	114-174 cm	8 SEISHOMARU
22	May, 1963	13°-16° N, 20°-22°W	289	118-164 cm	25 SAKIYOSHIMARU
49	May, 1963	11°-13° N, 28°W	161	122-180 cm	21 AZUMAMARU
50	June, 1963	12° N, 45°W	32	84-164 cm	do.
21	June, 1963	8°-11° S, 1E°-1°W	79	124-164 cm	18 AZUMAMARU
2	July, 1963	11°-12° N, 40°-41°W	175	104-162 cm	18 YUKOMARU
3	Aug., 1963	10°-11° N, 39°-40°W	270	110-168 cm	25 SAKIYOSHIMARU
11	Aug., 1963	8°-9° S, 11°-12° E	257	110-162 cm	21 AZUMAMARU
16	Sept., 1963	4°-5° N, 39°-40°W	404	92-168 cm	17 AZUMAMARU
6	Sept. ,1963	14°-15° N, 23°-24°W	101	128-156 cm	18 YUKOMARU
1	Oct., 1663	8°-9° N, 52°-53°W	81	128-158 cm	18 YUKOMARU
18	Nov., 1963	4° N, 0°W	319	104-170 cm	21 ZUIKOMARU
9	Dec., 1963	0°-1° S, 8°-9° E	324	102-172 cm	18 AZUMAMARU
17	Feb., 1964	3°-5° N, 18°-21°W	887	84-166 cm	17 AZUMAMARU
25	Mar., 1964	4° N, 19°W	36	84-156 cm	21 ZUIHOMARU
26	Mar., 1964	2°-3° S, 33°-34°W	69	110-164 cm	do.
28	Apr., 1964	0°-2° S, 37°-38°W	72	92-160 cm	do.
29	Apr., 1964	0° N, 41°W	101	90-160 cm	do.
32	Apr., 1964	1°-2° S, 31°W	182	80-180 cm	18 AZUMAMARU
33	Apr., 1964	4°-6° S, 30°W	57	120-168 cm	do.
36	Apr., 1964	1° S, 29°-30°W	130	112-193 cm	8 SEISHOMARU
39	Apr., 1964	3°-5° S, 0°W	327	100-158 cm	GOYOMARU
42	Apr., 1964	14°-15° S, 62°W	70	120-178 cm	3 BOCHOMARU
43	Apr., 1964	11°-15N°, 56°-57°W	70	100-156 cm	do.
45	May, 1964	20° N, 62°-63°W	20	120-160 cm	do.
61	June, 1964	18°-22° N, 49°-53°W	61	120-164 cm	KOUNMARU
47	July, 1964	10°-11° N, 30°-32°W	143	112-164 cm	57 KOTOSHIROMARU
48	Aug., 1964	15° N, 24°-26°W	63	114-162 cm	do.

VI. DISCUSSION

As shown in Table 6, the asymptotic size, l_∞, and the sizes at time of ring-

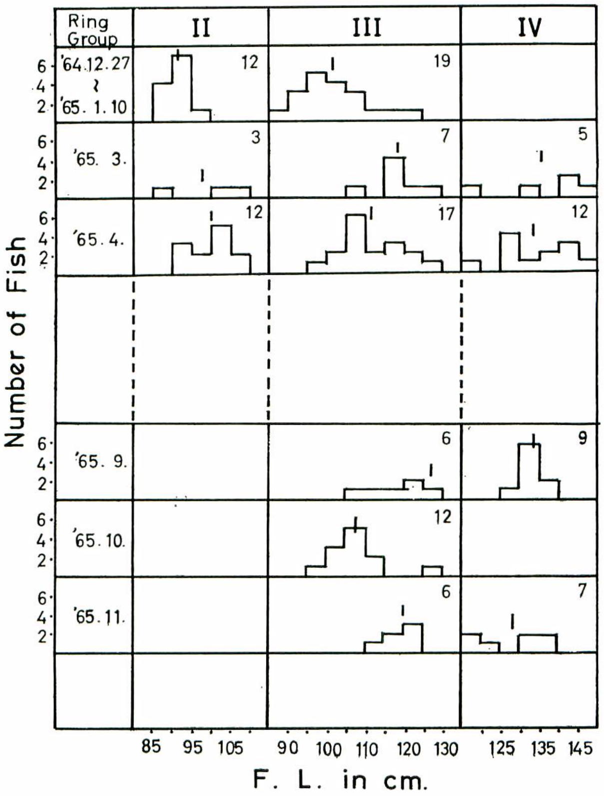

Fig. 10. Monthly length frequency distribution, by ring group, of the Atlantic yellowfin tuna. Figures in the body of graph indicate the number of specimens.

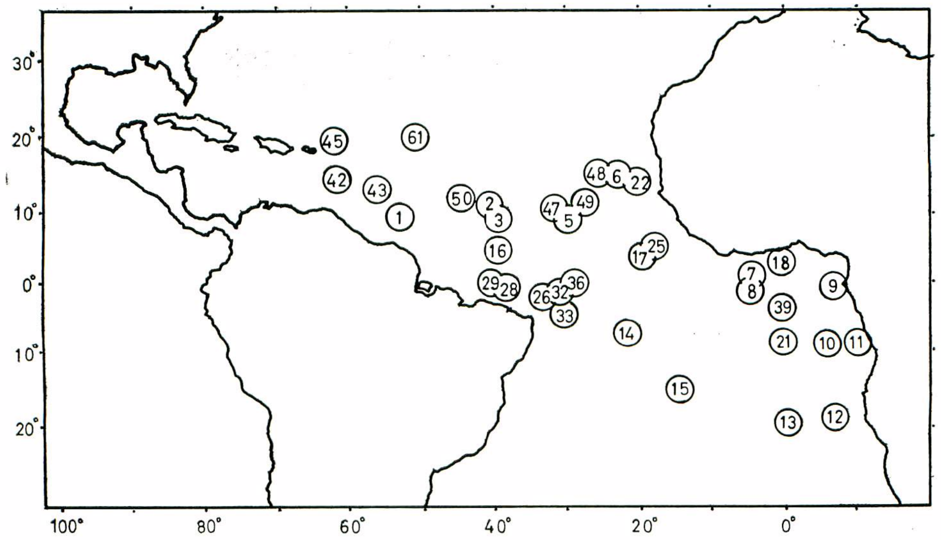

Fig. 11. Geographic distribution of the Atlantic yellowfin tuna samples with size composition data. Figure in the circle indicate sample number.

formation, l_i, estimated for the Atlantic specimens are apparently larger in values than those for the Pacific specimens; and, consequently, the derived growth curves show difference between the two oceans as shown in Figure 6.

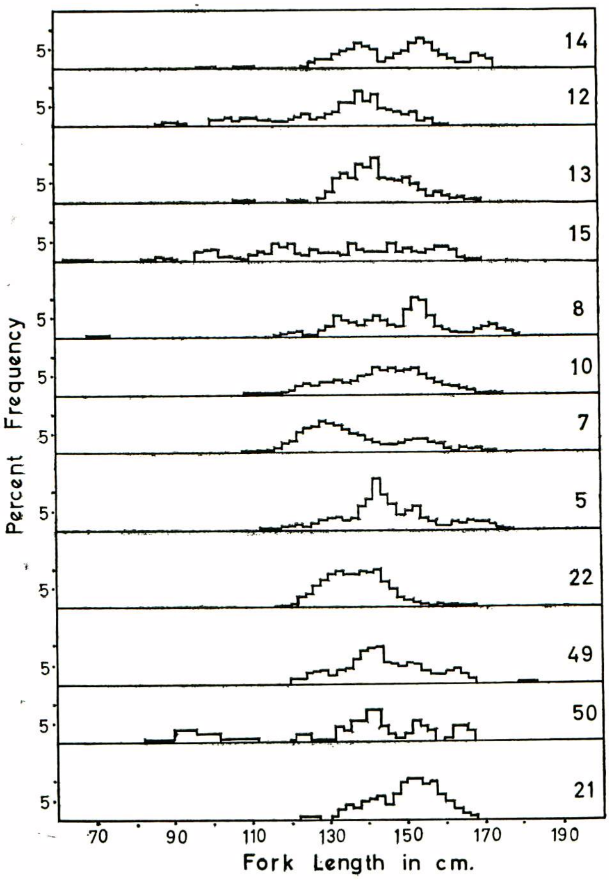

Fig. 12. Length frequency distributions of yellowfin tuna caught by Japanese long-line fishery in the Atlantic Ocean. Figures in the body of graph indicate sample number.

On examining the growth curves in Figure 6, however, we are convinced that the growth after l_1 is almost parallel to each other; and it can be regarded that the growth rate is almost the same, so far as the range of fork length is concerned, i. e., the range from l_1 to l_∞. What is more, since the two growth curves are almost parallel, shifting of the curve of the Atlantic specimens right——in other words, moving the estimated value of l_1 to l_2, l_2 to l_3,……, and l_5 to l_6, respectively——, then, two curves will overlap each other. But, if the estimated value of l_i was actually the value of l_{i+1} for the Atlantic specimens, it would mean, in effect, that we had mis-read the first-ring, r_1, on the scale of the Atlantic specimens.

Before proceeding with further consideration on the possibility of mis-reading of the first-ring for the Atlantic specimens, let us return to the difference between the l_i values of the specimens from the two oceans. The l_i values were derived upon the regression of fork length on scale-radii; and so, the difference between the l_i vales is due, first, to the difference between the regressions of fork length on scale-radii; and, second, to the r_i values of the specimens from two oceans.

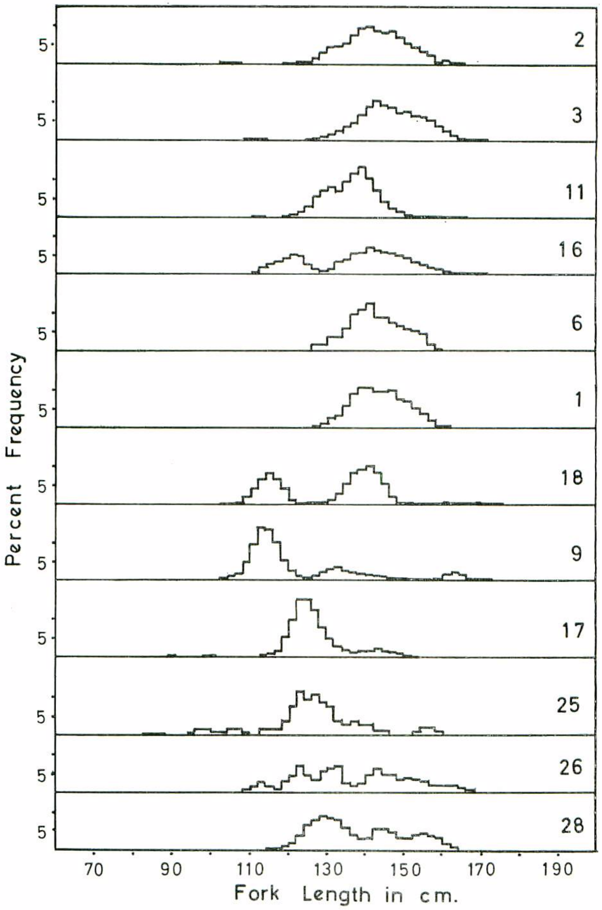

Fig. 12. ···continued.

On the difference between the relationships of scale-radii and fork length, as described in Section V-1 and V-3, the size of scale, from not only the body portion just below the sixth dorsal finlet but also the various portions as shown in Figure 1, of the Atlantic specimens are much smaller than that of the Pacific spacimens of same fork length as shown in Table 2. Besides, as mentioned in Section III, measurements of fork length on the Pacific specimens in the present study were made on the fresh or thawed specimens, while that for the Atlantic specimens were made on the frozen fish. According to GODSIL and GREENHOOD (1951), tuna in frozen condition will undergo a shrinkage of body length in 1.35%. So, if compensation against the effect of freezing would be made for the Atlantic specimens, in the present study, then the difference between the regression of fork length on scale-radii would be still more distinguished.

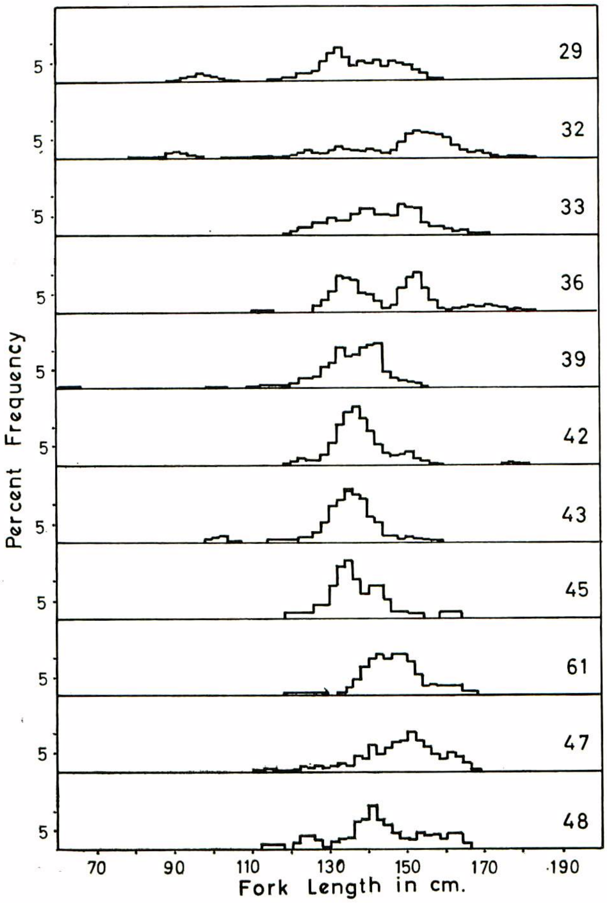

Fig. 12. ...continued.

Next, on the r_i values that almost equal in values between the two oceans (Table 5), one might be inclined to think, considering the conspicuous difference in size of scale for the same fork length, that the first ring for the Atlantic specimens was mis-read, i.e., what we read for r_1 was actually the value of r_{i+1}. In fact, we do have considered that the first-ring might have been mis-read for the Atlantic specimens; and we have re-examined the scales through and compared with scales of the Pacific specimens again. But, results we obtained were all negative…we found out neither the occurence of "ring" smaller in size than what we read as r_1, nor any difference between the scale characters of the specimens from the two oceans.

Summarizing the accounts mentioned above, it seems that the value of r_i, and hence the l_i value and l_∞ value, we read and derived for the Atlantic specimens are as reasonable and acceptable as those for the Pacific specimens; and the growth curve estimated for the Atlantic specimens, in the range of l_1 and l_∞, is acceptable too. However, there is still a point for discussion. Supposing that the first-ring corresponding to the r_1 of the Pacific yellowfin is not formed on the scales in the case of the Atlantic yellowfin, then, what we read for the value of r_i was actually the value of the ring corresponding to r_{i+1} of the Pacific yellowfin. Considering the fact that the scales of the Atlantic yellowfin are smaller than that of the Pacific yellowfin, the absence of first-ring corresponding to the r_1 of the Pacific yellowfin, in the case of the Atlantic yellowfin, is not absolutely improbable. If the difference in scale size between the Pacific and Atlantic yellowfin is due to the different initial body length (fork length) of scale-formation, and, at the same time, if ring-formation on the scale depends not on the size of the fish but the size of the scale, then the absence of the first-ring corresponding to the r_1 of the Pacific specimens seems

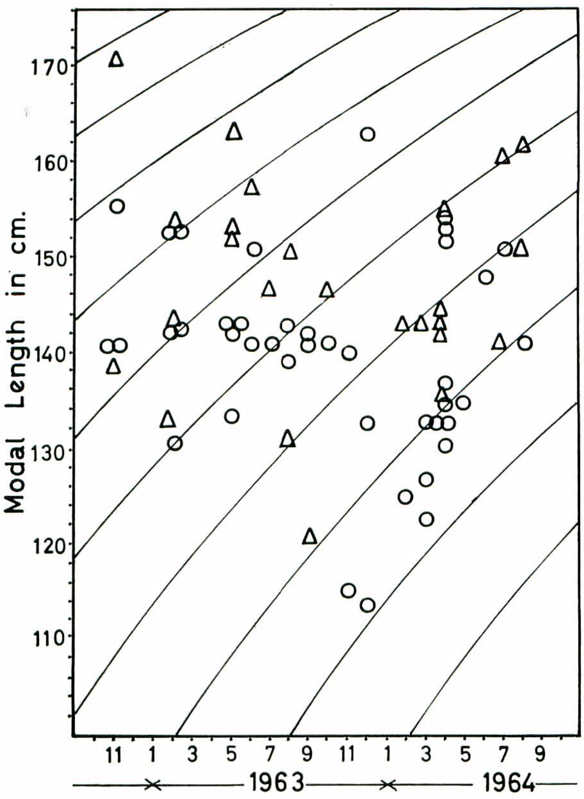

Fig. 13. Monthly modal length of the Atlantic yellowfin tuna.
○ modal length by each sample;
△ secondary modal length, when present in the case of large samples.
Solid lines showing the growth curve estimated in the present study.

to be probable in the case of the Atlantic yellowfin. But, all of the above assumptions are mere conjecture; we have neither the information about the mechanisms of ring-formation on the scale of yellowfin nor the Atlantic specimens so small in size as to examine the initial length of scale-formation.

For the present, although we are not sure whether the r_i we read for the Atlantic specimens corresponds to the r_i of the Pacific specimens, the discussion on the difference between the "apparent growth curves" of the Pacific and Atlantic specimens that were obtained by conneting the successive values of l_i has been done based on the assumption that the r_i we read for the Atlantic specimens corresponds to the r_i of the Pacific specimens. So far as the results revealed (Figure 6), the "rates" of growth after l_1 are almost the same for the Pacific and Atlantic specimens. However, since the l_1 value for the Atlantic specimens is much larger than that of the Pacific specimens (Table 6 and Figure 6), the growth rate in the period prior to l_1 must be much rapid than that of the Pacific specimens, excepting in those cases where the duration needed for the formation of r_1 of the Atlantic specimens is longer than that for the Pacific specimens. The l_1 value of the Atlantic specimens is larger than that of the Pacific specimens and the growth rates after l_1 are almost the same, the asymptotic size of the Atlantic specimens (222.8 cm) is larger than that of the Pacific specimens (195.2 cm).

The information we obtained about the growth of the Pacific and Atlantic yellowfin tunas by means of scale-reading are as mentioned above. Among these informations, however, we still regard the difference of the l_i values between the two oceans as the most important one. We have no information about the spawning season of the Atlantic yellowfin tuna and we are not sure as to which rings are the true year-ring. Yet, the apparent difference in l_i values do mean that the yellowfin tunas of the same ring number are different in size between the two oceans; and it means, in effect, that the yellowfin tunas of same "age" are different in size between the two oceans, excepting in those cases where the r_i we read for the Atlantic specimens does not correspond to the r_i of the Pacific specimens.

VII. SUMMARY AND CONCLUSIONS

1. Scales from the body portion just below the sixth dorsal finlet, counted from behind, were selected for study on the age and growth of yellowfin tuna from the Pacific and Atlantic Oceans.
2. The variances of scale-radii within fish are almost independent of size and ring number on scale of fish, while that between fish are apparently greater in values for the fish larger in size.
3. The regression of fork length on scale-radii shows significant difference be-

tween the specimens from the two oceans.

4. There is no difference between the scale characters of the specimens from the two oceans; and rings on the scale can be distinguished by crowding of circuli in the anterior sector and by discontinuous circuli in the lateral sectors of scale.
5. The sizes at time of ring-formation derived upon the regressions of fork length on scale-radii show much difference in values for the two oceans as follows:

	l_1	l_2	l_3	l_4	l_5	l_6	l_∞
Atlantic	66.1 cm	86.1	104.1	120.0	132.9	—	222.8
Pacific	45.9 cm	69.2	90.0	108.7	123.5	133.6	195.2

6. The asymptotic size estimated for the Pacific and Atlantic specimens are as listed above.
7. Rings on scale were formed twice a year for the Atlantic specimens, i. e., one in March-April and the other in September-October, as that for the Pacific yellowfin tuna estimated by other authors.
8. The growth curve, obtained by connecting the size at time of ring-formation, for the Atlantic specimens agree practically with the progression of modal length of size composition data.
9. It seems that the growth in the period prior to l_1 of the Atlantic yellowfin tuna is rapid than do the Pacific yellowfin tuna, excepting in those cases where the duration needed for the formation of r_1 of the Atlantic yellowfin is longer than that for the Pacific yellowfin.
10. The apparent difference in l_i value reveals that the yellowfin tuna of the same "age" are different in size between the two oceans, supposing that the r_i we read for the Atlantic specimens corresponds to the r_i of the Pacific specimens.

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