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GROWTH OF SKIPJACK TUNA, *KATSUWONUS PELAMIS*, IN THE EASTERN PACIFIC OCEAN

by

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C O N T E N T S

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ABSTRACT

The rate of growth of skipjack tuna, *Katsuwonus pelamis*, was estimated by the "increment technique", using the length-frequency distributions of fish caught by baitboats and purse-seiners in the eastern Pacific Ocean during 1954 through 1962. It was estimated that skipjack tuna of about 45 to 70 cm grow at an average rate of 9 mm per month; it is believed that the true rate of growth is somewhat greater than this.

INTRODUCTION

Since its inception, the Inter-American Tropical Tuna Commission has conducted research to attain the knowledge necessary to maintain the populations of yellowfin and skipjack tunas in the eastern Pacific Ocean at the levels of abundance necessary to permit their maximum sustained yield. Concomitant with the decreased abundance of yellowfin tuna, *Thunnus albacares*, in recent years, the fishing pressure on skipjack tuna, *Katsuwonus pelamis*, has increased as fishermen have substituted skipjack for yellowfin in their catches. Since the skipjack tuna has become more important, detailed information on its biology and population dynamics are necessary to ascertain the maximum sustainable catch and to formulate management policies if and when needed. Age and growth studies are an important part of such investigations. This paper presents the results of a study on the growth of skipjack tuna from the eastern Pacific Ocean based on length-frequency distributions obtained from nine consecutive years of sampling the commercial catches.

Many members of the fishing industry, boat owners, captains, engineers, fishermen, cannery owners, and cannery employees, in the United States and Latin America, have kindly cooperated in supplying information. Their help is gratefully acknowledged. Thanks are expressed to the staff of the Computer Center, University of California, San Diego, for their assistance in programming and the use of the

computer facilities. The writer is also indebted to Commission staff members Messrs. Javier Barandiaran, Edwin B. Davidoff, Kenneth R. Feng, Antonio Landa, Craig J. Orange, Sueichi Oshita, and Robert T. Umlor for their assistance in collecting samples on the size composition of skipjack tuna, to Mr. Bernard D. Fink for furnishing data on the growth rate of skipjack tuna from tagging experiments, and to Dr. William H. Bayliff for reading the manuscript and offering suggestions.

MATERIALS AND METHODS

The Tuna Commission commenced in 1954 to collect data on the size composition of skipjack tuna by month, area, and gear in the commercial catches landed at San Diego and San Pedro, California, and in Ecuador and Peru. The sampling methodology has been described and analyzed by Hennemuth (1957).

ANALYSIS AND RESULTS

Hennemuth (1961) and Davidoff (1963) identified groups of yellowfin tuna of the same age from length-frequency data, assigned ages to them, and fitted the von Bertalanffy growth equation (Beverton and Holt 1957) to the modal values of the lengths of the fish plotted against their ages ("year-class technique"). Diaz (1963), using the same data, also identified groups of yellowfin tuna of the same age, but instead of assigning ages to the fish used the regression of the increments of growth against the corresponding mean lengths to estimate $\underline{L_\infty}$ and $\underline{K}$ of the von Bertalanffy growth equation. He assumed $\underline{t_0}$ in the equation to equal 0, and assigned ages to the fish on that basis ("increment technique"). This approach is employed for the skipjack tuna in the present report.

Schaefer (1962, 1963) and Diaz (1963), for eastern Pacific skipjack, and Rothschild (1965), for eastern and central Pacific skipjack, have expressed the opinion that the modal maxima may not represent the same age groups of fish but, possibly, different groups of fish passing through a given fishing region. It seems likely that the eastern Pacific skipjack fishery exploits only a fraction of a population which perhaps extends off the Pacific coast of the Americas far to the westward (Schaefer 1960, 1962, 1963), possibly originating in the central equatorial Pacific (Rothschild 1965). Two tag recoveries near Hawaii (Schaefer 1963) and one tag recovery east of Christmas Island (Inter-American Tropical Tuna Commission 1964) of skipjack tuna tagged off Baja California, Mexico, further indicate that at least some of the fish off the west coast of the Americas migrate to the central Pacific. In addition, studies of the gonads of skipjack tuna (Orange 1961) and investigations on the distribution of the larvae and juveniles (Matsumoto 1958; Strasburg 1960; Klawe 1963) suggest that reproduction of skipjack tuna occurs mostly outside the present fishing areas of the eastern Pacific Ocean. Thus, in some cases, the observed modal progressions may not represent growth of age groups. However, it is believed that in most cases the increase in modal length with time of presumably related size groups is the result of growth of skipjack rather than different groups of fish passing through a given fishing area.

The eastern Pacific fishing grounds have been divided into 14 sampling areas (Figure 1) based on the distribution of the total catch of tunas during 1951-1953 (Hennemuth 1961). The size-composition samples of skipjack tuna collected from the commercial landings during 1954-1962 were tabulated by type of fishing gear (baitboat and purse seine), area, year, and month of capture. The frequencies were grouped by 10-mm intervals, and the samples pertaining to the same fishing gear, area, year, and month of capture were combined. From these combined data, monthly percentage length-frequency distributions, representing the size composition of the monthly catches in each area by type of fishing gear, were computed. The central tendency of the size groups was emphasized by smoothing the percentage length-frequencies with a moving average of three intervals, giving the central interval double weight (example in Figure 2).

The monthly modes were determined from the smoothed length-frequency distributions according to Hennemuth's (1961: p.10) criteria. The following additional criteria were employed: (a) modes provening from only one fish were ignored; (b) when two adjacent 10-mm size intervals reflected the same modal percentage value, the mode was assigned to a mid-size interval. The modes are indicated by dots in Figure 2.

The modes were plotted against their corresponding month of capture, as may be seen by the dots in Figure 3. The dots of successive months were then connected according to subjective criteria, which are believed to indicate the growth of related size groups. These criteria were: (1) the maximum time gap within a modal group was three months; (2) the maximum positive increment in the average modal length was 50 mm, while the maximum monthly average negative increment in the average modal length was 20 mm. When these criteria were not met, the continuity of the progression was broken and a new one initiated at a subsequent month.

For each progressions, values of $\underline{\Delta L/\Delta t}$ (monthly length increment and $\underline{\bar{L}}$ (mean modal length for the two months) were calculated for the seemingly related modes (Tables 1 and 2) and graphed (Figure 4). The individual points were grouped by 50-mm intervals and the means computed for all the points within a given interval. A straight line was fitted to these means by Bartlett's (1949) method, for use when both variables of a linear functional relationship are subject to error.

The regression obtained for the relationship between the change in length per month on the mean lengths of eastern Pacific skipjack tuna measuring 45 to 70 cm in length is

$$\Delta L/\Delta t = 15.2 - 0.0111 \bar{L}$$

The slope of this line is not significantly different from 0 ($\underline{t}$ = 1,085, d.f. = 3, $\underline{t}_{0.05}$ = 3.182). This indicates that the rate of growth is uniform within the range of 45 to 70 cm, or that the variability of the data is so great as to obscure any difference that exists. Thus meaningful estimates of the constants in the von Bertalanffy growth equation cannot be obtained from these data.

The maximum reported for the skipjack tuna in the Pacific Ocean is 75 pounds (Pacific Fisherman 1950). The length of these specimens, estimated from Tester and Nakamura's (1957) length-weight relationship, is about 113 cm. Thus the length range of 45 to 70 cm represents only a small portion of the total length range of the species, and it is apparently not feasible to estimate the parameters in the growth equation with data from the eastern Pacific fishery alone.

The average rate of growth between 45 and 70 cm is about 9 mm per month. From this it is estimated that the fish remain in the eastern Pacific fishery for about 2 1/2 years (assuming that each fish has only a single sojourn in the area, as hypothesized by Rothschild, 1965). Schaefer (1959, 1960) believed 45-cm skipjack tuna to be 1 or 2 years of age, so 70-cm fish would be 3 1/2 or 4 1/2 years old.

The length-frequency data for skipjack tuna from the individual sampling areas (Figure 1) are too few to compute separate growth rates for each of the areas individually. Broadhead and Barrett (1964) and Rothschild (1965) have suggested that the skipjack tuna of the eastern Pacific Ocean are divided into two components, one extending from the Gulf of Tehuantepec northward to about the United States-Mexico border and the other from the Gulf of Tehuantepec southward to Chile. Tagging experiments in the eastern Pacific Ocean (Blunt and Messersmith 1960; Schaefer, Chatwin, and Broadhead 1961) have tended to confirm this separation. Of the 4,419 tagged skipjack tuna recovered (from 90,885 released) from eastern Pacific tagging experiments, only three had migrated across the Gulf of Tehuantepec (Inter-American Tropical Tuna Commission 1964, 1966). Therefore the skipjack tuna length-frequency data for each of the two regions were analyzed separately, Areas 01-04 and 08 being assigned to the northern region and Areas 05-07 and 09-14 to the southern region. There was no significant difference for the slopes ($\underline{F}$ = 0.71; d.f. = 1, 419; $F_{0.05}$ = 3.86), but the levels were significantly different at the 5-percent level ($\underline{F}$ = 6.24; d.f. = 1, 420; $F_{0.05}$ = 3.86). Thus it appears that the growth of the fish for these two regions is somewhat different. However, since the sampling errors and biases are probably substantial, it is not believed that any useful purpose would be served at present by calculating the growth separately for the two regions.

The increment technique was also applied to the length-frequency data obtained from baitboats and purse-seiners separately to determine whether or not the estimates of the rate of growth of the skipjack tuna obtained from each fishing gear were different. There was no significant difference for either the slopes ($\underline{F}$ = 0.23; d.f. = 1, 419; $F_{0.05}$ = 3.86) or the levels ($\underline{F}$ = 2.73; d.f. = 1, 420; $F_{0.05}$ = 3.86) of the regressions for each individual fishing gear. Thus, the length-frequency data obtained from baitboat and purse-seine catches were combined for this study.

DISCUSSION

The estimate of the average rate of growth of eastern Pacific skipjack tuna, 9 mm per month, is thought to be low for the following reasons:

(1) When the increment technique was applied to size-composition data of yellowfin tuna, the estimate of the rate of growth was somewhat less than that obtained by the year-class technique (Diaz 1963).

(2) The "best" estimate of the average rate of growth of tagged skipjack tuna (based on 1,032 recoveries made during 1955-1964) from the eastern Pacific Ocean, is about 11 mm per month B.D. Fink 1965, personal communication), a rate slightly higher than that estimated by the increment technique. It has been shown, however, for a large variety of fishes, including yellowfin and skipjack tunas, that the growth rate of tagged individuals is less than that of the untagged ones (Schaefer, Chatwin, and Broadhead 1961; Chadwick 1963; Jensen 1963; Kelly and Barker 1963; Kotthaus 1963).

(3) Size selection can cause a lower estimate of the rate of growth. It is known that fishermen discriminate against the smaller fish in order to comply with the minimum legal size established in California for skipjack tuna (4 lb or about 45 cm). Only the larger fish of the younger age groups and perhaps only the smaller fish of the older age groups may be exploited at present, which would tend to decrease the apparent rate of growth (Ricker 1958:187). Size selection may be detected by an apparent lower growth rate of the smaller fish, as was found for yellowfin tuna (Diaz 1963: Figure 2).

Size selection was not detected for skipjack tuna, however. Thus when the increment technique was applied to skipjack tuna length-frequency data there was no indication that size selection would introduce a significant bias in the growth-rate computations. This can be observed from Figure 4, where the large dots, representing the calculated means for each 50-mm length interval, seem to exhibit a normal linear trend. However, it is believed that size selection was not detected for skipjack tuna because of the relatively short length range of the skipjack captures by the eastern Pacific fishery.

If the estimate of the rate of growth is low, the estimate of the time spent in the eastern Pacific fishery, 2 1/2 years, must be correspondingly high. (Tagging also provides an indication of the time spent in the eastern Pacific fishery. Of the tagged skipjack recovered in the eastern Pacific Ocean through 1965, 22 of the fish were at liberty 1 to 2 years, and one other was at liberty 788 days. This fish was not measured when it was tagged, but it was only 500 mm in length when it was recovered (B.D. Fink 1966, personal communication).)

The estimate of the rate of growth would be higher if the criteria on page 3 were altered to exclude more of the larger negative increments and/or include more of the larger positive increments. However, no useful purpose would be served by altering the criteria to obtain results as close as possible to those obtained or inferred by other methods.

In Table 3 are shown estimates of the growth of skipjack tuna from the Pacific Ocean obtained by different techniques. The estimate obtained in the present paper is less than those obtained by most other investigators, which supports the belief that it is an underestimate.

SUMMARY

The increment technique, which yields estimates of the rate of growth without reference to age, was applied to skipjack tuna length-frequency data. Although the eastern Pacific fishery for skipjack tuna appears to be exploiting only a part of a population which extends far to the westward, it is believed that in most cases the increase in modal lengthswith time of presumably related size groups provides usable estimates of the growth rate of skipjack tuna. It is estimated that eastern Pacific skipjack tuna of about 45 to 70 cm grow at an average rate of 9 mm per month; it is believed that the true rate of growth is somewhat greater than this, as previous experience with the technique, results of tagging experiments, and consieration of the sampling problems all tend to indicate that the growth rate given here is an underestimate.

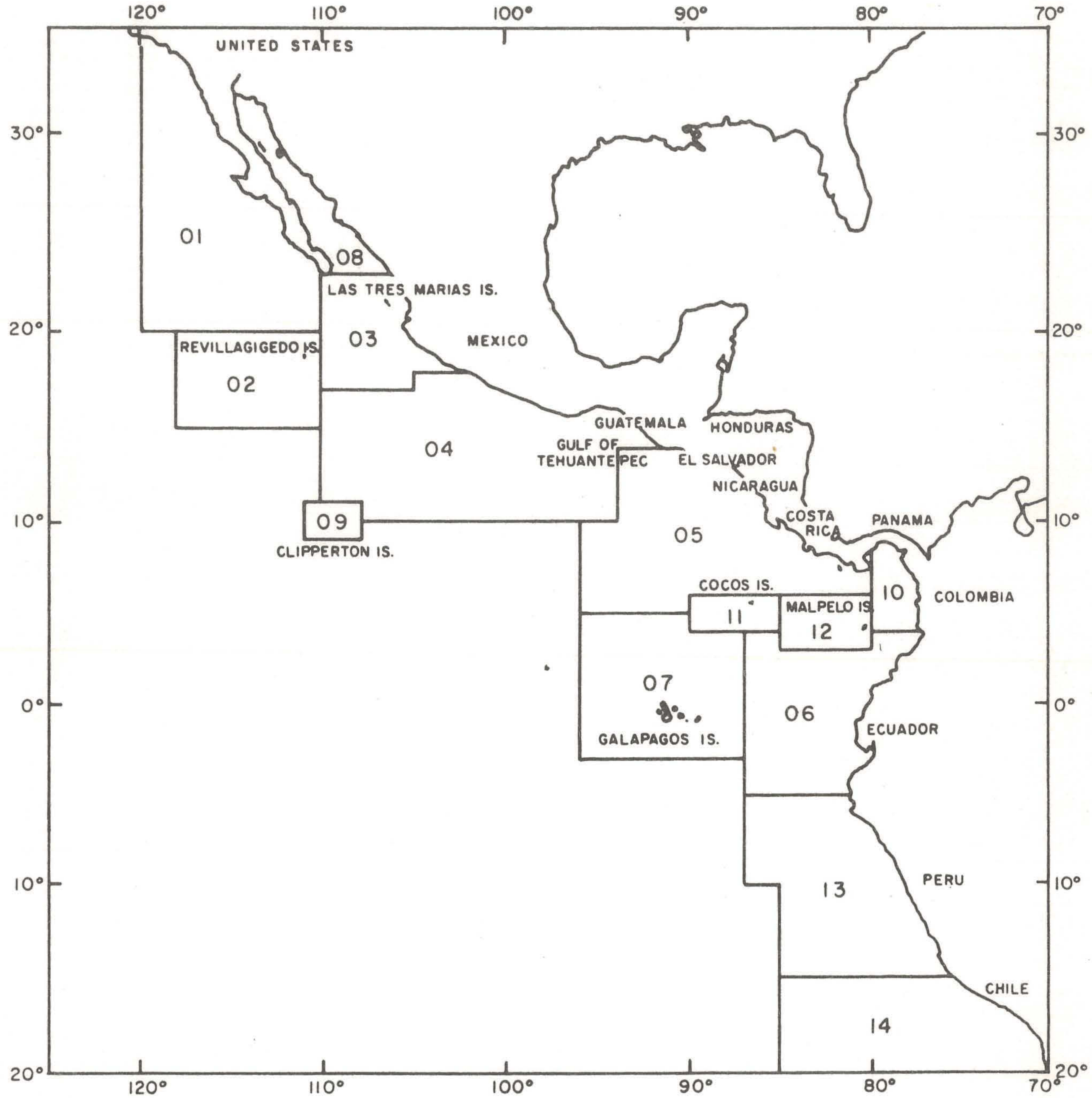

FIGURE 1. Areas used by the Inter-American Tropical Tuna Commission for length-frequency sampling

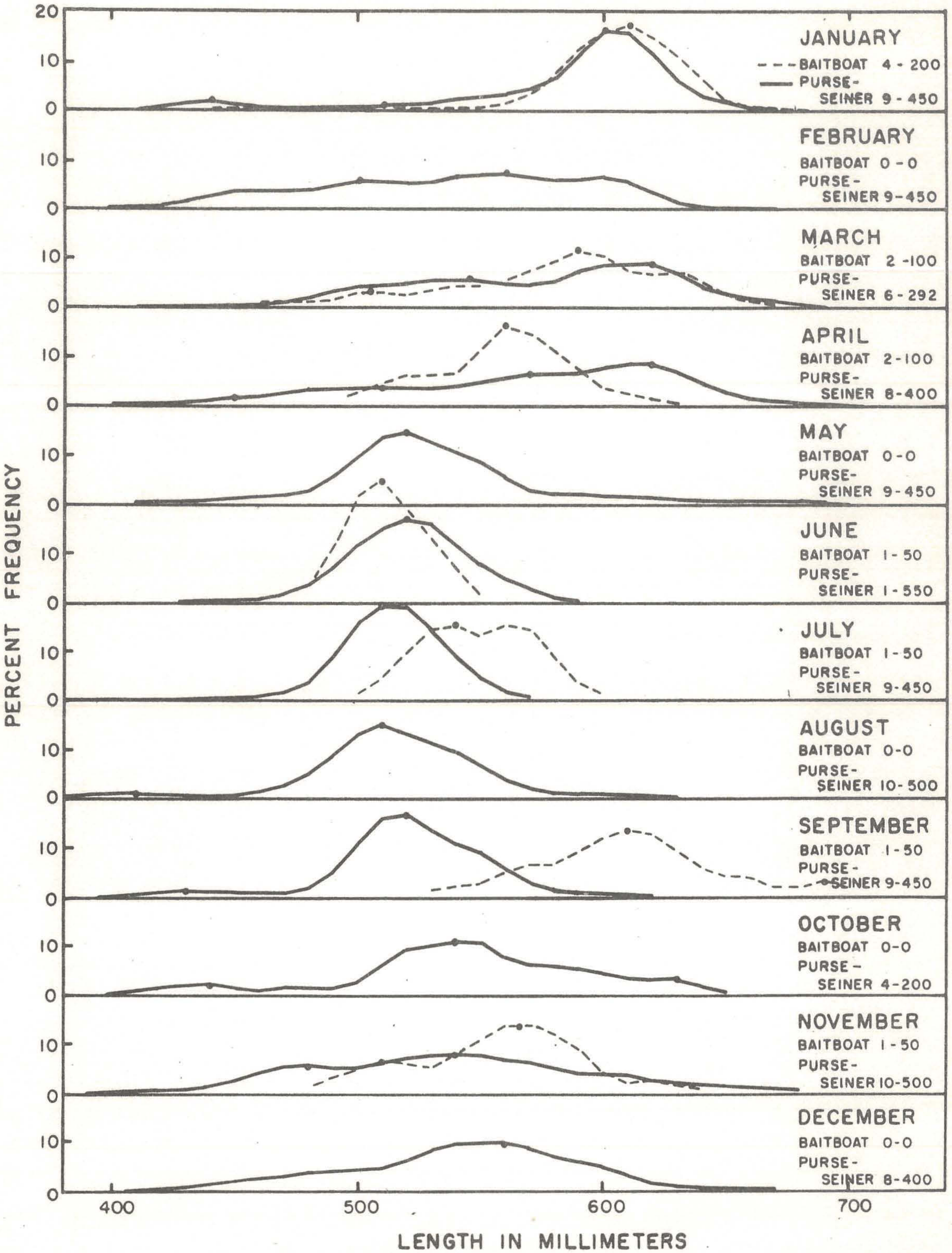

FIGURE 2. Smoothed length-frequency distributions of the monthly catches of skipjack tuna by baitboats and purse-seiners in Area 06 in 1962. The dots indicate modes. The numbers after "baitboat" and "purse-seiner" indicate the numbers of samples and the total numbers of fish sampled, respectively.

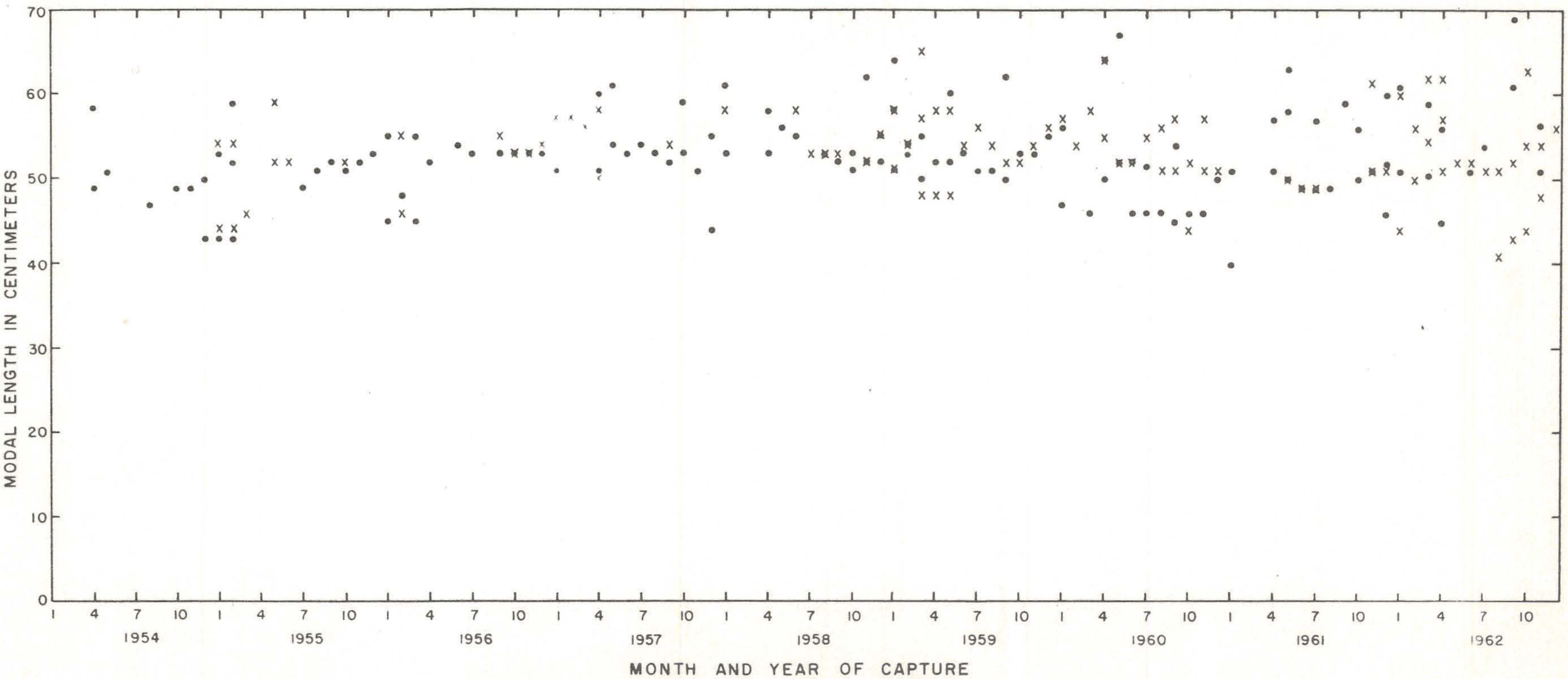

FIGURE 3. Modal lengths of skipjack tuna plotted against the month of capture for Area 06 for 1954-1962 by baitboats (dots) and purse-seiners (crosses).

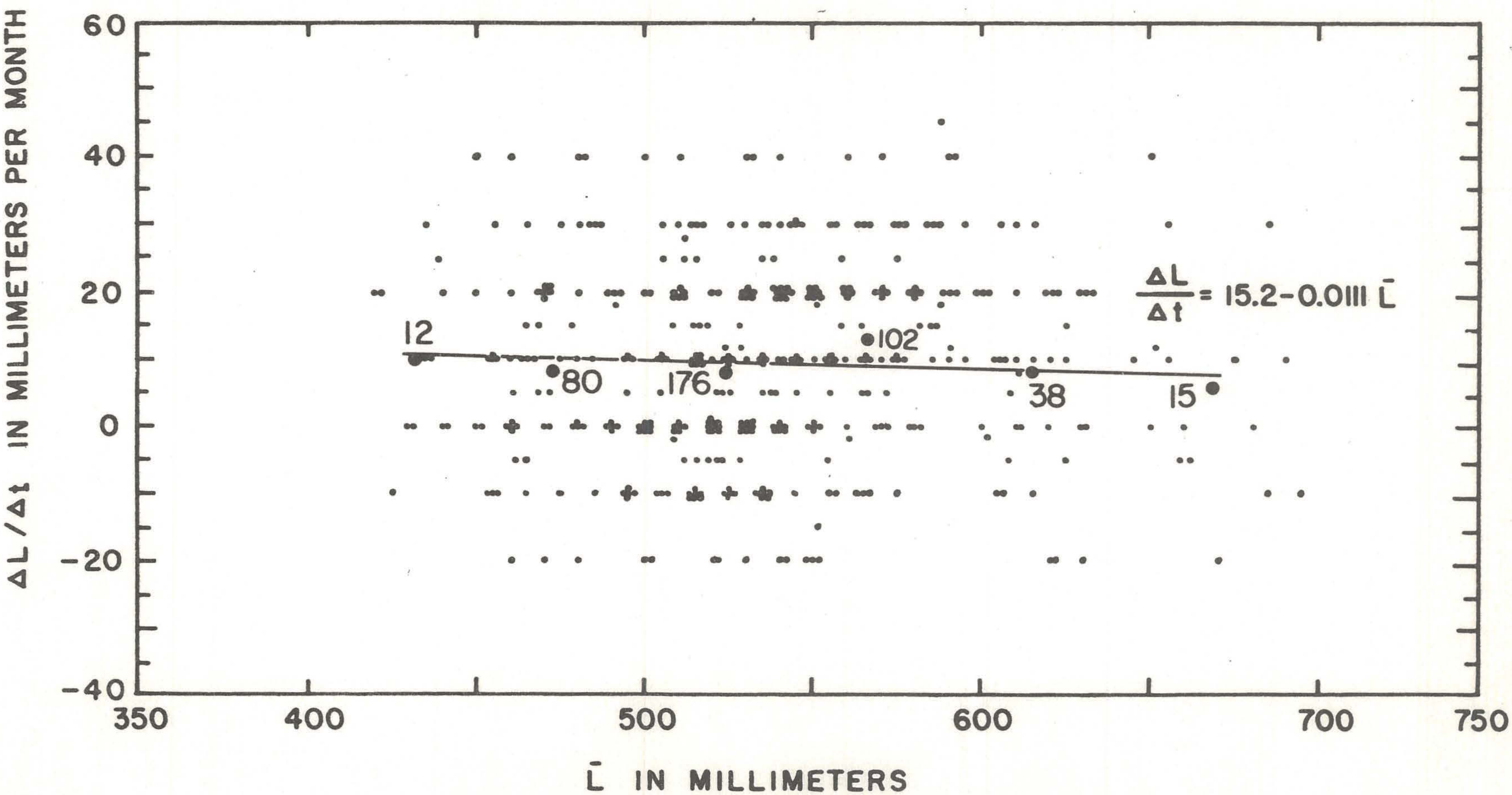

FIGURE 4. Relationship between the change in length per unit of time and the mean length, obtained by applying the increment technique to atelic progressions for skipjack tuna from the eastern Pacific Ocean. The large dots represent the means for each 50-mm length interval.

TABLE 1. Mean modal length in millimeters for successive months ($\overline{L}$), and the increment of growth in millimeters per month ($\Delta L/\Delta t$), for skipjack tuna taken by baitboats in the eastern Pacific Ocean, calculated using atelic progressions for data for 1954 through 1963

AREA											
01		02		03		04		05		06	
$\overline{L}$	$\frac{\Delta L}{\Delta t}$	$\overline{L}$	$\frac{\Delta L}{\Delta t}$	$\overline{L}$	$\frac{\Delta L}{\Delta t}$	$\overline{L}$	$\frac{\Delta L}{\Delta t}$	$\overline{L}$	$\frac{\Delta L}{\Delta t}$	$\overline{L}$	$\frac{\Delta L}{\Delta t}$
495	10	620	-20	615	10	630	-20	545	30	480	10
430	0	620	10	625	10	630	20	550	0	490	0
435	10	630	0	625	- 5	555	30	560	20	495	10
545	10	562	- 2	540	20	565	-10	585	30	515	30
495	-10	570	10	545	-10	528	15	605	10	525	-10
510	40	515	- 5	550	20	580	20	575	-10	430	0
505	10	620	20	510	0	658	- 5	585	15	515	10
530	40	650	40	465	15			470	20	515	-10
540	-20	685	30	545	30			505	25	515	10
540	20	695	-10	570	20			540	20	525	10
525	-10	685	-10	592	12			550	0	540	20
465	10	690	10	612	8			555	10	465	30
475	10	590	10	515	25			550	-20	500	20
490	20	615	30					580	0	530	10
500	0	520	10					595	30	535	-10
530	30	540	20					610	0	530	0
550	-20	570	40					610	0	530	0
485	-10	600	20					605	-10	520	-20
480	0	585	30					480	20	535	-10
480	0	630	20					515	30	535	10
590	20	652	12					530	0	535	-10
545	10	662	- 5					530	0	525	-10
455	-10	615	-10					535	10	525	10
460	20	625	15					540	0	540	10
535	10	645	10					540	0	545	30
545	5	535	-10					540	0	555	-10
565	30	480	-20					565	-10	525	-10
515	15	485	30					575	30	515	-10
545	30	510	20					505	-10	515	10
565	10	522	5					510	20	520	0
585	15	500	0					522	5	515	-10
460	0	540	20					538	25	520	20
470	20	558	15					560	20	540	20
490	20	588	45					572	5	575	25
510	20	608	- 5					582	15	510	20
530	20	602	- 2					620	20	520	0
550	20	500	-20					495	-10	525	10
420	20	505	30					555	5	510	0
450	40	520	0					575	30	505	-10
530	0	610	20					600	20	515	30
528	- 5	455	10					605	-10	530	0
522	- 5	480	40					540	20	540	20
530	20	495	-10					490	0	555	10
535	-10	552	18					555	-10	465	- 5
540	20	588	18							655	30
560	20	555	10							510	20
465	-10	560	0							520	0
470	20	575	30							518	- 5

AREA 01 $\bar{L}$	01 $\frac{\Delta L}{\Delta t}$	02 $\bar{L}$	02 $\frac{\Delta L}{\Delta t}$	03 $\bar{L}$	03 $\frac{\Delta L}{\Delta t}$	04 $\bar{L}$	04 $\frac{\Delta L}{\Delta t}$	05 $\bar{L}$	05 $\frac{\Delta L}{\Delta t}$	06 $\bar{L}$	06 $\frac{\Delta L}{\Delta t}$
485	10	595	10							528	12
455	-10	455	30							460	0
540	20	478	15							460	0
555	10	512	28							455	-10
515	-10	465	10							455	10
462	- 5	515	-10							460	0
470	20	560	20							480	40
520	0	470	0							505	10
525	5									575	10
435	30									505	-10
460	10									495	-10
520	-20									490	0
535	25									490	0
440	20									495	5
455	10									505	10
470	20									515	10
438	25									580	20
455	10									605	10
538	5									508	- 2

AREA 07 $\bar{L}$	07 $\frac{\Delta L}{\Delta t}$	10 $\bar{L}$	10 $\frac{\Delta L}{\Delta t}$	11 $\bar{L}$	11 $\frac{\Delta L}{\Delta t}$	12 $\bar{L}$	12 $\frac{\Delta L}{\Delta t}$	13 $\bar{L}$	13 $\frac{\Delta L}{\Delta t}$	14 $\bar{L}$	14 $\frac{\Delta L}{\Delta t}$
440	0	515	15	608	5	545	10	540	0	545	10
500	0	520	0			550	0	530	-20	565	15
460	0	545	10			565	30	525	10	465	10
515	10	550	0					535	5	472	5
530	20	570	20					535	-10	600	0
680	0	500	0					535	10		
670	-20	540	0					545	10		
590	20	520	0					560	20		
620	20	540	-20					585	30		
468	15							485	30		
492	18							500	0		
600	20							500	0		
512	- 5							500	0		
518	15							500	0		
540	30							505	10		
460	-20							565	5		
450	0							590	40		
560	20							500	20		
575	10							500	-20		
655	10							495	10		
660	0										

TABLE 2. Mean modal length in millimeters for successive months ($\overline{L}$), and the increment of growth in millimeters per month ($\Delta L/\Delta t$), for skipjack tuna taken by purse-seiners in the eastern Pacific Ocean, calculated using atelic progressions for data for 1954 through 1963.

AREA									
01		02		05		06		10	
$\overline{L}$	$\frac{\Delta L}{\Delta t}$	$\overline{L}$	$\frac{\Delta L}{\Delta t}$	$\overline{L}$	$\frac{\Delta L}{\Delta t}$	$\overline{L}$	$\frac{\Delta L}{\Delta t}$	$\overline{L}$	$\frac{\Delta L}{\Delta t}$
510	20	530	40	570	20	440	0	480	30
462	5	550	0	630	0	450	20		
468	5	650	0	675	10	540	0		
585	10	508	15	538	5	550	20		
605	30	605	10	550	20	570	0		
475	-10			565	10	565	-10		
570	0			510	20	570	20		
590	40			535	30	530	0		
630	20			555	10	530	0		
495	10			565	10	530	0		
520	20			580	20	525	-10		
560	40			510	30	535	30		
610	30			550	10	565	30		
525	10			580	20	525	30		
535	10			570	20	555	30		
470	-20			590	20	575	10		
470	20					580	0		
500	40					480	0		
530	20					480	0		
550	20					550	20		
470	0					550	-20		
540	10					520	0		
560	10					530	20		
580	20					550	20		
485	30					565	10		
512	25					575	10		
522	-5					580	0		
425	-10					530	20		
540	40					520	0		
565	5					555	10		
450	0					565	10		
455	10					570	0		
475	30					510	0		
						515	10		
						515	-10		
						510	0		
						495	-10		
						490	0		
						510	0		
						610	10		
						620	0		
						552	-15		
						558	25		
						505	5		
						515	10		
						520	0		
						515	-10		
						510	0		
						515	10		
						530	20		
						540	0		
						550	20		
						420	20		
						435	10		
						460	40		

TABLE 3. Estimates of the growth rate of Pacific skipjack tuna obtained by diverse techniques

Technique	Region	Approx. years of data	Approx. length range (cm)	Approx. growth rate (mm/mo.)	Reference
Length-freq.	Japan	1923-1924	6-21	40	Kishinouye, 1924
"	Hawaiian Islands	1944-1945	36-83	12*	Bonham, 1946
"	"	1946-1951	44-81	14*	Brock, 1954
"	Japan	1951-1953	30-70?	19*	Kawasaki, 1955
"	Central America	1953-1955	40-70	10	Schaefer and Orange, 1956
"	Mexican coast	1954-1959	40-71	11	Schaefer, 1961
Tagging	Hawaiian Islands	1955	54	13*	Yamashita and Waldron, 1959
"	Eastern Pacific	1953-1956	44-67	13*	Blunt and Messersmith, 1960
"	"	1955-1959	40-70	10	Schaefer, Chatwin, and Broadhead, 1961
"	"	1955-1963	40-70	11	B.D. Fink 1965 (personal comm.)
Vertebrae	Japan	1934	35-53	8*	Aikawa, 1937
"	Palau Islands	1937	32-64	8*	Aikawa and Kato, 1938
In captivity	Hawaiian Islands	1960	37	13*	Nakamura, 1962
Increment	Eastern Pacific	1954-1962	40-70	9	Present report

*as interpreted from the reference

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