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STUDY OF AGE DETERMINATION BY HARD PARTS OF ALBACORE FROM CENTRAL NORTH PACIFIC AND HAWAIIAN WATERS

BY TAMIO OTSU AND RICHARD N. UCHIDA

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CONTENTS

ABSTRACT

Various hard parts of large (93–128 cm.) albacore, *Germo alalunga* (Bonnaterre), from Hawaiian waters and smaller fish (50–112 cm.) from the central North Pacific were examined for marks that could be used in determining age in this species. A cursory examination of the opercular bones and fin spines revealed no usable marks. A study of scale samples from 100 albacore showed that only one-half of them were readable, and these only with a considerable degree of subjectivity.

Several workers in other areas have reported apparent success in aging albacore by means of the rings on the vertebral centra. Their results could not be duplicated in the present study. In attempts to read the rings in the vertebrae of 212 Hawaiian and 53 central North Pacific albacore, the authors found little agreement between the counts of the different readers or even between successive counts by the same reader. Indications were seen that the rings on the vertebrae are not annuli but rather that they may be growth marks laid down randomly with time. As a clue to relative age, however, they may provide an explanation of the unbalanced sex ratio of large albacore, for they indicate the possibility that among mature fish the males grow faster than the females.

The results of this study, though largely negative, are presented for the information of those engaged at present in similar studies and for others who may work on this problem in the future.

STUDY OF AGE DETERMINATION BY HARD PARTS OF ALBACORE FROM CENTRAL NORTH PACIFIC AND HAWAIIAN WATERS

By Tamio Otsu and Richard N. Uchida, *Fishery Research Biologists*, U. S. Bureau of Commercial Fisheries

As part of the research program of the Pacific Oceanic Fishery Investigations (POFI), Fish and Wildlife Service, a study was initiated to determine the age and growth of albacore, *Germo alalunga* (Bonnaterre), occurring in the region of the Hawaiian Islands and in the central North Pacific. This study and other investigations of the albacore resources of the Pacific are conducted by POFI under Public Laws 329 (80th Congress) and 466 (Saltonstall-Kennedy Act, 83d Congress).

Several workers have reported on the age and growth of albacore as determined from surface markings on the vertebral centra. Uno (1936a, b) working with albacore taken by pole-and-line fishing in the waters east of Cape Nojima, Japan, made age determinations on 988 fish. Aikawa and Kato (1938) reported on age determinations of albacore based on 10 large fish taken near Midway Island and 5 small fish taken off northeastern Japan. Partlo (1955) studied the age and growth of the eastern Pacific albacore, utilizing the vertebrae of 531 fish taken in 1950 from offshore waters adjacent to California, Oregon, Washington, and British Columbia. Finally, Figueras (1955) reported on age determination of 67 albacore taken off the coast of Galicia in northwestern Spain.

It was our hope to extend these findings to include central North Pacific albacore and the exceptionally large fish occurring in the Hawaiian area. We assumed that methods employed in other areas to determine the age of albacore could be successfully employed in this study. Our efforts in this respect were entirely unsuccessful, however, as we were unable to verify or duplicate findings of the other workers. It was our conclusion that the markings on albacore hard parts, particularly on the vertebrae, are not true year marks, and therefore, cannot be used in the aging of these fish. The results of our study, though largely negative, are presented here for the information of those who are presently engaged in similar studies and for others who may work on this problem in the future.

MATERIALS

Scales and vertebrae were routinely collected and certain other skeletal structures such as the operculum and the fin spines were also examined. Between January 1955 and July 1956, vertebrae and scales were collected from 212 albacore taken in Hawaiian waters and 53 from the central North Pacific.

Albacore taken by the Hawaiian longline fishery from an area within 20 miles of the main islands, were generally large, ranging in length from 93 to 128 cm. (weight, 33 to 93 lbs.) (fig. 1). These fish were sampled at the two Honolulu auction markets, the Hawaii Fishing Co., Ltd., and the United Fishing Agency, Ltd., where the landings of the Honolulu-based longline vessels were sold. Albacore were obtained from the central North Pacific on POFI's exploratory fishing cruises,

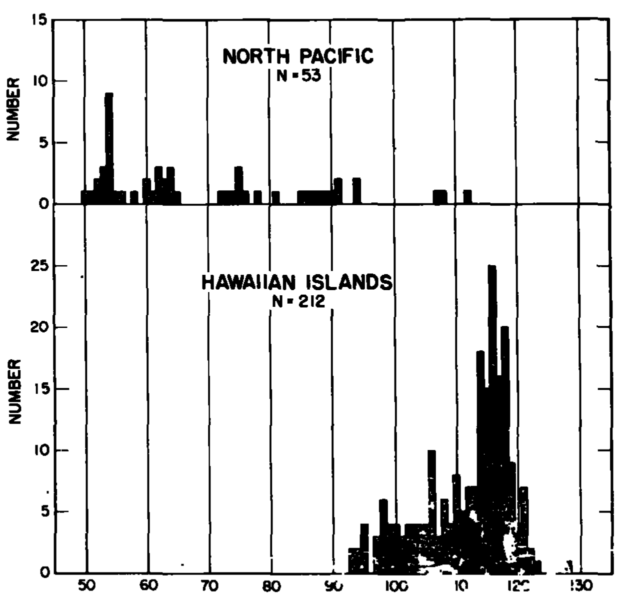

FIGURE 1.—Length frequency of albacore from which scales and vertebrae were collected.

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which sampled an area between 140° W. and 180° longitude, from 30° to 50° N. latitude. These fish, taken by longline, trolling, and gill nets, were smaller, ranging in length between 50 and 112 cm. (6 to 65 lbs.) (fig. 1).

Scales were collected from the region of the body just below the second dorsal fin. The selection of this region was largely based on recommendations of researchers in California who were similarly engaged in the problem of aging the albacore, and who found scales from that region of the body "most promising" (personal correspondence). The 15th and 16th caudal vertebrae were selected for this study. While past investigators have used the thoracic vertebrae, our choice of the caudal vertebrae was based chiefly on accessibility, or the ease with which they could be acquired in the field or at the auction markets. This difference in the choice of vertebrae appears to be of little significance, since a careful examination of each of the 38 vertebrae of a single albacore revealed no notable differences in the appearance of the concentric markings.

METHODS

The scales were soaked in water overnight, after which the slime and adhering tissue were easily removed. The scales were then either dry-mounted between two glass slides or impressed on 0.030-inch thick cellulose acetate (1″ x 3″) strips, which were first softened by immersing in 95-percent ethyl alcohol for 5 minutes.

Scale images were projected on a white paper screen with a microprojector. Because of the variable sizes of the scales, the distance between the projected image and the microprojector was varied so that approximately equal-sized images could be produced. This tended to diminish to some extent the influence of the scale size in making ring counts.

In processing the vertebrae for study, the tail section, cut off at or near the 5th dorsal finlet, was boiled in water until the flesh could easily be removed from the bone. After washing, the vertebrae were sun-dried for about 2 days.

The method described by Partlo (1955) was followed in preparing the vertebrae for study. Where the 15th caudal vertebra was cut through or damaged during collection, the 16th vertebra was used. An electric jig saw was employed to cut each vertebra along a sagittal plane slightly to one side of the median line. The larger of the resulting two parts was sanded down until the center of the centrum was clearly exposed (fig. 2). Additional cleaning and accentuating of the concentric rings were done by immersing the vertebra in a 1-percent solution of potassium hydroxide for about 48 hours, followed by rinsing in fresh water and preservation in 95 percent ethyl alcohol.

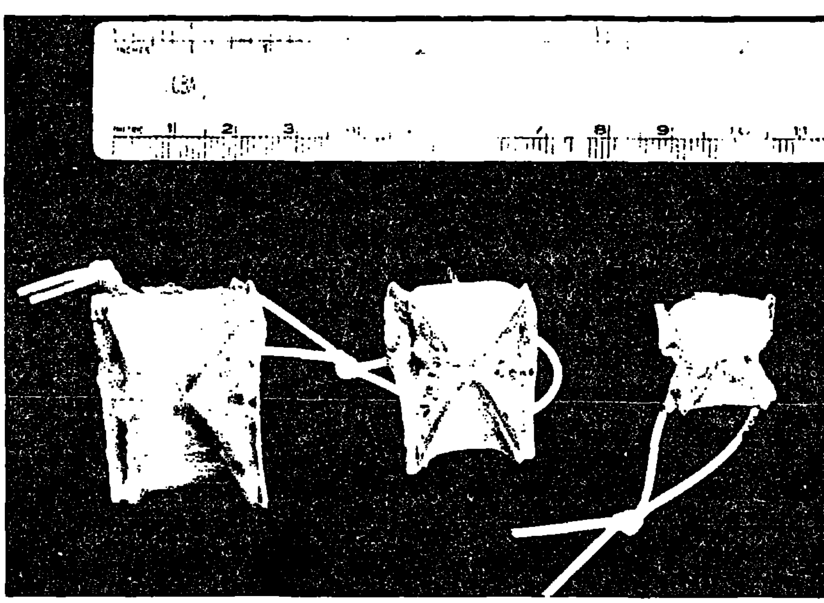

FIGURE 2.—Sectioned and prepared caudal vertebrae taken from albacore 113.9, 100.8, and 75.1 cm. long.

Measurements were made from the vertex of the cone to each ring (ring radius) and also to the outer margin of the cone (vertebral radius) along the four exposed edges. Ring radii were measured with a pair of dividers under a dissecting microscope and read off to the nearest 0.1 mm. on a ruler graduated in 0.5-mm. intervals. The anterior and posterior cone measurements were treated independently. The two corresponding ring and vertebral radii measurements of each cone were averaged.

RESULTS

Various Skeletal Structures

Cursory examination of the operculum, dorsal and pectoral fin spines, and the hypural plate produced no evidence that these structures possessed any markings which could be interpreted as "age marks." The operculum showed distinct marks only on the outer free edge; the central area was invariably thickened and devoid of any markings.

Scales

The albacore scale is cycloid and either oval or roughly rectangular in general outline. The circuli are concentric with the margin of the scale. Examination revealed that the smaller scales generally exhibited a rather distinct focus and clearly defined circuli, but that the larger scales (from fish larger than 90 cm.) were mostly characterized by obscure sculpturing and a thickened central area. Furthermore, it was noted in several instances that scales from the same specimen (usually in large fish) were of variable size and shape. A count was made of the rings on different sized scales from the same fish following the definition of an annulus as given by Nose and others (1955), who state: "The ring appears as a transparent line, near by which the circuli become fine and discontinuous . . ." Though the counts on the larger scales were necessarily somewhat subjective, because of the general opaqueness of the scales, there appeared to be some trend in the number of rings, the smaller scales having a lesser count than the larger. This would seem to indicate that the smaller scales had originated more recently than the larger ones.

Results of ring counts

Scales from 100 fish were examined. Of this total, the scales from 43 fish were considered unreadable, in large part because of opaqueness of the central area. The samples from the remaining 57 fish varied widely in the degree of readability. Despite the obvious difficulties, an attempt was made to count the rings on scales which had the greatest number of annuli for each sample. The ring counts are plotted against fish size in figure 3. There is a tendency for ring

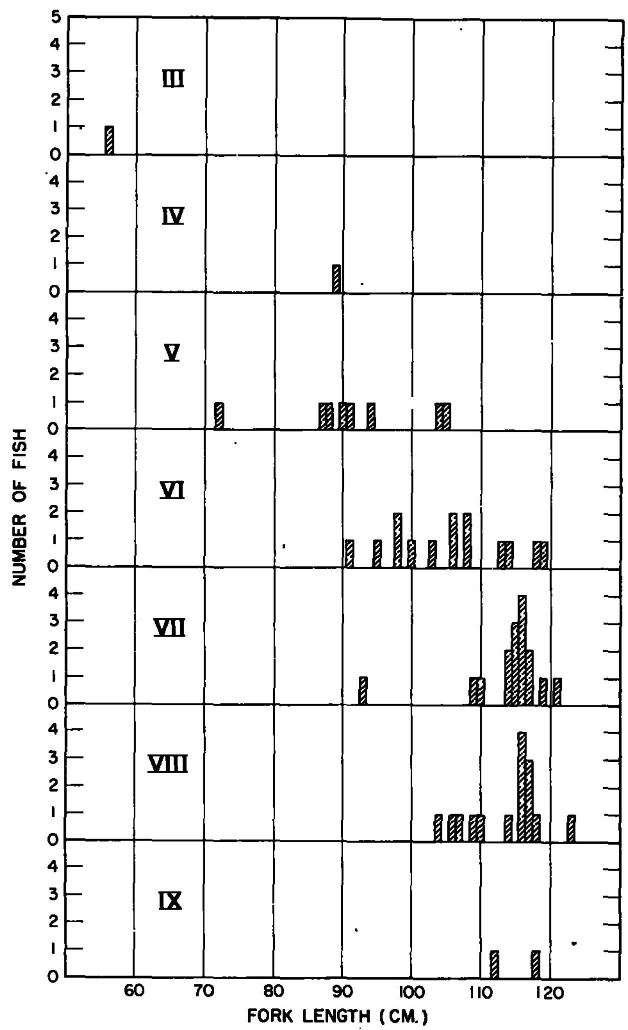

FIGURE 3.—Age of 57 albacore, determined by scale reading, plotted against fish size. (The Roman numerals represent the number of rings, or "age".)

counts to increase with increasing fish size, up to 8 rings. The size ranges of fish with 5 or more rings were broad, however, with a great amount of overlapping between successive groups.

Moore (1951) in working with Hawaiian yellowfin tuna encountered similar difficulties. He also observed that small specimens of yellowfin, weighing about 5 pounds, had no scales except on the corselet region. He therefore concluded that scales were formed first on the anterior and later on the posterior part of the body. He stated that "if this is the case, any marks laid down in the scales would be of little value until the nature of scale formation and its relation with size and age of fish was known." The nature of scale formation on the albacore has not as yet been determined. Since it was our experience that only about half of the scales examined were considered readable, and these were read with considerable subjectivity, further work with scales was discontinued.

VERTEBRAE

Description

The albacore vertebra is amphicoelous, or concave at both ends of the centrum. A sectioned vertebra shows two cones, the vertices of which meet at or near the middle of the centrum, with their bases forming the margins of the vertebra. On the inner surface of these cones are concentric rings running parallel to the outer margin of the centrum. These rings are described by Partlo (1955) as "narrow translucent zones separated by broad, opaque zones similar to those described by Freidenfelt (1922) for *Lucioperca*. In the albacore the narrow zones were observed not only as translucent bands but also as eruptions or ridges on the centrum surface. The innermost ring differed slightly from the others but was nevertheless clearly marked." We also observed certain rings that appeared as translucent ridges on the surface of the centrum; there were other rings, however, that resembled narrow, translucent bands without any surface eruptions, and still others that were mere suggestions of lines or bands.

Change in the Shape of Vertebrae With Growth of Fish

In the course of examining a wide series of vertebrae, it was noted that while the two cones of an amphicoelous caudal vertebra were nearly the same size in small fish, the posterior cone was larger than the anterior in large fish, indicating that the vertebra changed its shape with growth of the fish. The lengths of the two cones (vertebral radii) were measured and the ratio of the two measurements was plotted against the size of the fish (fig. 4). While the ratio was nearly 1 : 1 in the smallest vertebrae examined (fish around 50 to 60

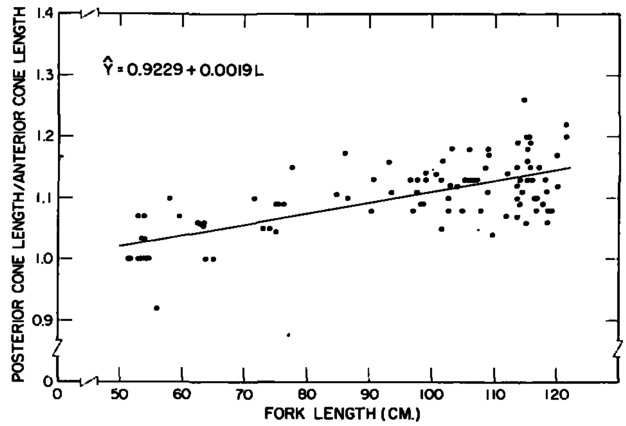

FIGURE 4.—Ratio of the average length of the posterior and anterior cones plotted against fish size to demonstrate the disproportionate growth of the two cones of the amphicoelous vertebrae of albacore.

cm. long), the posterior cone was definitely larger than the anterior in the larger vertebrae. This changing proportion is described by the rectilinear regression:

$$\hat{Y}=0.9229+0.0019\ L$$

where $\hat{Y}$ is the ratio of the two cones and L is the fork length in centimeters. Although the two cones of a caudal vertebra grow disproportionately, each cone in itself exhibits a linear growth with growth of the fish. Thus, in working with caudal vertebrae from a wide size range of fish, it is important that any measurements of ring or vertebral radii, for the purpose of estimating the growth increments of the fish, should be confined to either the anterior or the posterior cones and not to averages of the two. By working with one cone, growth calculations can be based on the simple linear relation between size of the vertebrae and size of fish.

Criterion for an annulus

Because of the great variability in the appearance of the rings, it was extremely difficult to formulate a satisfactory criterion for an annulus. In the beginning, we followed the definition of Partlo (1955), who considered as annuli those rings which appeared as ridges on the centrum surface. However, as will be discussed, our original criterion was later expanded to include rings which appeared as translucent bands with no surface eruptions.

Results of ring counts

After deciding upon the criterion to be followed, we made a series of independent ring counts and ring-radii measurements. A total of 9 series of counts and measurements resulted in agreements between any 2 series of as low as 8 percent and as high as 45 percent. There was poor agreement not only between counts of the two readers but also between counts made by the same person. Table 1 shows the best agreement attained between readers (44.8 percent) and between sets of readings made by the same reader (38.9 percent for reader *A* and 43.9 percent for reader *B*). While most of the disagreement was by 1 ring (31 to 50 percent), discrepancies of as many as 4 rings occurred in many of the comparisons. Consistency was often not achieved even between counts of the anterior and posterior cones of the same vertebra.

TABLE 1.—*Best agreement in ring counts between two readers and between any two series of the same reader*

[The readers are designated as *A* and *B*; the numerals denote separate readings; for example, A_2 represents the second reading made by reader *A*.]

Readings compared	Percentage agreement	Percentage disagreement by:			
		1 ring	2 rings	3 rings	4 rings
A_2 vs. B_3	44.8	38.8	11.9	3.7	0.7
A_1 vs. A_3	38.9	50.5	9.8	0.8	0.0
B_3 vs. B_4	43.9	47.0	8.3	0.8	0.0

It was observed that much of the inconsistency in the counts could be attributed to the difficulty in distinguishing rings near the vertex of the cone and also at its margin. This does not mean, however, that the rings on the central portion of the cones were clear and easily distinguishable, because here also there were many inconsistencies.

Samples from small fish

Age determination by means of hard parts frequently becomes more difficult and often breaks down completely in older fish. Therefore, attempts were made to age fish less than 90 centimeters in length in order to determine whether or not the use of vertebrae from larger, older fish was the cause of the poor results. In one trial consisting of two series of counts, the agreement was 56 percent for fish less than 90 centimeters as compared with 30 percent for larger fish. The higher agreement with smaller fish is, of course, to be expected because of the fewer rings. Further trials with samples of small fish disclosed that the counts were still far too variable to be acceptable as indicators of age.

The vertebrae were examined under natural and incandescent light and also under polarized and various colored lights with no noticeable improvement in the appearance of the rings. Various types of stains were also tried, but here again the results were disappointing from the standpoint of improving the readability of the rings. Thus, we found that we could not satisfactorily duplicate ring counts and therefore could not meet the first prerequisite to the use of vertebrae for aging albacore. Our findings are in contrast to Partlo's, who reported that "counts of rings were reproducible with high consistency."

Determination of time of ring formation

In order to validate the vertebral method for aging albacore, it is necessary that some direct evidence be obtained to show that the rings on the centra are true year marks, which are laid down annually. It appears reasonable to assume that if these rings are laid down regularly once each year, rather than randomly, a study of the margins of vertebrae collected periodically throughout a year should indicate the approximate period of ring formation. The width of the margin from the last ring to the edge of the centrum (the increment of the last ring) should be at a maximum immediately before, and at a minimum just at or after the formation of the last ring. A description of such a method of analysis for the determination of time of ring formation on tuna scales is given by Nose and others (1955).

An attempt was made to obtain some indication of the time of ring formation, despite the fact that any such study would probably be futile unless the rings or annuli could first be read with assurance. Measurements were made from the mid-point of the centrum to the margin of the vertebra (vertebral radius *T*) and to the last ring (ring radius R_n). Although the last ring was carefully selected in each instance, there was a possibility of error because rings on the margins were often indistinct. The difference between the vertebral and last-ring radii was considered the increment. Figure 5 shows a plot of the relative increment (absolute increment/vertebral radius) plotted against the month of capture of the fish. The data show no indication of regularity in time

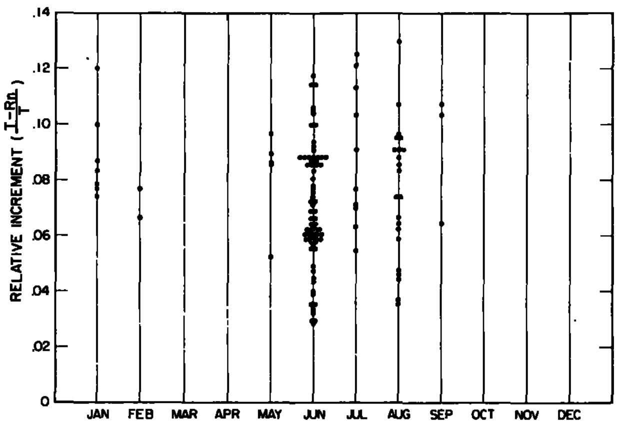

FIGURE 5.—Relative increment of the last ring plotted by month of capture of the fish.

of ring formation. Similarly, a plot of the absolute increment against time of capture resulted in a random scatter of points.

DISCUSSION

Previous investigators working on albacore age and growth have reported the presence of definite rings on the inner surface of the centrum of albacore vertebrae which, they believed, could be used as age indicators. They concluded that each of these rings represented an annulus and, therefore, assigned fish to specific age groups after making counts of these rings. Aikawa and Kato (1938) found that Uno's mean lengths (Uno 1936a, b) for age groups IV, V, and VI fell within the length range that they had established for these same age groups. Partlo (1955), on the other hand, found his ring radii values to be at variance with those observed by Aikawa and Kato, but stated that the disagreement was largely caused by the latter's not recognizing the ring closest to the vertex of the cone. Aside from this discrepancy, there was remarkable agreement between their ring radii values. Figueras (1955), who based his work largely on Partlo's technique, concluded that his results were in fair agreement with the latter.

Aikawa and Kato, Figueras, and Uno, so far as can be determined, have not satisfactorily established or presented any evidence showing that the rings on the vertebrae are age rings and annual in nature. Partlo, however, hypothesized that the rings are true year marks by the following: (1) by assuming that the length groups in the size frequencies are age groups, he found that there was acceptable agreement between the mean length of fish assigned to each vertebral ring-class and the mean length of corresponding length-groups in the sample, and (2) there was agreement between the lengths of young fish calculated from vertebral measurements of older fish and the observed lengths of young fish. For the latter, Partlo, working with a subsample of 98 fish, found that the observed lengths were consistently greater than the calculated lengths because the fish were captured some time after the last ring was formed. Partlo concluded that "from the above it seems clear that the third and subsequent vertebral rings are produced annually. It is assumed, in the absence of contrary evidence, that the inner two rings are annual also."

While Partlo's results indicated that the vertebral rings were true year marks, it was felt that more direct evidence would be desirable. One possible approach to obtaining such evidence is presented on page 357.

In this study, ring counts were not reproducible with consistency, due largely to the difficulty in formulating suitable criteria for the identification of the rings. Since it was demonstrated that there was a linear relation between the vertebral radius and the body length of the albacore (fig. 4), it was difficult to make a reading without first forming an opinion as to how many rings a certain-sized vertebra should have. Also, in making ring measurements the selection of a ring often depended on whether or not its radius fell within a certain range which encompassed all previous radii for that ring. Any extreme deviation was inadvertently questioned, and a subsequent remeasurement was made on a more "reasonable" ring, which was invariably found after closer scrutiny. For example, if the investigator measures the radius of the second ring at 5 mm. in a particular vertebra, and if all previous second-ring radii have fallen between 3 and 4 mm., he re-examines the vertebra for a second ring which he may have "missed." More often than not he will "find" the "missing" ring. In fact, it was observed that "rings" could be located at will almost anywhere on the centrum.

Aikawa and Kato (1938) state that "where the variation of the radius in comparison with other rings is very marked, the line cannot be considered an annual ring." Figueras (1955) found that in 40 percent of the specimens he examined, the first annulus as well as the succeeding annuli were located closer to the center of the centrum than the corresponding annuli in the remaining specimens (60 percent). He therefore considered the 40 percent to belong to a different spawning season and discarded them from calculations of growth increments. From the above, it appears that these workers also experienced some difficulty in rigidly adhering to established criteria.

The fact that we have not been able to reproduce ring counts with any reasonable consistency does not in itself prove that this method of aging albacore is invalid. There are other points which should also be considered. As stated earlier, no direct evidence has yet been presented to show that the rings on the vertebral centra are "annuli." Furthermore, if we examine the results presented by some of the other workers, we find that the increments that are noted do not give either a reasonable or consistent pattern of growth. Referring to Aikawa and Kato's results, Brock (1943) stated that "it may be seen that the growth increment from the age of one to that of eight is exactly the same each year, resulting in a growth curve that is absolutely linear. This is totally at variance with what is known of growth curves in general and in all other species of fishes that have been studied. If the number of "age rings" bears this relationship to the length of the fish it is probable that they do not represent annuli and bear no direct relationship to age." Partlo's results are somewhat similar. In figure 6 we show a plot of body-length at earlier ages as calculated from 5- and 6-year fish; the data were derived from Partlo (1955: table VIII, p. 57). The calculated lengths

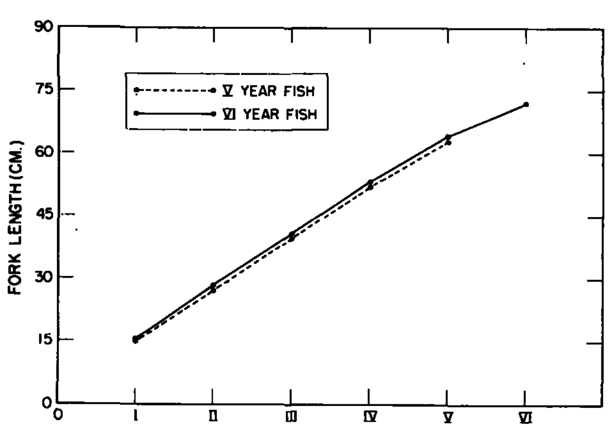

FIGURE 6.—Calculated lengths of albacore at earlier ages based on 5- and 6-year fish. (Taken from Partlo, 1955, table VIII.)

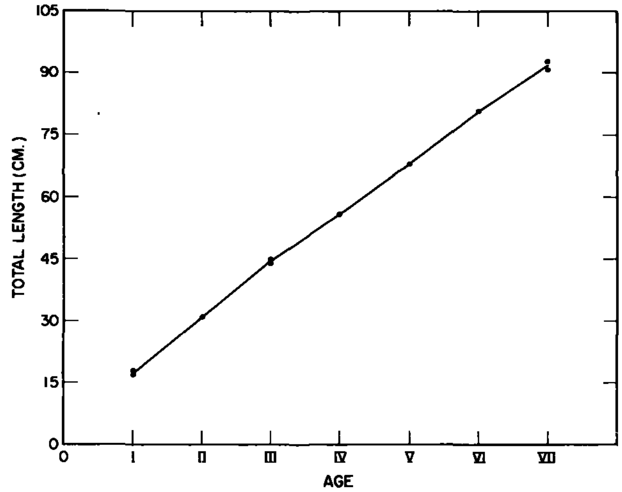

FIGURE 7.—Mean length at each age of albacore captured off northwestern Spain as reported by Figueras (1955). (Lengths given are total lengths.)

from ages 1 to 4 based on 5-year fish and the lengths for ages 1 to 5 based on 6-year fish form curves which are almost perfectly linear. The results presented by Figueras are shown in figure 7. Here again, the growth curve is remarkably linear, contrary to the general concept of growth curves.

Another consideration is that the various estimates do not appear to be consistent with growth as evidenced by tag returns. The information from this source is meager, however, and not much weight should be given it at the present time. A summary of albacore tag recoveries is given in table 2. The 5 tag recoveries which contribute information on growth are shown in figure 8.

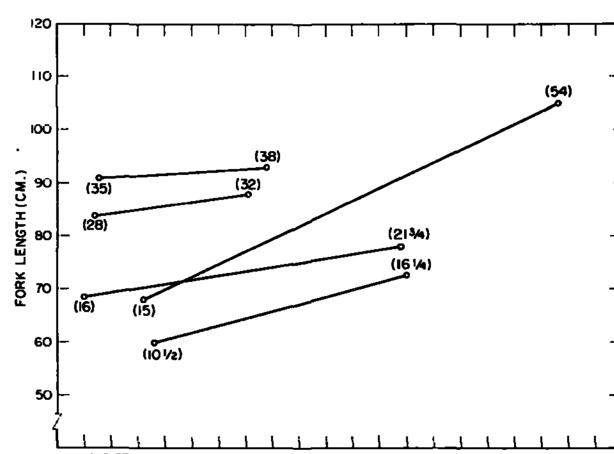

FIGURE 8.—Growth shown by 5 tagged albacore; data presented in table 2. (Body weight, in pounds, in parentheses.)

TABLE 2.—*Albacore tag recoveries reported by POFI and the California Department of Fish and Game* [1]

No.	Date of release	Locality of release	Released by	Date of recovery	Locality of recovery	Fish size	
						Release	Recovery
						cm.	*cm.*
1	Aug. 4, 1952	33°25′ N., 118°15′ W	CF&G [2]	June 23, 1953	31°30′ N., 149°40′ E	76	
2	Aug. 11, 1953	Guadalupe Is.	do	Feb. 2, 1954	36°40′ N., 178°12′ E	84	88
3	Aug. 16, 1953	do	do	Feb. 23, 1954	30°10′ N., 178°54′ W	91	93
4	Sept. 26, 1954	33°42′ N., 121°15′ W	do	Apr. 6, 1955	31°55′ N., 143°15′ E		
5	Oct. 4, 1954	46°30′ N., 159°18′ W	POFI [3]	Nov. 28, 1955	35°45′ N., 157°39′ E	78.2	
6	Oct. 5, 1954	43°31′ N., 161°16′ W	do	Jan. 19, 1956	35°23′ N., 141°20′ E	68	105
7	Oct. 9, 1955	42°16′ N., 147°16′ W	do	June 24, 1956	31°54′ N., 158°37′ E	63.4	
8	Oct. 17, 1955	44°55′ N., 144°48′ W	do	Aug. 1, 1956	31°21′ N., 117°17′ W	59.9	72.3 (16¼ lbs.)
9	July 31, 1956	44°31′ N., 174°55′ W	do	July 23, 1957	30°08′ N., 119°03′ W	68.4	78.0 (21¾ lbs.)

[1] The data for the California tag recoveries are derived from the reports of Ganssle and Clemens (1953), Blunt (1954), and Anonymous (1955).
[2] Department of Fish and Game, Sacramento, California.
[3] Pacific Oceanic Fisheries Investigations, U. S. Fish and Wildlife Service.

Variable growth is indicated, ranging from 2 cm. in about 6 months to 37 cm. in 16 months (4 to 28 cm. per year). The weights indicated in figure 8, with the exception of the last two recoveries (Nos. 8 and 9, table 2), are estimated weights based on the following length-weight relation:

$$\text{Log Weight} = -7.0239 + 2.87912 \text{ Log Length}^{1}$$

In terms of weight, a rough estimate of growth amounted to 6, 9, 27, 6, and 10 pounds per year, respectively, for the 5 fish shown from top to bottom in figure 8. Clearly, no conclusions can be drawn from these data. It is to be noted, however, that there are indications here of a moderately rapid growth rate, somewhat greater than the various estimates provided by the vertebral method of age determination.

It is possible, of course, that the rings on the centra are associated with growth but not necessarily with age of the fish. Unlike many of the fishes of the north temperate zone, it appears that albacore live under fairly uniform conditions by migrating to areas where food is available and where water temperature is suitable. They are not subject to extremes of winter and summer conditions as are certain fishes that occupy a more limited range. In the absence of any environmental extremes that might produce marked changes in the metabolic activity of the fish, it is quite possible that "winter" rings do not appear on the albacore's scales and vertebrae.

We have concluded that the rings on the vertebrae are probably not age rings which are laid-down annually or at such regular intervals that they can be used to tell the age of the fish; however, even if the rings were laid down randomly with respect to time, older fish in general would be expected to possess more rings than the younger ones. Assuming this applies to the albacore, the number of rings in relation to the size of fish might be used to differentiate rapidly growing fish from slower growing individuals. Counts of rings in albacore separated by sex show that among larger fish, the females, at a given ring count are smaller than the males (fig. 9). The number of rings in the counts ranged from 3 to 12, and the females were represented for each count up to 11 rings. Although the female albacore apparently do not grow so large as the males, having reached their maximum size at around 112 cm. (fig. 10, also Otsu and Uchida, 1959), the ring counts indicate that the largest females may be about as old as the largest males.

A great predominance of males has been noted among the larger sizes of several species of tunas (e. g. Shomura and Murphy 1955). This unequal sex ratio among the larger sizes has been attributed to "either differential mortality or differential growth, or to combinations of the two factors." Differential availability has also been suggested. For albacore there is a similar situation, but somewhat more pronounced, for the males attain a markedly larger size than females (fig. 10). Returning to figure 9, fish having 7 or more rings show growth differentiation by sex, the males being the larger for each ring class. This bit of evidence suggests that after about the seventh ring, the males have a faster growth rate than females. It is interesting to note that this apparent differentiation in growth commences when the fish attain a length of about 90 cm., which is the size at which albacore are believed

[1] Computed by POFI based on 77 fish (51–119 cm.) taken in the central North Pacific.

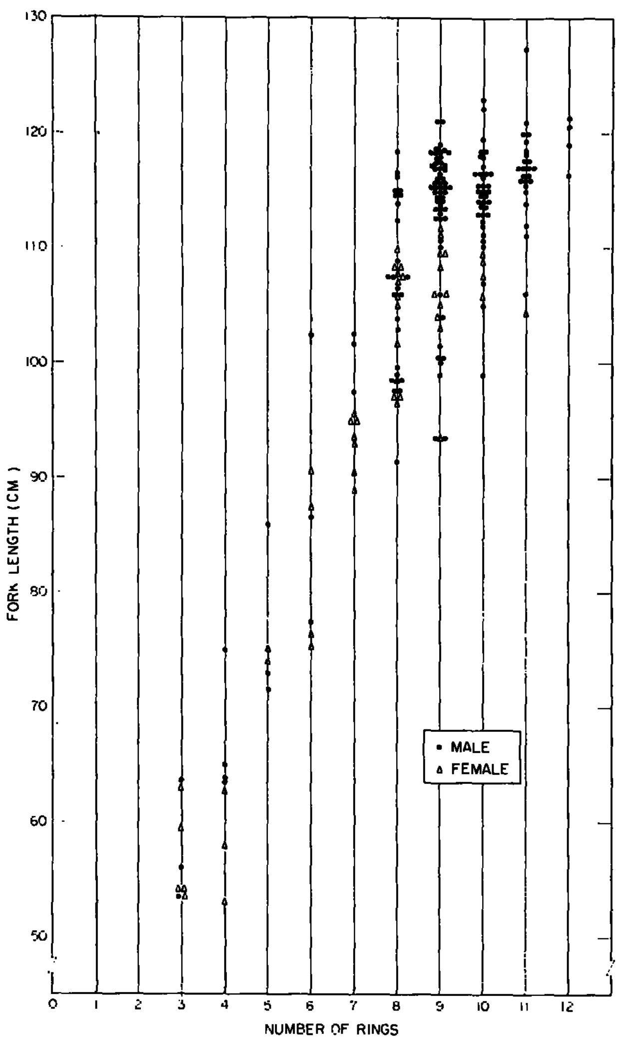

FIGURE 9.—Ring counts shown by fish size and sex for one series of anterior cone readings.

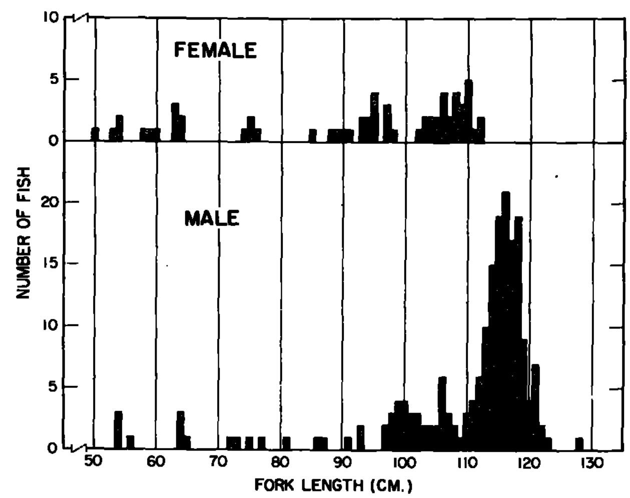

FIGURE 10.—Length and sex distribution of albacore used in this study. (The numbers of fish in smaller size classes differ from those of figure 1, which includes unsexed specimens.)

to reach sexual maturity (Otsu and Uchida, 1959; Ueyanagi 1955). Thus, as juveniles, both sexes seem to grow at about the same rate, then upon attaining sexual maturity, the males outgrow the females, so that among the larger sizes males predominate even though the larger females are just as old as the larger males. If our assumption that the rings on the vertebrae indicate "relative age" is valid, then our data suggest that this phenomenon of unbalanced sex distribution among larger albacore is due primarily to differential growth, with differential mortality or differential availability playing a possible secondary role.

It is also apparent that differential growth is not the sole factor in operation here, since size frequencies, such as in figure 10, lack a mode of large females of a magnitude comparable to the last mode of males. We would expect to find two large modes, one of females slightly to the left of that for males, in accordance with the difference in growth rates. This is not the case. Although evidence points to differential growth as being the main factor, other factors are probably acting in conjunction to cause the apparent reduction in numbers of the larger females. Here again, we must use caution in accepting any conclusions drawn from data presented in figure 9 since, ring counts could not be duplicated with any degree of consistency. Despite the questionable validity of these data, the fact that they showed the relatively smaller females to have, in general, nearly as many vertebral rings as the larger males has prompted the authors to present this discussion as a possible explanation of the puzzling phenomenon of unbalanced sex distribution encountered among the larger sizes.

SUMMARY AND CONCLUSIONS

(1) This study is based on the examination of vertebrae and scales collected from 212 Hawaiian and 53 central North Pacific albacore. In addition to scales and vertebrae, a cursory examination was made of the operculum, dorsal and pectoral fin spines and the hypural plate for possible indications of age.

(2) The sample represents fish taken by longline, trolling, and gill nets during the period January 1955 to July 1956.

(3) None of the various structures examined revealed any markings which could be interpreted as age marks.

(4) Scales from 100 fish were examined; of these, the scales of 43 fish were considered unreadable. Samples from the remaining 57 fish varied greatly in degree of readability. A plot of the ring counts against fish size showed considerable overlapping between successive groups.

(5) Scales taken from the same fish were often of variable size. It was noted that small scales contained fewer rings than large scales, indicating that the origin of the scales was not uniform.

(6) Because of the undetermined nature of scale formation, and the fact that only about one-half of the scales were considered readable, further work with scales was discontinued.

(7) A change was observed in the shape of the caudal vertebrae with growth of the fish. Among the smaller vertebrae, from fish of about 50 to 60 cm. in length, the ratio of the length of the anterior cone to that of the posterior cone was nearly 1:1. The posterior cone was larger than the anterior in the larger vertebrae. Although the two cones of a caudal vertebra grow disproportionately, each cone in itself exhibits a linear growth with growth of the fish.

(8) In comparing independent sets of readings made by readers *A* and *B*, the highest agreement between the two readers was 44.8 percent. The best agreement between any two readings of the same reader was 38.9 percent for reader *A* and 43.9 percent for reader *B*. The most difficult rings to distinguish were those near the vertex and the margin of the cone.

(9) Although the vertebrae of small albacore were somewhat more readable than those of large albacore, it was still not possible to achieve sufficient consistency in ring counts and measurements to validate this method of age determination.

(10) The results indicated that the rings on the vertebral centra are laid down randomly with respect to time, rather than periodically. It is realized, however, that the validity of this method of analysis is questionable, since it is based on the recognition of the last ring and since the ring counts could not be duplicated with any consistency. If our results are valid, it would appear that the rings are simply growth marks rather than age marks.

(11) Considerable personal bias was inadvertently introduced into the readings and measurements. It was almost impossible to make a reading without first forming an opinion as to the number of rings that should be expected on a vertebra of a certain size.

(12) The growth increments reported by previous investigators did not appear to give either a reasonable or a consistent pattern of growth.

(13) The growth estimates of past investigators do not appear to be consistent with growth as evidenced by tag returns. Although the data derived from tagged fish are meager, they indicate that albacore have a moderately rapid growth, somewhat greater than the various estimates provided by the vertebral method of age determination.

(14) Unlike many north temperate species which occupy limited environments, the albacore appears to spend its life under fairly uniform conditions by migrating to areas of abundant food and favorable water temperature. Thus, these fish are probably not subject to the extreme summer and winter conditions which would cause "winter" marks to appear on scales and vertebrae.

(15) Although rings on the vertebrae are probably not age rings which are laid down annually or at such intervals that they could be used to tell the actual age of the fish, it was pointed out that the rings could possibly be used to assess the relative age, that is, older fish would have more rings than younger fish.

(16) Results of a series of ring counts were examined for differences between sexes. There was evidence that the unbalanced sex distribution among larger albacore, with a great predominance of males, was largely due to differential growth which sets in with the onset of sexual maturity, after which the males grow at a faster rate than the females.

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