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# GROWTH OF BLUEFIN TUNA OF THE WESTERN NORTH ATLANTIC

BY FRANK J. MATHER III AND HOWARD A. SCHUCK

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## ABSTRACT

Growth of bluefin tuna *Thunnus thynnus* (Linnaeus) based on specimens captured mostly in the Cape Cod and Long Island areas was studied by counting annuli on scales and vertebrae and by analyzing length-frequency data. Similar results obtained by these two methods support their validity for ages 0–4. Older ages were determined by counting annuli only, but tag returns and weight-frequency data afford some corroboration for ages 5–7. Growth is believed to be extremely rapid during the first summer and about four-fifths of an inch per month in the first winter. During the next 3½ years, bluefin tuna grow at a rate of about 1¼ inches per month in summer and about one-third of an inch per month in winter, or about 7 inches per year. Tables of estimated sizes for each month of the first 5 years of life, and at midsummer through the age of 10 years, are presented. The growth rate appears to decline gradually to about 4 inches per year in this range. Only slight differences were found between the sizes and growth rates of fish of the same age taken in different years.

# GROWTH OF BLUEFIN TUNA OF THE WESTERN NORTH ATLANTIC

By Frank J. Mather III and Howard A. Schuck

Information on the growth of bluefin tuna (*Thunnus thynnus*) of the western North Atlantic Ocean is incomplete, and limited to the smaller sizes for which age-with-length studies are published (Westman and Gilbert, 1941; Westman and Neville, 1942). Only fragmentary data are available on specimens longer than 46 inches. As a result of the growing interest in bluefin tuna by sport and commercial fishermen, we began a cooperative project, in 1950, to accumulate material for an age-determination study of the bluefin throughout its entire size range. The present paper is an account of our interpretation of this material to date.

In the preparation of this paper, we received valuable advice from Dr. Lionel A. Walford of the U.S. Bureau of Commercial Fisheries, and Dr. Henry B. Bigelow and Dr. William C. Schroeder, both of the Woods Hole Oceanographic Institution and Harvard University. Dr. James R. Westman of Rutgers University made available to us his extensive data on bluefin tuna. Other material was collected and measurements were obtained through the kindness of several Cape Cod commercial fishermen, notably Capts. John Vetorino, Adam Rupkus, Mike Goulart, and Nathaniel Wixon of Barnstable; also John A. Worthington of North Truro, Joseph Francis and Stuart Joseph of Provincetown, as well as through the cooperation of many sport fishermen and charter boat captains. Many of the length measurements were made by Frank Riley of the U.S. Bureau of Commercial Fisheries at Provincetown, Mass. Several other people contributed length measurements as noted in the frequency tables. Assistance in obtaining and processing data and in preparing this paper was received from members of the U.S. Bureau of Commercial Fisheries at Woods Hole, including Donald M. Allen who worked 4 years on this study, also from several members of the Woods Hole Oceanographic Institution. Their assistance is gratefully acknowledged.

## READINGS OF ANNULI

As in other species of fishes, including several other tunas, annuli are formed on the scales, and also on the centra of the vertebrae (Sella, 1929; Aikawa and Kato, 1938; Westman and Gilbert, 1941; Westman and Neville, 1942; Partlo, 1955). Because these annuli are not consistently distinct in either of these two structures, and for other reasons which will be explained later in the text, we examined both. In the beginning we assumed that the annuli which we counted were formed once each year and therefore indicated the age in years. For verification of this assumption we depend on the internal evidence furnished by our material, including consistency of the age determinations with analysis of length-frequency data.

Most of our data are from fish caught in the vicinity of Cape Cod in pound nets or by hook and line. We took scales or vertebrae (or both) from as many specimens as time and opportunity permitted. There was rarely any difficulty in obtaining scales from fishermen's catches. This was less true for vertebrae, for frequently we were permitted to take them only from the tail, which is usually cut off in dressing the fish. Owing to unfavorable working conditions, it was not always possible to measure the fish from which the tails were cut. In such cases, we estimated the length from a regression of fork length against caudal spread [1] or, if the weight of the fish could be obtained, from a length-weight curve based on 778 specimens from 34 to 270 centimeters long.

We prepared celluloid impressions of the scales (Arnold, 1951), and studied them with the aid of a magnifying projector. Figure 1 shows the annuli, zones of crowding, or discontinuity of the circuli, which research workers consider to be formed annually. We also counted the rings on the centra of the vertebrae (fig. 2). These rings were marked

[1] Regression formula with a correlation coefficient of 0.997 computed from 155 specimens, 29 to 270 centimeters long, where X is fork length, Y is caudal spread—$\text{Log } X = 0.7271 + 0.8642 \text{ Log } Y$.

Note.—Frank J. Mather III, Woods Hole Oceanographic Institution, Woods Hole, Mass.; Howard A. Schuck, Alaskan Air Command, Anchorage, Alaska, formerly fishery biologist, U.S. Bureau of Commercial Fisheries, Woods Hole, Mass.

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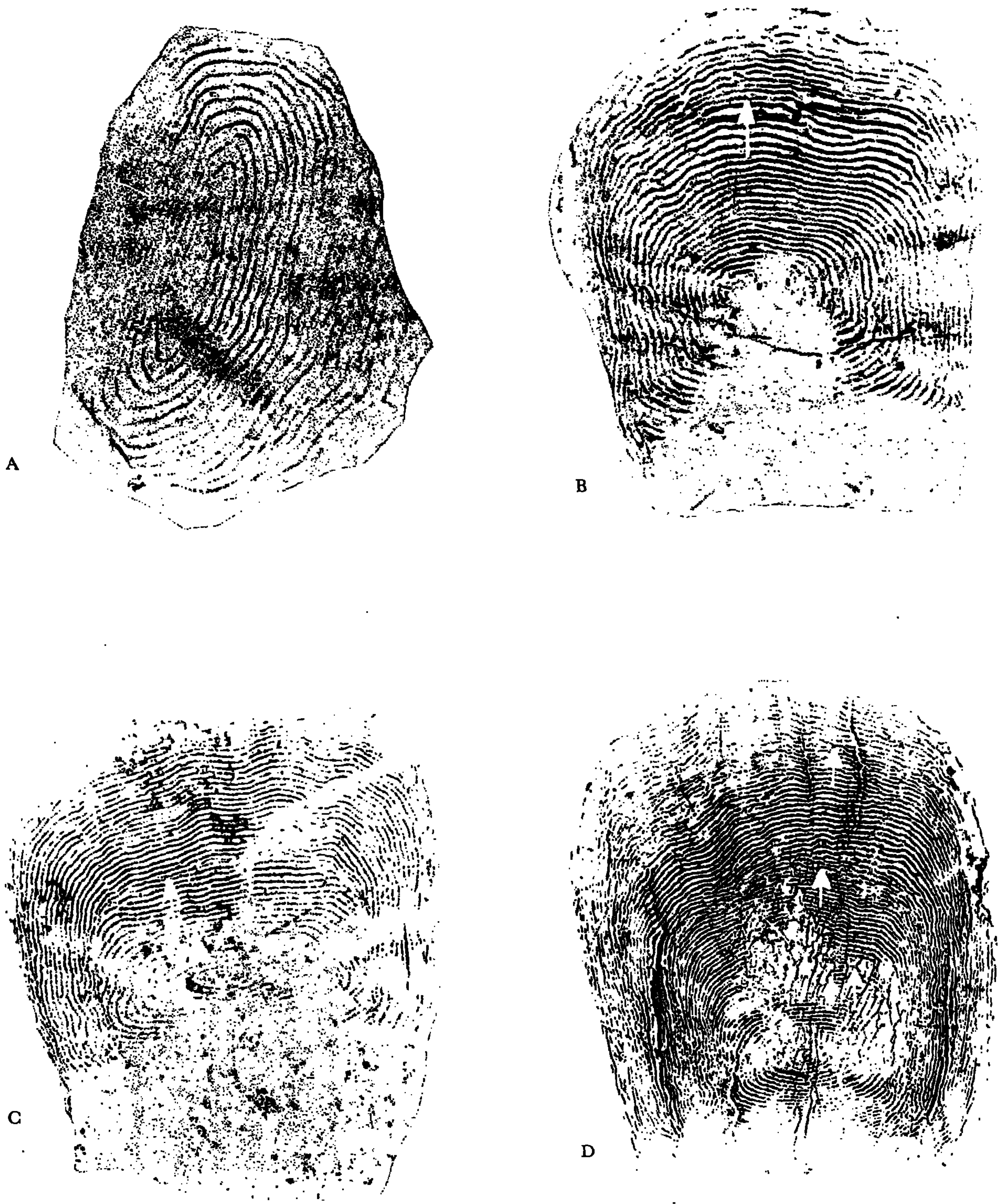


FIGURE 1.—Projected impressions of scales of bluefin tuna. Arrows indicate annuli. A. Scale from fish 34 cm. long taken off Martha's Vineyard, September 1952; no annulus. B. Scale from fish 60 cm. long taken off Martha's Vineyard, July 1950; 1 annulus. C. Scale from fish 80 cm. long taken off Martha's Vineyard, August 1952; 2 annuli. D. Scale from fish 104 cm. long taken off Cape Cod, October 1950; 3 annuli.

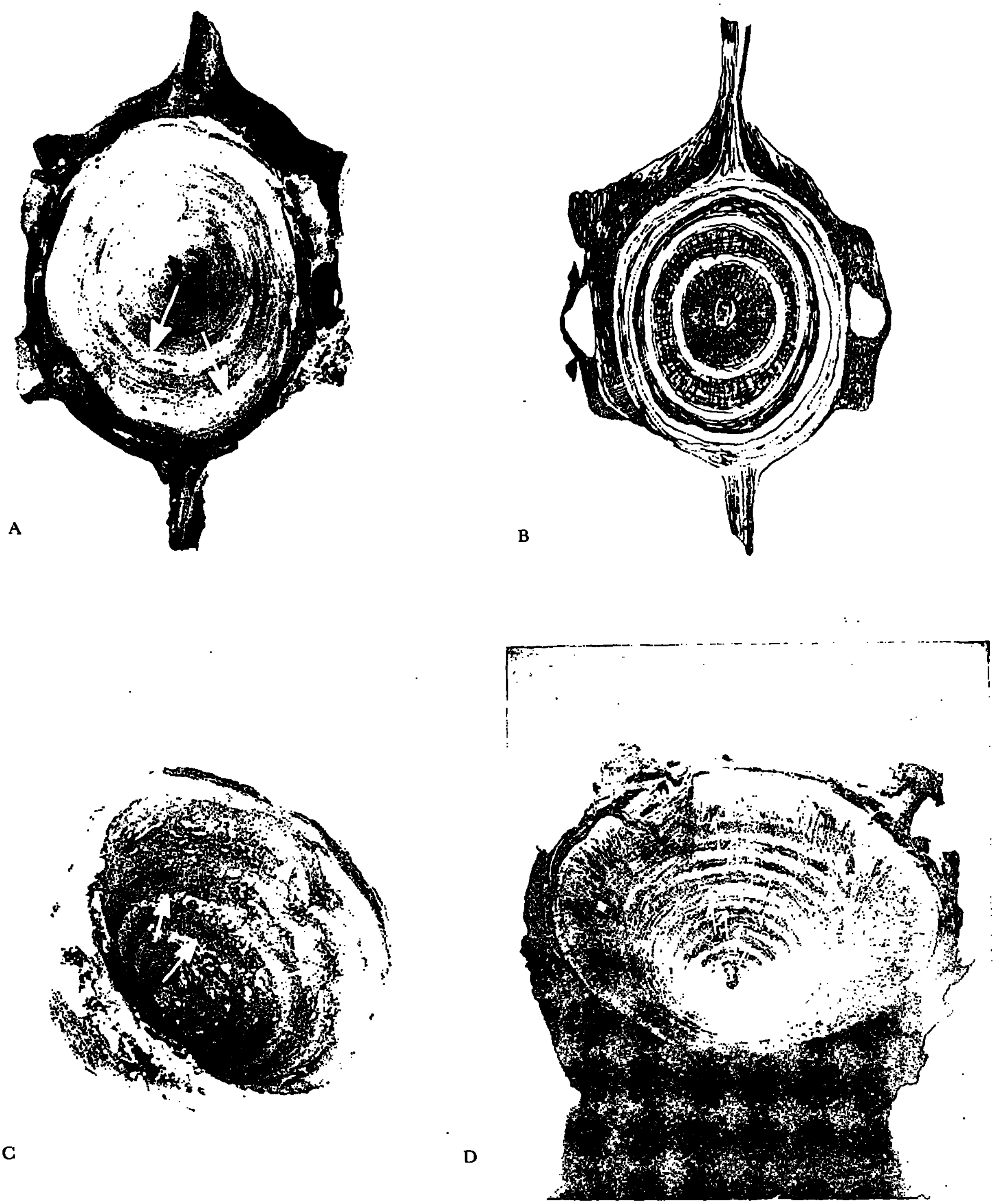


Figure 2.—Centra of vertebrae of bluefin tuna. Arrows indicate annuli. A. Vertebra from fish 77.5 cm. long taken off Martha's Vineyard, August 1951; 2 annuli. B. Drawing of stained vertebra from a fish 104 cm. long, taken off Cape Cod, October 1950; 3 annuli. Scale in figure 1D is from the same fish. (Reproduced from Galtsoff (1952) by permission of the author and publishers.) C. Stained vertebra of fish 110 centimeters long taken off Cape Cod, October 1950; 4 annuli. D. Vertebra of giant tuna taken off Cape Cod; about 11 annuli. Annuli beyond the 9th or 10th are usually small and indistinct and disappear soon after dissection. (A, C, and D, unretouched.)

TABLE 1.—*Fork lengths (in cm.) of bluefin tuna taken in the vicinity of Cape Cod, for each number of annuli*

[Numbers in parentheses estimated from regression of length on caudal spread or on weight]

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34.2 | 51.5 | 71.0 | 84.0 | 107.2 | (120.3) | (144.4) | 155.8 | 162.9 | 179.0 | 182.0 | 223.4 | 207.5 | 236.6 | 247.0 |
| 35.3 | 52.1 | 71.0 | 84.7 | 107.7 | (124.5) | (145.0) | 156.7 | 170.8 | 179.4 | 184.5 | 225.6 | 229.0 | 237.0 | 248.0 |
| (37.5) | 52.2 | 73.0 | 85.3 | 108.0 | (126.0) | (151.5) | (157.6) | 174.8 | 183.0 | 190.4 | | 234.0 | 240.0 | (249.0) |
| 37.8 | 53.3 | 74.0 | 85.7 | 108.6 | 126.2 | 153.0 | (161.7) | 176.5 | 185.2 | 218.0 | | 241.5 | 240.6 | |
| 41.2 | 53.8 | 74.0 | 85.7 | 110.0 | (127.1) | (153.2) | (164.4) | 176.6 | 193.6 | 221.5 | | 244.3 | 244.0 | |
| 42.2 | 55.4 | 74.0 | 85.9 | 110.0 | (129.0) | (153.7) | (165.8) | 177.8 | (196.6) | 224.0 | | 245.7 | 248.0 | |
| | 56.0 | 74.5 | 85.9 | 112.1 | 130.0 | 154.0 | (169.0) | 182.0 | | | | | 257.0 | |
| | 56.1 | 74.7 | 86.1 | (113.7) | (130.4) | (156.0) | | | | | | | | |
| | 58.2 | 74.8 | 87.1 | 114.1 | 130.8 | 158.2 | | | | | | | | |
| | 58.8 | 74.9 | 87.4 | 114.5 | (131.3) | (158.7) | | | | | | | | |
| | 59.0 | 75.0 | 87.8 | 114.6 | 132.0 | (166.0) | | | | | | | | |
| | 59.7 | 75.0 | 88.2 | 115.0 | (132.0) | (170.9) | | | | | | | | |
| | 60.0 | 75.6 | 88.4 | 115.0 | (132.0) | | | | | | | | | |
| | | 75.7 | 88.7 | 116.1 | (133.0) | | | | | | | | | |
| | | 75.7 | 89.0 | 116.6 | (133.5) | | | | | | | | | |
| | | 76.3 | 89.0 | 117.5 | (134.0) | | | | | | | | | |
| | | 76.7 | 89.7 | (118.3) | 135.0 | | | | | | | | | |
| | | 76.9 | 90.2 | 118.5 | 135.0 | | | | | | | | | |
| | | 77.1 | 90.8 | (118.6) | (135.5) | | | | | | | | | |
| | | 77.5 | 91.1 | (119.0) | (137.2) | | | | | | | | | |
| | | 77.5 | 91.6 | 119.6 | (137.4) | | | | | | | | | |
| | | 77.6 | 92.1 | 120.0 | 140.0 | | | | | | | | | |
| | | (77.9) | 92.9 | 122.0 | 140.0 | | | | | | | | | |
| | | 78.2 | 95.0 | (122.8) | (140.0) | | | | | | | | | |
| | | 78.5 | (98.0) | (123.0) | 142.2 | | | | | | | | | |
| | | 79.1 | 103.3 | 124.4 | 146.0 | | | | | | | | | |
| | | 79.5 | 104.4 | 124.5 | (150.2) | | | | | | | | | |
| | | 80.0 | 104.8 | 125.6 | (157.0) | | | | | | | | | |
| | | (80.8) | | 129.0 | (160.3) | | | | | | | | | |
| | | (81.8) | | (130.2) | | | | | | | | | | |
| | | 81.9 | | (130.4) | | | | | | | | | | |
| | | | | (130.7) | | | | | | | | | | |
| | | | | (132.1) | | | | | | | | | | |

by depressions in the surface and also by variations in color, which were accentuated when the vertebrae were soaked in water, or when they were stained (Galtsoff, 1952). We examined the vertebrae either with the naked eye or with the aid of a wide-field binocular microscope. We believe that these annuli on scales and vertebrae are probably formed during winter or early spring.

Scales were legible for most fish weighing 50 pounds or less, but rarely for larger ones. As scales could be more readily collected than vertebrae, we used scales for most of our age determinations of small fish, resorting to vertebrae for larger specimens. The material from each specimen was usually examined independently, and often also by our colleague Donald Allen. When readings differed, material was reexamined. If the difference between extremes remained greater than 2, the specimen was discarded. For differences of 2 or less, the average value or the unit closest to it was used. Actually, there were few disagreements in readings for fish up to 50 or 60 pounds. Legible scales and vertebrae were found for 28 fish and counts of annuli on scales agreed with those on the vertebrae. Readings for fish of 70 to 270 pounds often differed by 1 year; those for larger fish sometimes differed by 2 years or more. Lengths (table 1) are from annuli counted from scales or vertebrae, or both; length-frequency distributions (fig. 3) are for each year of age; average length (table 2) is for each year.

TABLE 2.—*Average fork length of bluefin tuna taken in the vicinity of Cape Cod, for each year of age from readings of annuli on scales and vertebrae*

| Age in years | Length in cm. | Number of specimens |
|---|---|---|
| 0 | 38.0 | 6 |
| 1 | 55.9 | 13 |
| 2 | 76.5 | 31 |
| 3 | 90.5 | 28 |
| 4 | 118.8 | 34 |
| 5 | 135.0 | 29 |
| 6 | 155.4 | 12 |
| 7 | 161.6 | 7 |
| 8 | 174.4 | 7 |
| 9 | 186.1 | 6 |
| 10 | 203.4 | 6 |
| 11 | 224.5 | 2 |
| 12 | 233.7 | 6 |
| 13 | 243.3 | 7 |
| 14 | 248.0 | 3 |

## ANALYSIS OF LENGTH FREQUENCIES

Another method of estimating age and growth is by following the seasonal progression of dominant size groups. This is especially useful for species that spawn over a fairly short season and grow rapidly. Evidently the bluefin tuna meets these conditions, as even casual observers notice the regularity with which catches of small tuna can be ranked in size categories by eye. Moore (1952) and Postel (1954) analyzed size frequencies to determine the ages of yellowfin tuna in the Pacific and the tropical eastern Atlantic, respectively. Aikawa and Kato (1938) used the same method in conjunction with counts of vertebral rings in studying the growth of western Pacific tunas, as did Partlo (1955) for northeastern Pacific albacore. Westman and Gilbert (1941) and Westman and Neville (1942) used the method in conjunction with scale studies for bluefin tuna taken off Long Island, N.Y.

We have based our size-frequency study on lengths rather than on weights, as we believe that, for fish of a given age, lengths are subject to smaller and more regular variations. Because we lack sufficient data on the large sizes, we have not attempted to analyze lengths greater than 56.5 inches.

From various sources, we have compiled length measurements of 4,990 bluefin tuna less than 56.5 inches long. With the exception of the 1941 sample which was measured on Long Island by Westman and Neville (1942), and several fish less than 20 inches long which were from more southerly waters, most of these were taken in the New England area from 1950 to 1957. With the exception of a few specimens less than 20 inches long, the fish were caught from late June to mid-October. We have followed the method of Westman and Neville in measuring the fish to the nearest inch with a tape from the snout to the fork of the tail, following the curvature of the body. Where we used calipers for determining length, we estimated the "curved" measurement from a conversion factor.[2] The measurements for fish more than 20 inches long, for all localities and years combined, are listed by half monthly periods in table 3. The data for smaller fish were gathered from more diverse localities and extend over a greater portion of the year, hence are listed in more detail in table 4.

TABLE 3.—*Length frequencies of bluefin tuna from 20.5 to 56.5 inches long taken off Long Island [1] in 1941 and off New England [2] in 1950–57 from late June to mid-October*

| Length in inches | Number of tuna: July [3] 1–15 | July 16–31 | August 1–16 | August 17–31 | September 1–15 | September 16–30 | October 1–18 | Age in years |
|---|---|---|---|---|---|---|---|---|
| 21 | 7 | | | | | | | |
| 22 | 9 | 31 | 4 | 1 | | | | |
| 23 | 5 | 33 | 13 | 9 | 4 | 1 | | |
| 24 | | 25 | 17 | 31 | 42 | 4 | | |
| 25 | | 4 | 12 | 10 | 58 | 7 | 2 | I |
| 26 | | 1 | 1 | 1 | 26 | 14 | | |
| 27 | 1 | 2 | | 1 | | 3 | | |
| 28 | | 5 | 3 | | 1 | 2 | | |
| 29 | 23 | 24 | 10 | 3 | | | | |
| 30 | 60 | 68 | 88 | 5 | 3 | 1 | | |
| 31 | 57 | 114 | 122 | 41 | 1 | 1 | 2 | |
| 32 | 25 | 64 | 65 | 97 | 3 | 7 | 3 | |
| 33 | 10 | 28 | 22 | 72 | 3 | 15 | 8 | II |
| 34 | 9 | 1 | 6 | 17 | 9 | 15 | 15 | |
| 35 | | | | 4 | 6 | 5 | 9 | |
| 35 | 30 | 27 | 7 | 3 | | | | |
| 36 | 69 | 50 | 44 | 13 | 4 | 5 | 4 | |
| 37 | 87 | 120 | 119 | 46 | 8 | 6 | 6 | |
| 38 | 53 | 100 | 178 | 153 | 24 | 6 | 8 | |
| 39 | 14 | 56 | 141 | 253 | 40 | 26 | 22 | |
| 40 | 1 | 20 | 96 | 203 | 94 | 29 | 26 | |
| 41 | | 7 | 31 | 112 | 76 | 28 | 18 | III |
| 41 | 1 | 8 | | | | | | |
| 42 | | 2 | 9 | 33 | 52 | 23 | 10 | |
| 42 | 13 | 10 | 4 | | | | | |
| 43 | 19 | 15 | 11 | 11 | 16 | 14 | 5 | |
| 44 | | | | | 4 | 2 | 3 | |
| 44 | 28 | 17 | 18 | 23 | 8 | | | |
| 45 | 37 | 14 | 11 | 57 | 9 | 4 | 6 | |
| 46 | 58 | 11 | 8 | 23 | 8 | 2 | 11 | |
| 47 | 29 | 8 | 7 | 6 | 15 | 6 | 13 | |
| 48 | 24 | 3 | 4 | | 9 | 4 | 21 | IV |
| 49 | 5 | 3 | 6 | | 5 | 1 | 9 | |
| 49 | | 1 | | | | | | |
| 50 | 5 | 1 | | 4 | 1 | | 7 | |
| 51 | 5 | 2 | 2 | 1 | | | 7 | |
| 52 | 2 | | | 2 | | 2 | 2 | |
| 53 | 5 | 2 | | | | 2 | 1 | |
| 54 | 1 | 3 | | | | 1 | 6 | |
| 55 | 2 | 2 | | 4 | | 2 | 6 | |
| 56 | 3 | | | 5 | 1 | 3 | 1 | |

[1] Westman and Neville's (1942) sample consisting of 1,129 fish, was measured at Freeport, L.I., (N.Y.).
[2] A few fish caught off Nova Scotia, Long Island (N.Y.), and New Jersey are included. Most of this sample was taken in the vicinity of Cape Cod, but many of the fish were from the offshore waters, mostly in the vicinity of Georges Bank. Frank Riley measured 1,891 fish at Provincetown (Mass.) in 1953–54. We are indebted to Lewis R. Day of the Fisheries Board of Canada for measuring 5 fish in Nova Scotia in 1950, Jean McClean Wight of West Hartford (Conn.) for measuring 5 fish in Nova Scotia in 1954, Capt. Charles A. Mayo, Jr., of Provincetown (Mass.) for measuring 57 fish there in 1956, and Dr. Robert H. Gibbs, Jr., recently of the Woods Hole Oceanographic Institution, for measuring 69 fish in the Cape Cod area in 1956 and 1957. The remainder of the sample was measured by the authors and Donald M. Allen.
[3] Includes 102 fish measured June 28–30, 1953.

TABLE 4.—*Lengths of bluefin tuna less than 20 inches long, with dates and localities of capture and sources*

| Date | Length in inches | Number of fish | Locality | Source |
|---|---|---|---|---|
| June 9, 1953 | 1.8 | 1 | Miami area, Fla. | Rivas (1954). |
| July 14, 1953 | 11.7 | 1 | do | Do. |
| July 17, 1953 | 12.3 | 1 | do | Do. |
| July 19, 1953 | 10.3 | 1 | do | Do. |
| July 16–23, 1954 | 12.0 | 1 | Atlantic City, N.J. | William Upperman.[1] |
| July 19–26, 1954 | 9.0 | 1 | do | Do. |
| July 23, 1953 | 11.4 | 1 | Miami area, Fla. | Rivas (1954). |
| July 23, 1957 | 7.7 | 1 | do | Al Pflueger.[2] |
| July 24, 1953 | 11.8 | 1 | do | Rivas (1954). |
| Do | 12.9 | 1 | do | Do. |
| July 25, 1954 | 12.7 | 1 | do | Al Pflueger.[1] |
| July 26, 1953 | 11.9 | 1 | do | Rivas (1954). |
| July 29, 1953 | 12.2 | 3 | do | Do. |
| Do | 13.5 | 1 | do | Do. |
| July 30, 1953 | 11.2 | 1 | do | Do. |
| July 31, 1953 | 11.7 | 1 | do | Do. |
| July 31, 1954 | 12.0 | 2 | do | Al Pflueger.[2] |
| Aug. 10, 1953 | 12.4 | 1 | do | Rivas (1954). |
| Aug. 12, 1954 | 13.0 | 1 | Brielle, N.J. | Mrs. K. R. Mayer.[3] |
| Aug. 23, 1940 | 14.2 | 1 | do | Manasquan Marlin and Tuna Club. |
| Aug. 25, 1953 | 9.0 | 1 | do | Mrs. K. R. Mayer.[3] |
| Aug. 29, 1938 | 12.7 | 1 | do | C. W. Hoffman.[1] |
| Aug. 29, 1952 | 15.5 | 1 | Off Martha's Vineyard, Mass. | R/V *Bear*, R. Wolf.[2] |
| Sept. 2, 1939 | 12.5 | 1 | Brielle, N.J. | Westman and Gilbert (1941). |
| Sept. 1–7, 1953 | 12.7 | 4 | Gulf of Mexico, (29°03′ N, 88°54′ W). | U.S. National Museum.[4] |
| Do | 13.8 | 1 | do | Do.[4] |

See footnotes at end of table.

[2] A straight line fitted by inspection to a plot of straight (calliper) length against curved (tape) length, based on measurements for 185 individuals 37 to 257 cm. long, indicated that straight length was 0.958 of curved length.

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TABLE 4.—*Lengths of bluefin tuna less than 20 inches long, with dates and localities of capture and sources*—Continued

| Date | Length in inches | Number of fish | Locality | Source |
|---|---|---|---|---|
| Sept. 5, 1953 | 16.0 | 2 | Brielle, N.J | Mrs. K. R. Mayer.[3] |
| Do | 16.5 | 1 | do | Do.[3] |
| Sept. 5, 1957 | 12.0 | 1 | Ocean City, Md | F. J. Mather. |
| Sept. 6, 1952 | 15.6 | 1 | Off Martha's Vineyard, Mass. | Do. |
| Sept. 7, 1957 | 12.0 | 1 | Ocean City, Md | M. L. Dennis. |
| Do | 13.0 | 1 | do | Do. |
| Sept. 12, 1952 | 15.0 | 1 | Off Long Island, N.Y. | Rivas (1954). |
| Sept. 12, 1953 | 9.8 | 1 | Brielle, N.J | Mrs. K. R. Mayer.[3] |
| Do | 11.0 | 1 | do | Do.[3] |
| Do | 14.0 | 3 | do | Do.[3] |
| Sept. 14, 1957 | 13.2 | 20 | Ocean City, Md | M. L. Dennis. |
| Sept. 15, 1953 | 18.0 | 1 | Brielle, N.J | Mrs. K. R. Mayer.[3] |
| Sept. 17, 1952 | 14.1 | 1 | Off Martha's Vineyard, Mass. | R/V *Caryn*, F. J. Mather. |
| Sept. 18, 1952 | 16.9 | 1 | do | Do. |
| Sept. 20, 1957 | 14.0 | 1 | Ocean City, Md | M. L. Dennis. |
| Sept. 21, 1954 | 13.9 | 1 | Off the Carolinas, (33°10′ N, 77°25′ W). | U.S. Fish and Wildlife, Brunswick, Ga. |
| Sept. 21, 1957 | 31.0 | 3 | Ocean City, Md | M. L. Dennis. |
| Do | 14.0 | 1 | do | Do. |
| Sept. 22, 1957 | 14.0 | 1 | do | Do. |
| Do | 15.0 | 1 | do | Do. |
| Sept. 23–24, 1953 | 17.4 | 1 | Off Martha's Vineyard, Mass. | M/V *Albatross III*, J. Taylor.[2] |
| Sept. 24, 1957 | 13.0 | 1 | Ocean City, Md | M. L. Dennis. |
| Do | 14.0 | 10 | do | Do. |
| Do | 15.0 | 6 | do | Do. |
| Oct. 11, 1953 | 15.0 | 1 | Brielle, N.J | Mrs. K. R. Mayer.[3] |
| Oct. 13, 1952 | 14.5 | 1 | Cape Hatteras, N.C. | F. J. Mather. |
| Oct. 18, 1953 | 17.0 | 4 | Brielle, N.J | Mrs. K. R. Mayer.[3] |
| Nov. 10, 1953 | 15.6 | 1 | Miami area, Fla | Rivas (1954). |
| Nov. 12, 1952 | 17.7 | 1 | do | Do. |
| Nov. 16, 1952 | 16.6 | 1 | do | Do. |
| Nov. 27, 1952 | 17.6 | 1 | do | Do. |
| Jan. 5, 1951 | 18.3 | 1 | do | Do. |
| Jan. 27, 1959 | 18.8 | 3 | Off Cape Hatteras, N.C. | M/V *Albatross III*. R. Brigham and L. Lawday.[2] |

[1] Measurements were checked with ruler on photographic prints.
[2] Specimens were made available to us by kindness of the individuals listed.
[3] Measurements taken by charter boat captains who tagged the tuna, and collected for us by Mrs. Mayer.
[4] Measurements were made by Isaac Ginsburg and transmitted to us by Dr. L. P. Schultz.

The length frequencies for all localities combined between late June and mid-October are shown graphically for each half monthly period by years in figures 4–10, and for all years combined, by half monthly periods in figure 11. The number of fish in any given size group and period varies considerably from year to year, due to nonuniform sampling and availability, and to variations in the numerical strength of year classes. The general pattern of size groupings is consistent, however, with maximum and minimum numbers occurring around the same lengths year after year. It seems obvious that these groupings represent different ages. We have arbitrarily designated with vertical lines the points which we believe best separate the various age groups. Usually there seems to be little question as to where these lines should be drawn. If doubtful we based our judgment on a comparative study of data for the entire series of years. In a few such cases, we assigned some of the fish at a low point to one age and the rest to the other. Corresponding broken lines separate the data in table 3.

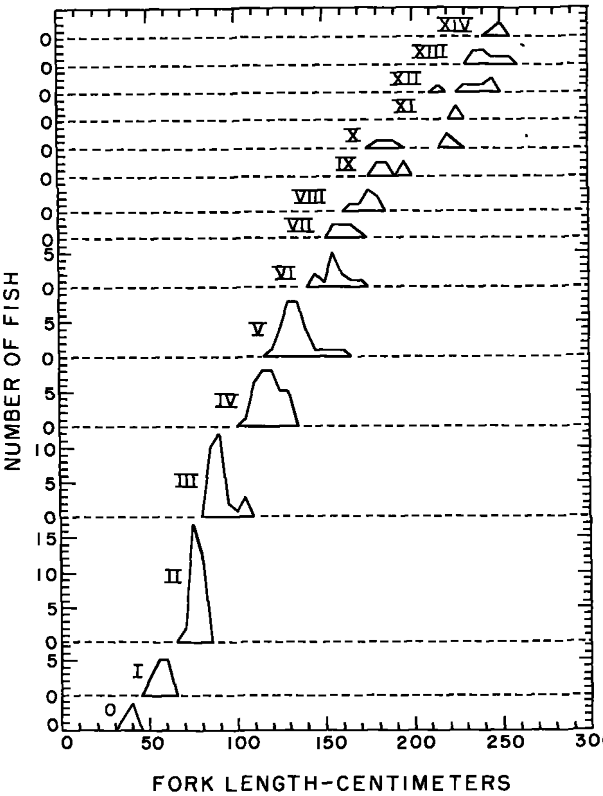


FIGURE 3.—Frequency distribution by 5-centimeter groups of lengths of bluefin tuna for counts of annuli.

## AGE DETERMINATION

The question arises as to whether or not the fish forming the first modal group appearing in our length frequency study are young of the year. In figure 12, we have compared the lengths of fish in each age group as determined by counts of annuli with the lengths of those in corresponding age groups as determined by length frequencies. On examining this figure, we find the assumption that fish in the first modal group are young of the

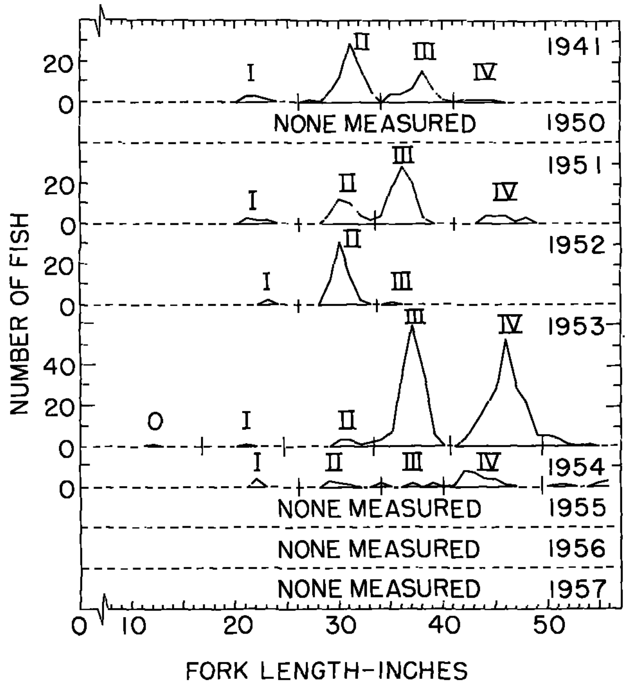


FIGURE 4.—Frequency distribution by 1-inch groups of lengths of bluefin tuna taken July 1–15, by years. The 1953 sample includes 102 fish measured June 28–30.

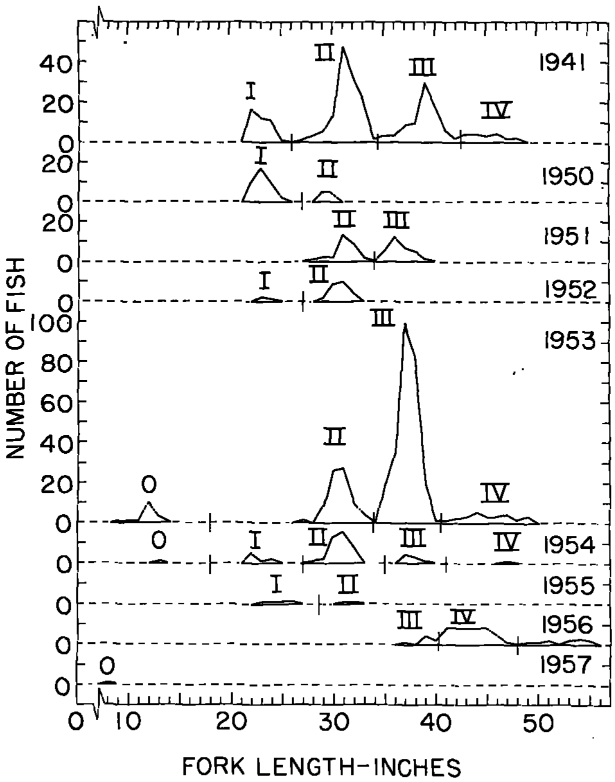


FIGURE 5.—Frequency distribution by 1-inch groups of lengths of bluefin tuna taken July 16–31, by years.

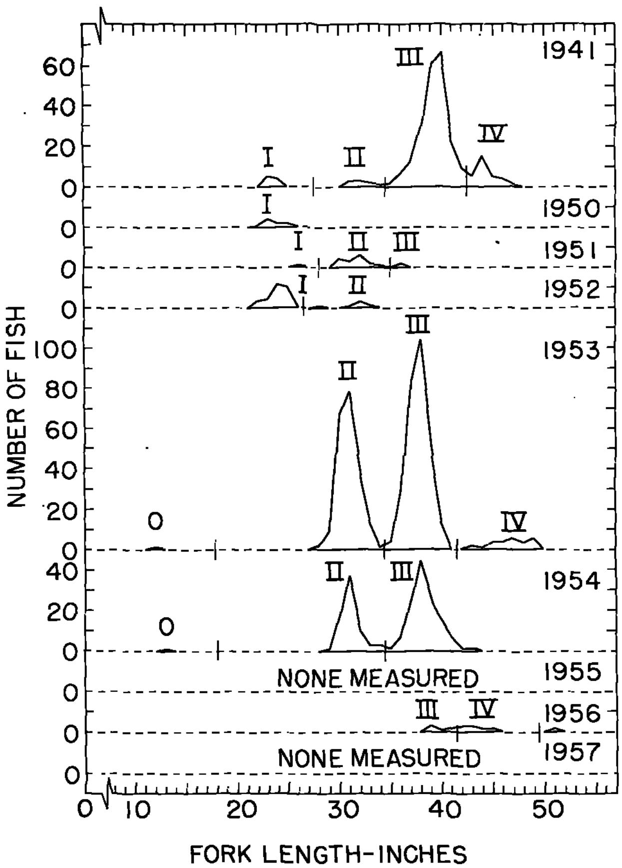


FIGURE 6.—Frequency distribution by 1-inch groups of lengths of bluefin tuna taken August 1–16, by years.

year is supported by the fact that no annuli are found on scales and vertebrae of fish of this size. Moreover, it is in accord with the conclusions of Sella (1929) and others studying the European bluefin tuna, which were officially accepted by the International Council for Exploration of the Sea in 1932 at Malaga (Conseil International pour l'Exploration de la Mer, 1933), and with those reached by Westman and Gilbert (1941), Westman and Neville (1942), and by Rivas (1954), for bluefin taken off New York and Miami, Fla. It is supported by our failure in all our observations, inquiries, and searching of literature and records, to find any evidence that a smaller size group exists. We conclude therefor that tuna in the second size group (corresponding to fish with 1 annulus) are 1 year old; in the third size group (2 annuli) are 2 years old; and so on through 4

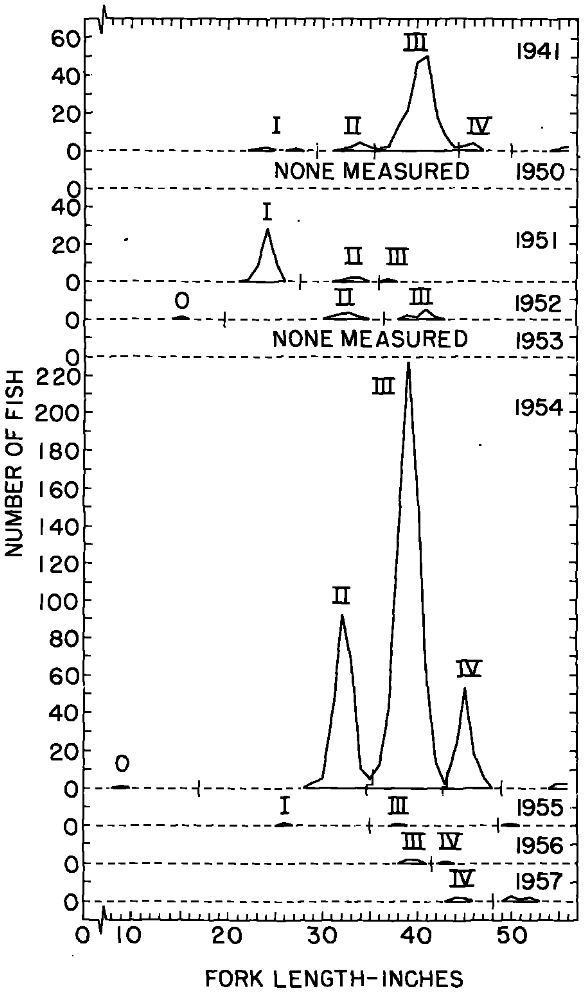


FIGURE 7.—Frequency distribution by 1-inch groups of lengths of bluefin tuna taken August 17–31, by years.

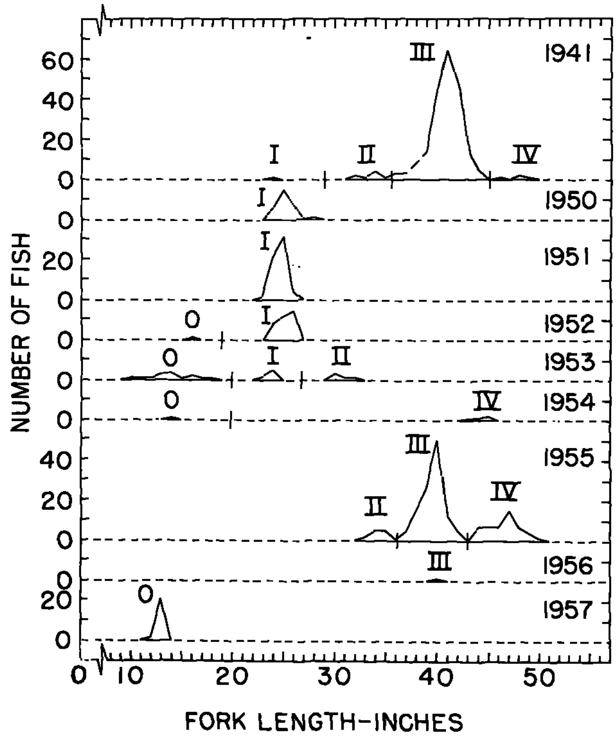


FIGURE 8.—Frequency distribution by 1-inch groups of lengths of bluefin tuna taken September 1–15, by years.

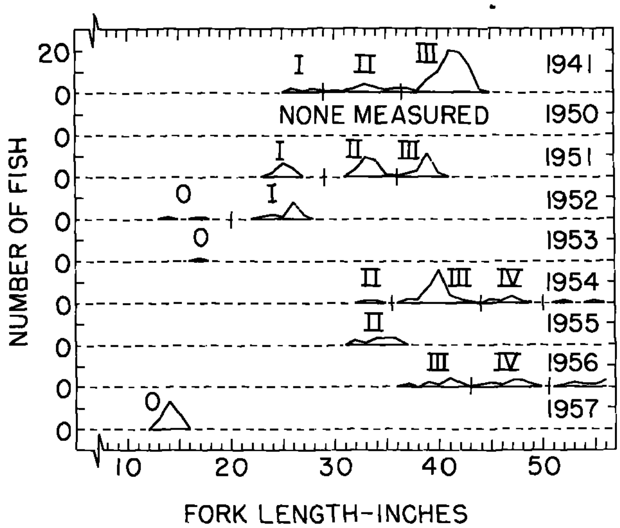


FIGURE 9.—Frequency distribution by 1-inch groups of lengths of bluefin tuna taken September 16-30, by years.

years. Although length data on older ages are not sufficient for analysis, we believe that counts of annuli are useful for estimating the age of older fish despite the decreasing reliability of readings with increasing age.

We find also that the analysis of length-frequency curves is consistent with age determinations by counts of annuli on scales and vertebrae. Such discrepancies as exist probably result from the fact that the samples for age readings were smaller and less uniformly distributed through the seasons than were those taken for length measurements. For example, most of our samples for counts of annuli of 3-year-olds were collected in early summer or fall rather than in midsummer. Even so, correspondence in conclusions reached from the two kinds of data is close.

Weight frequencies of landings of medium-sized bluefin tuna in Cape Cod Bay and Nova Scotia in the years 1948–51 (fig. 13) show a tendency for modal weights to coincide with sizes determined by counts of annuli for ages 5–7. Most clear cut cases are the 5-year-olds in Cape Cod Bay and 6-year-olds in Nova Scotia in 1948,

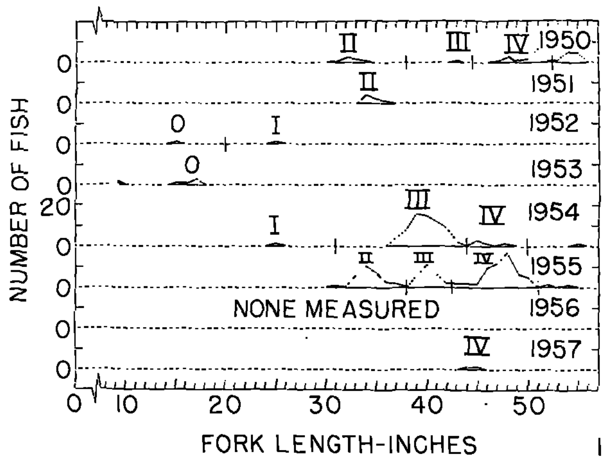


FIGURE 10.—Frequency distribution by 1-inch groups of lengths of bluefin tuna taken October 1–18, by years.

and the 6-year-olds in Nova Scotia in 1949. Split modes show a preponderance of 7-year-olds *in both areas in 1950, suggesting the progression* of the year class of 1943 through the Cape Cod Bay fishery 1948–50 and the Nova Scotia fishery *1949–50.*

Two successful tagging experiments with bluefin tuna yielded approximate data on their actual growth. One fish, tagged off Cape Cod, Mass., July 27, 1954, was recaptured by French fishermen in the Bay of Biscay August 16, 1959. When tagged, the fish measured 72.5 cm., and its weight when recaptured was reported as approximately 65–70 kilograms (143–154 pounds equivalent to about 150–154 cm.). These sizes are near the lower limits for ages 2 and 7, respectively, from table 1. The other was tagged August 11, 1957, off Chatham, Mass., and recaptured August 30, 1959, off Gloucester, Mass. Its weight when tagged was estimated as 65 pounds (equivalent to about 114 cm.) by an experienced fisherman, and it weighed 130 pounds (equivalent to about 150 cm.) when recaptured. These lengths are in good agreement with those listed in table 1 for ages 4 and 6, respectively. Hence the results of these experiments are in reasonable agreement with our age determinations by counts of annuli.

## GROWTH OF YOUNG BLUEFIN TUNA

As length measurements are several times as numerous as counts of annuli, and permit us to trace growth during each summer as well as from year to year, we shall base our discussion of growth of young tuna on length frequency analysis.

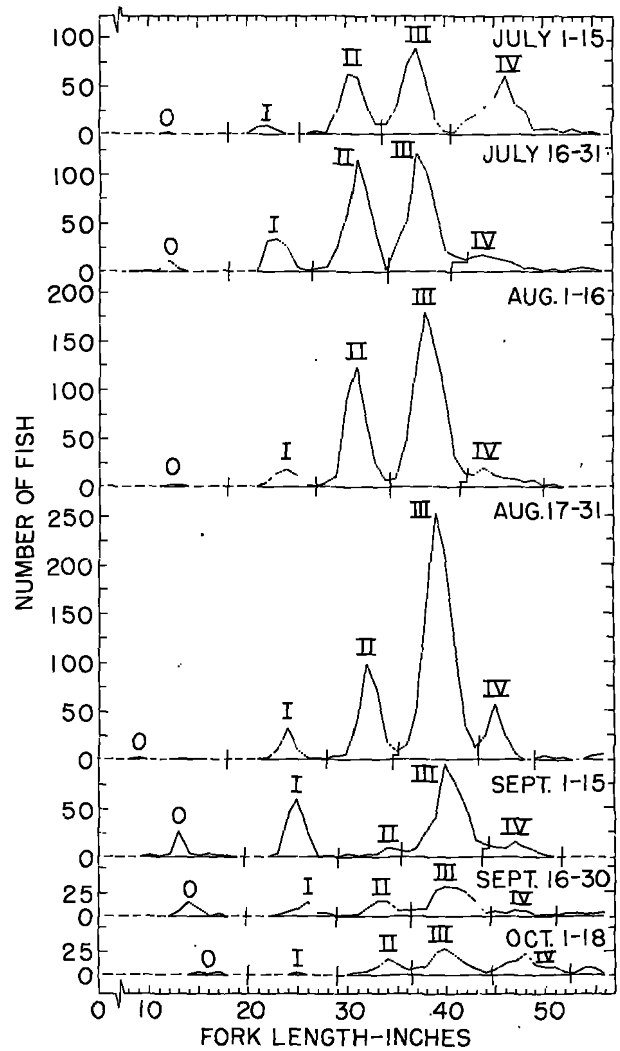


FIGURE 11.—Frequency distribution by 1-inch groups of lengths of bluefin tuna taken in 1941 off Long Island and in 1950–57, mostly off New England, by periods. Three very small tuna taken off New Jersey in 1938–40 are also included.

Table 5 lists the average lengths of the fish in each age group of fish more than 20 inches long, as demarcated by vertical lines in figures 4–11. It identifies year classes and also shows average lengths for all years combined. We plotted these lengths by periods in figure 14 and fitted curves to them empirically, taking into account the number of measurements represented by each point, except in 2 or 3 where the preponderant samples were not, in our opinion, composed of average-sized fish.

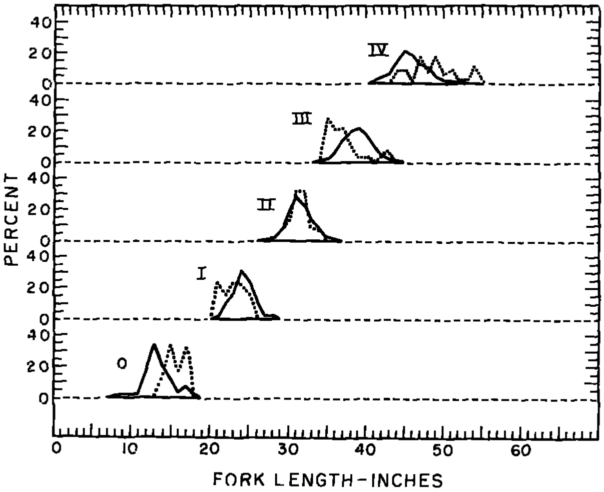


FIGURE 12.—Frequency distribution by 1-inch groups of lengths of bluefin tuna for age groups 0–IV as determined by length frequencies (solid lines) and by counts of annuli (dotted lines).

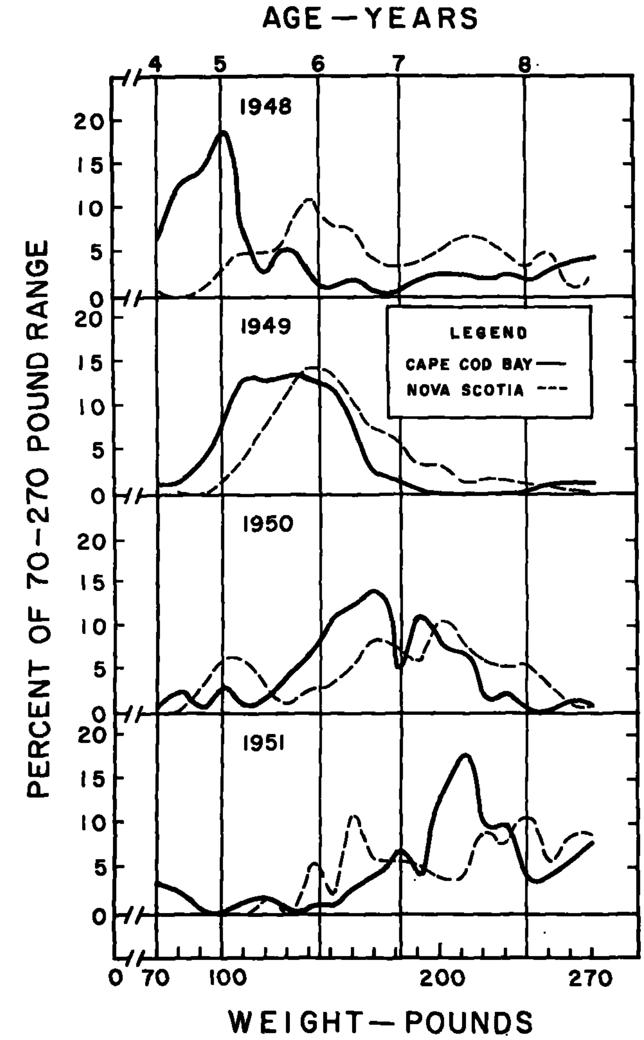


FIGURE 13.—Weight frequencies by 10-pound groups of bluefin tuna from 70 to 270 pounds, taken in Cape Cod Bay and off Nova Scotia in 1948–51, by years.

The fish less than 20 inches long listed in table 4 obviously form a distinct age group. Figure 15 shows the averages of these measurements with a curve drawn by inspection to fit the points and also to fit in with the curve for 1-year-olds from figure 14. Although our unpublished studies of the distribution of the bluefin tuna indicate that all these fish belong to one population, samples from different areas have been designated by different symbols. Figure 16 shows a curve of estimated growth of bluefin tuna for the first 4½ years of life, and table 6 lists the average sizes at the middle of each month, as indicated by this curve.

Figure 16 indicates extremely rapid initial growth and distinct seasonal variations in growth rate. Bluefin tuna spawn during an undefined period in spring (Rivas, 1954; Bullis and Mather, 1956). Assuming, as we did in drawing figure 16, that hatching occurs in mid-May, the young may grow at a rate of nearly 6 inches per month to reach a size of 8½ inches by July 1. In the ensuing discussion, however, we shall consider July 1 as the date of birth and shall refer to the period July 1–October 16 as "summer" and the remainder of the year as "winter." The growth rate diminishes rapidly during the first summer, but the average rate is estimated at 2 inches per month. The rate continues to decrease during most of the first winter, averaging about four-fifths of an inch per month. For the remainder of the period studied, ages 1–4, the growth rate does not change greatly with age, averaging about 1½ inches per month in summer and about one-third of an inch per month in winter.

## ESTIMATED ANNUAL GROWTH OF BLUEFIN TUNA THROUGH 10 YEARS

The average sizes at each age, determined by length frequency analysis for ages 0–4, and by counts of annuli for older ages, are plotted in figure 17. The curve shown was derived graphically, starting from the point for 3-year-olds, from the

Walford (1946) transformation of our data. As we found it possible to read only a small percentage of the material available for ages beyond 10 years, we have drawn the curve to that point only. Average sizes at mid-summer for bluefin tuna of ages 0–10 as indicated by this curve are listed in table 7.

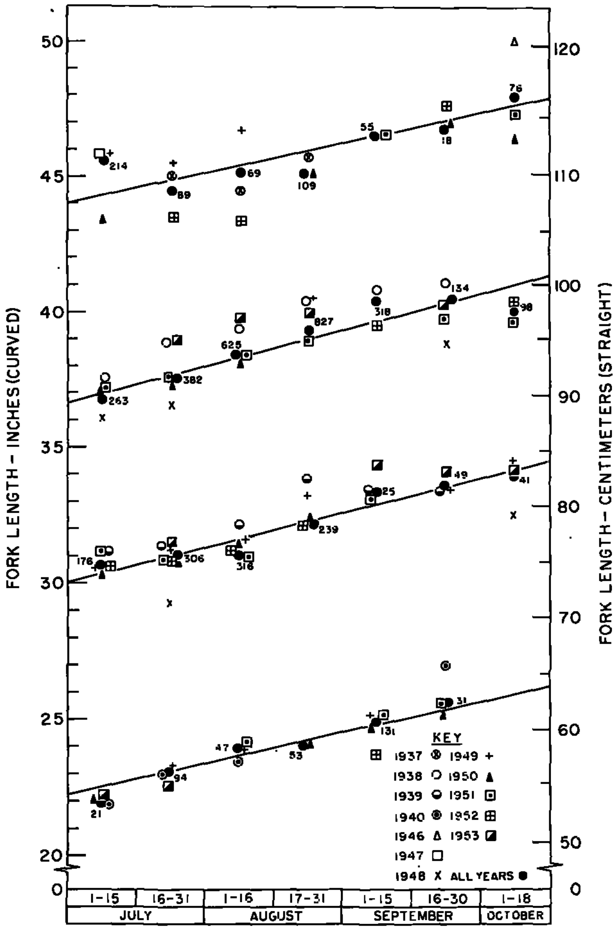


FIGURE 14.—Average lengths of bluefin tuna by age groups as indicated in figures 4 to 11. Curves were fitted empirically. The numbers of fish in the samples for all years combined are indicated. Samples consisting of less than 5 fish were not shown.

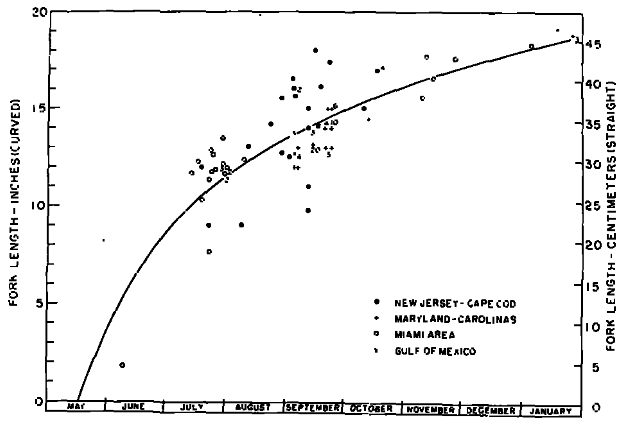


FIGURE 15.—Lengths of bluefin tuna less than 20 inches long (young of the year), from table 4. The curve of estimated growth was fitted by inspection.

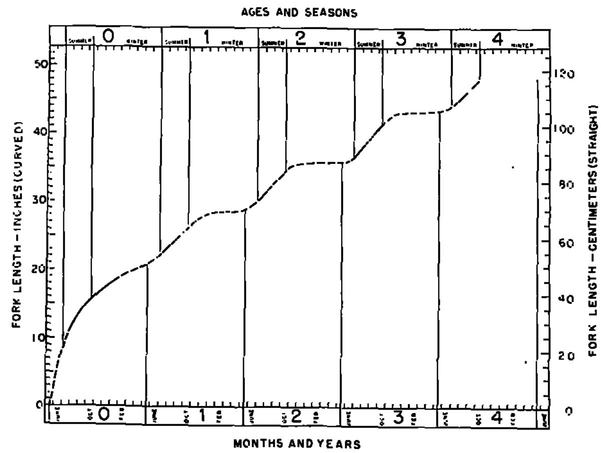


FIGURE 16.—Estimated growth of young bluefin tuna. Broken lines indicate estimated lengths in periods for which data are lacking. The upper scale shows ages and seasons as assumed in the text, and the lower scale shows ages assuming that hatching occurs at mid-May.

## CONCLUSIONS

Our results through the fifth summer of life for bluefin tuna taken off New England are substantially in agreement with those of Westman and Neville (1942) for fish taken off Long Island. Our study of the growth of these young tunas, however, was based on a much larger sample, and the sampling was spread over several years rather than 1 year. Differences in growth between year classes were found to be slight and the results of the analysis of the composite sample are believed to approximate the average encountered in nature. Although it was not possible to fully verify the readings of annuli for older fish by the analysis of size frequencies, and difficulties in reading the annuli increased with their number, we have extended our determinations to considerably older ages than has previously been done for western Atlantic bluefin tuna.

TABLE 5.—*Average lengths of bluefin tuna, in each age group as indicated in figures 4 to 11, listed by ages, years of measurement, and year classes*

| Age in years | Year of measurement | Average lengths of fish in inches (numbers of fish in parentheses) | | | | | | | Year class |
|---|---|---|---|---|---|---|---|---|---|
| | | July | | August | | September | | October | |
| | | 1–15 | 16–31 | 1–16 | 17–31 | 1–15 | 16–30 | 1–18 | |
| I | 1941 | 21.8(7) | 22.9(40) | 23.4(9) | 24.5(4) | 24.0(1) | 27.0(5) | | 1940. |
| | 1950 | | 23.1(39) | 23.6(8) | | 25.2(29) | | | 1949. |
| | 1951 | 21.9(7) | | 26.0(1) | 24.0(48) | 24.6(59) | 25.1(12) | | 1950. |
| | 1952 | 23.0(2) | 23.3(3) | 24.0(28) | | 25.2(35) | 25.6(14) | 25.0(1) | 1951. |
| | 1953 | 21.0(1) | | | | 23.7(7) | | | 1952. |
| | 1954 | 22.0(4) | 22.6(8) | | | | | 25.0(1) | 1953. |
| | 1955 | | 24.5(4) | | 26.0(1) | | | | 1954. |
| | All years | 21.9(21) | 23.1(94) | 23.9(47) | 24.1(53) | 24.8(131) | 25.6(31) | 25.0(2) | All years. |
| II | 1941 | 31.1(71) | 31.3(126) | 32.1(9) | 33.8(9) | 33.5(8) | 33.3(14) | | 1939. |
| | 1950 | | 29.2(10) | | | | | 32.5(7) | 1948. |
| | 1951 | 30.5(33) | 31.2(29) | 31.6(16) | 33.2(5) | | 33.4(21) | 34.6(7) | 1949. |
| | 1952 | 30.2(57) | 30.7(25) | 31.4(6) | 32.3(9) | | | | 1950. |
| | 1953 | 31.2(9) | 30.7(75) | 30.9(214) | | 31.1(5) | | | 1951. |
| | 1954 | 30.8(7) | 30.6(39) | 31.2(71) | 32.2(216) | | 33.5(2) | | 1952. |
| | 1955 | | 31.5(2) | | | 34.4(13) | 34.2(12) | 34.2(29) | 1953. |
| | All years | 30.6(176) | 30.9(306) | 31.0(316) | 32.2(239) | 33.3(25) | 33.6(49) | 33.9(41) | All years. |
| III | 1941 | 37.5(37) | 38.9(78) | 39.3(208) | 40.4(163) | 40.8(202) | 41.1(72) | | 1938. |
| | 1950 | | | | | | | 43.0(1) | 1947. |
| | 1951 | 36.0(72) | 36.5(30) | 36.0(2) | 37.0(1) | | 38.8(17) | | 1948. |
| | 1952 | 35.0(1) | | | 40.5(9) | | | | 1949. |
| | 1953 | 36.9(147) | 37.2(259) | 37.8(285) | | | | | 1950. |
| | 1954 | 37.2(5) | 37.6(8) | 38.4(126) | 39.0(648) | | 39.8(34) | 39.8(65) | 1951. |
| | 1955 | | | | 38.0(1) | 39.6(113) | | 40.4(27) | 1952. |
| | 1956 | | 39.0(7) | 39.8(6) | 40.0(5) | 40.0(1) | 40.3(10) | | 1953. |
| | All years | 36.7(263) | 37.5(382) | 38.4(625) | 39.3(827) | 40.4(318) | 40.5(134) | 40.1(98) | All years. |
| IV | 1941 | 43.5(4) | 45.0(19) | 44.4(30) | 45.7(6) | 47.9(4) | | | 1937. |
| | 1950 | | | | | | | 50.0(15) | 1946. |
| | 1951 | 45.8(16) | | | | | | | 1947. |
| | 1953 | 45.8(160) | 45.5(24) | 46.7(27) | | | | 48.0(1) | 1949. |
| | 1954 | 43.3(25) | 47.0(1) | | 45.1(99) | 44.3(4) | 47.0(8) | 46.3(6) | 1950. |
| | 1955 | | | | | 46.6(48) | | 47.4(55) | 1951. |
| | 1956 | | 43.5(45) | 43.4(10) | | | 47.7(11) | | 1952. |
| | 1957 | | | | 44.5(4) | | | 44.5(2) | 1953. |
| | All years | 45.5(214) | 44.4(89) | 45.1(69) | 45.1(109) | 46.5(55) | 46.8(18) | 48.0(76) | All years. |

TABLE 6.—*Estimated sizes of young bluefin tuna at the middle of each month derived from figure 16*

| Month | Fork length in inches curved measurement | | | | | Fork length in centimeters straight measurement | | | | | Weight in pounds | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Age in years | | | | | Age in years | | | | | Age in years | | | | |
| | 0 | I | II | III | IV | 0 | I | II | III | IV | 0 | I | II | III | IV |
| May | 0 | 21.0 | 28.7 | 35.8 | 43.5 | 0 | 51.1 | 69.9 | 87.1 | 106.0 | 0 | 6.2 | 15.5 | 31.2 | 51.0 |
| June | 6.5 | 21.7 | 29.5 | 36.2 | 43.7 | 15.8 | 52.8 | 71.8 | 88.1 | 106.7 | 0.2 | 6.8 | 17.0 | 32.0 | 52.0 |
| July | 10.3 | 22.7 | 30.6 | 37.3 | 44.5 | 25.1 | 55.3 | 74.5 | 90.9 | 108.5 | 0.6 | 7.8 | 19.0 | 34.0 | 55.0 |
| August | 12.6 | 23.9 | 32.0 | 38.6 | 45.7 | 30.6 | 58.2 | 77.6 | 94.0 | 111.3 | 1.1 | 9.4 | 22.0 | 36.5 | 60.5 |
| September | 14.3 | 25.0 | 33.2 | 40.0 | 46.9 | 34.8 | 60.9 | 80.9 | 97.4 | 114.1 | 1.9 | 10.0 | 24.4 | 42.0 | 65.0 |
| October | 15.3 | 26.1 | 34.5 | 41.4 | 48.0 | 37.2 | 63.5 | 84.0 | 100.8 | 117.0 | 2.1 | 11.5 | 26.5 | 46.0 | 68.0 |
| November | 16.7 | 27.2 | 35.3 | 42.6 | | 40.6 | 66.2 | 85.9 | 103.9 | | 2.9 | 13.5 | 29.0 | 49.0 | |
| December | 17.6 | 27.8 | 35.4 | 43.0 | | 42.9 | 67.7 | 86.2 | 104.8 | | 3.5 | 14.2 | 30.0 | 49.5 | |
| January | 18.4 | 28.2 | 35.5 | 43.1 | | 44.8 | 68.6 | 86.4 | 105.0 | | 4.1 | 14.6 | 30.4 | 50.0 | |
| February | 19.1 | 28.3 | 35.6 | 43.2 | | 46.5 | 68.9 | 86.6 | 105.1 | | 4.6 | 14.9 | 30.6 | 50.2 | |
| March | 19.7 | 28.4 | 35.7 | 43.3 | | 48.0 | 69.1 | 86.9 | 105.3 | | 5.0 | 15.1 | 30.8 | 50.4 | |
| April | 20.2 | 28.5 | 35.8 | 43.4 | | 49.1 | 69.4 | 87.1 | 105.7 | | 5.4 | 15.3 | 31.0 | 50.7 | |

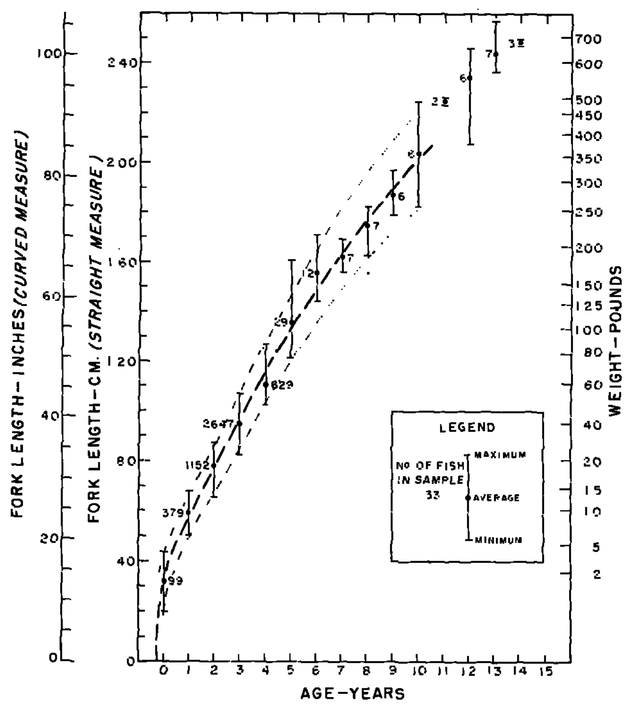


FIGURE 17.—Estimated growth curve for bluefin tuna (heavy broken line), with points derived from length frequencies for ages 0–IV years and from counts of annuli for older ages. Lighter broken lines, fitted by inspection, show estimated limits of variation.

TABLE 7.—*Estimated sizes of bluefin tuna during the summer for ages 0–10 years*

From figure 17

| Age in years | Length | | | | Weight in pounds | |
|---|---|---|---|---|---|---|
| | Centimeters (straight) | | Inches (curved) | | | |
| | Average | Range | Average | Range | Average | Range |
| 0 | 32 | 22–43 | 13.0 | 9–18 | 1.5 | 0.6–3.5 |
| I | 57 | 50–66 | 23.5 | 20–27 | 8.5 | 5–13 |
| II | 77 | 66–88 | 31.5 | 27–36 | 22.0 | 14–30 |
| III | 95 | 83–109 | 39.0 | 34–45 | 40 | 25–50 |
| IV | 114 | 102–127 | 47.0 | 42–52 | 69 | 45–90 |
| V | 133 | 122–148 | 55.0 | 50–61 | 100 | 80–140 |
| VI | 149 | 134–165 | 61.5 | 55–68 | 140 | 105–190 |
| VII | 163 | 148–182 | 67.0 | 61–75 | 185 | 140–250 |
| VIII | 177 | 161–197 | 73.0 | 66–81 | 240 | 180–320 |
| IX | 190 | 172–210 | 78.0 | 71–86 | 290 | 220–395 |
| X | 201 | 182–221 | 82.5 | 75–91 | 340 | 255–455 |

Our growth data for fish up to 10 years of age are in good agreement with those of Sella (1929) for Mediterranean bluefin tuna. Our few readings for older ages indicated somewhat larger sizes for western Atlantic fish for the respective ages. Sella's work was based on a larger sample than ours, and he used special instruments which we did not have. Therefore this apparent difference may result from less complete sampling and less precise reading of annuli for the western Atlantic bluefin, rather than to an actual difference in the growth of the larger fish from the respective areas.

## LITERATURE CITED

AIKAWA, HIROAKI, and M. KATO.
1938. Age determination of fish (Preliminary Rept. 1). Bull. Japanese Society Scientific Fisheries, vol. 7, No. 1, pp. 79–88. Translation from the Japanese by W. G. Van Campen in U.S. Department of the Interior, Fish and Wildlife Service, Special Scientific Report—Fisheries No. 21.

ARNOLD, EDGAR L., JR.
*1951. An impression method for preparing fish scales for age and growth analysis. U.S. Department of the Interior, Fish and Wildlife Service, Progressive Fish Culturist, vol. 13, pp. 11–16.

BULLIS, HARVEY R., JR., and F. J. MATHER, III.
1956. Tunas of the genus *Thunnus* of the northern Caribbean. American Museum Novitates, No. 1765, pp. 1–12.

CONSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER.
1933. Conference d'experts pour l'examen des méthodes scientifiques et techniques à appliquer à l'étude des poissons de la famille des thonidés. Conseil International pour l'Exploration de la Mer, Rapports et Procès-Verbaux, vol. 84, pp. 91–103.

GALTSOFF, PAUL S.
1952. Staining of growth rings in the vertebrae of tuna (*Thunnus thynnus*). Copeia, No. 2, pp. 103–105.

MOORE, HARVEY L.
1951. Estimation of age and growth of yellowfin tuna (*Neothunnus macropterus*) in Hawaiian waters by size frequencies. U.S. Department of the Interior, Fish and Wildlife Service, Fishery Bulletin, No. 65, vol. 52, pp. 133–149.

PARTLO, J. M.
1955. Distribution, age and growth of eastern Pacific albacore (*Thunnus alalunga* Gmelin). Journal of the Fisheries Research Board of Canada, vol. 12, pp. 35–60.

POSTEL, E.
1954. La croissance du thon á nageoires jaunes *Neothunnus albacora* (Lowe) dans l'Atlantique tropical. Bulletin de la Société Zoologique de France, vol. 79, No. 2–3, pp. 85–90.

RIVAS, LUIS RENE.
1954. A preliminary report on the spawning of the western North Atlantic bluefin tuna (*Thunnus thynnus*) in the Straits of Florida. Bulletin of Marine Science of the Gulf and Caribbean, vol. 4, pp. 302–322.

SELLA, MASSIMO.
1929. Migrazioni e habitat del tonno (*Thunnus thynnus* L.) studiati col metodo degli ami, con osservazioni su l'accrescimento, sul regime delle tonnare ecc. R. Comitato Talassografico Italiano.

SELLA, MASSIMO.
Mem. 156, pp. 3–24. Translation in U.S. Department of the Interior, Fish and Wildlife Service, Special Scientific Report—Fisheries No. 76.

WALFORD, LIONEL A.
1946. A new graphic method of describing the growth of animals. Biological Bulletin, vol. 90, pp. 141–147.

WESTMAN, J. R., and P. W. GILBERT.
1941. Notes on age determination and growth of the Atlantic bluefin tuna, *Thunnus thynnus* (Linnaeus). Copeia, No. 2, pp. 70–72.

WESTMAN, JAMES R., and W. C. NEVILLE.
1942. The tuna fishery of Long Island, New York. Board of Supervisors, Nassau County, Long Island, N.Y., pp. 1–31.