UNITED STATES DEPARTMENT OF THE INTERIOR, Fred A. Seaton, *Secretary*

FISH AND WILDLIFE SERVICE, Arnie J. Suomela, *Commissioner*

SEXUAL MATURITY AND SPAWNING OF ALBACORE IN THE PACIFIC OCEAN

BY TAMIO OTSU AND RICHARD N. UCHIDA

FISHERY BULLETIN 148

From Fishery Bulletin of the Fish and Wildlife Service

VOLUME 59

UNITED STATES GOVERNMENT PRINTING OFFICE • WASHINGTON • 1959

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. Price 20 cents.

Library of Congress catalog card for this bulletin:

Otsu, Tamio.
Sexual maturity and spawning of albacore in the Pacific Ocean, by Tamio Otsu and Richard N. Uchida. Washington, U. S. Govt. Print. Off., 1959.

iv, 287–305 p. illus., map, diagrs., tables. 26 cm. (U. S. Fish and Wildlife Service. Fishery bulletin 148)

"From Fishery bulletin of the Fish and Wildlife Service, volume 59."

Bibliography: p. 304–305.

1. Tuna fish. I. Uchida, Richard N., joint author. II. Title. (Series: U. S. Fish and Wildlife Service. Fishery bulletin, v. 59, no. 148)

[SH11.A25 vol. 59, no. 148] Int 59–11

U. S. Dept. of the Interior. Library
for Library of Congress

Library of Congress catalog card for the series, Fishery Bulletin of the Fish and Wildlife Service:

U. S. ***Fish and Wildlife Service.***
Fishery bulletin. v. 1–
Washington, U. S. Govt. Print. Off., 1881–19

v. in illus., maps (part fold.) 23–28 cm.

Some vols. issued in the congressional series as Senate or House documents.
Bulletins composing v. 47– also numbered 1–
Title varies: v. 1–49, Bulletin.
Vols. 1–49 issued by Bureau of Fisheries (called Fish Commission, v. 1–23)

1. Fisheries—U. S. 2. Fish-culture—U. S. I. Title.

SH11.A25 639.206173 9–35239 rev 2*

Library of Congress [r55e½]

CONTENTS

ABSTRACT

This report presents the results of a study of gonadal development and spawning in the albacore, *Germo alalunga* (Bonnaterre). The study is based on examination of the reproductive organs, principally the ovaries from albacore collected in three general areas: the North Pacific, the Hawaiian Islands, and the central equatorial Pacific.

The ovaries were classified in three stages of relative maturity: early developing, late developing, and advanced, on the basis of the most advanced eggs present. According to this classification, the early developing category included the thin ribbonlike ovaries from sexually immature fish as well as ovaries from the larger, adult fish which showed no signs of egg development beyond this particular stage. The other two categories, on the other hand, included only ovaries from adult fish.

The North Pacific albacore were either juveniles or sexually dormant adults with early developing gonads. The Hawaiian albacore showed varying degrees of maturity from early developing to advanced, with the bulk of the ovaries in the late developing stage. The ovaries from central equatorial Pacific fish were in the early developing and late developing stages, with the early developing stage predominating.

Our data show that albacore taken north of Hawaii by research vessels of the Pacific Oceanic Fishery Investigations, as well as albacore taken by the Japanese in the spring live-bait and winter longline fisheries, and those in the American west coast summer fishery are nonspawning fish, either juveniles or adult fish whose gonads show no signs of incipient or past spawning. Albacore apparently do not spawn in the temperate waters of the North Pacific. On the other hand, it appears that the albacore in the region of the Hawaiian Islands and in the central equatorial Pacific represent a segment of the population which, after attaining a certain size in temperate waters of the North Pacific, moves south into tropical and subtropical waters to reproduce.

SEXUAL MATURITY AND SPAWNING OF ALBACORE IN THE PACIFIC OCEAN

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

The albacore, *Germo alalunga* (Bonnaterre), is a commercially important tuna, valued highly for its excellent canning qualities. In the Pacific the major fisheries for this species are conducted by the Japanese in an area extending from the coast of Japan to the vicinity of the International Date Line, and by the Americans along the west coast of the United States. Tag recoveries during recent years have shown that albacore undertake extensive migrations across the Pacific (Ganssle and Clemens 1953, Blunt 1954, Otsu and Uchida 1959), thus suggesting that these major fisheries may be dependent on a single population.

Albacore are also widely distributed throughout the tropical Pacific, but in this region they are generally taken incidental to the catch of other species of tuna. It is not known whether albacore of the tropics belong to the same population as those of temperate latitudes, or whether they form part of another population. According to present knowledge, albacore do not spawn in temperate waters. Information on the areas of spawning might provide a clue to the general distribution of the populations that support the American and Japanese albacore fisheries.

The research program of the Pacific Oceanic Fishery Investigations (POFI) of the Bureau of Commercial Fisheries has included a study of gonadal development and spawning in the albacore, which has been financed by the Saltonstall-Kennedy Act (Public Law 466, 83rd Congress). The present report on the albacore is based on examination of the reproductive organs, principally the ovaries, collected in three general areas: the North Pacific, the Hawaiian Islands, and the central equatorial Pacific. Important differences in gonad development were noted for fish from these three areas. The size at which albacore attain sexual maturity was determined, and what appears to be a major spawning locality can now be defined.

NOTE.—Approved for publication January 13, 1958. Fishery Bulletin 148.

We gratefully acknowledge the contributions of the following persons: R. S. Shomura and B. Wyatt who collected ovaries at the Honolulu auction markets; the managements of the United Fishing Agency, Ltd., and the Hawaii Fishing Co., Ltd., and the several fish dealers who permitted us to sample the albacore landings; Shoji Ueyanagi of the Nankai Regional Fisheries Research Laboratory in Kochi, Japan, who sent us samples of ovaries; and H. S. H. Yuen for valuable suggestions pertaining to sampling procedure.

SOURCE OF MATERIALS

NORTH PACIFIC

A total of 126 gonads from both sexes was collected between January 1955 and November 1956 in the North Pacific on POFI's exploratory fishing cruises (table 1 and fig. 1). Most of the sampled fish, ranging in length from 50 to 112 cm. (weight, 6 to 65 lbs.), were taken at the surface by gill nets or trolling; the few albacore larger than 87 cm. were taken exclusively on longline

TABLE 1.—*The number of albacore gonads obtained in the three areas [1] in various years*

Month	North Pacific				Hawaii		Central Equatorial Pacific			
	1955		1956		1955	1956	1952	1953	1956	1957
	Male	Female	Male	Female						
January	4	5	0	0	0	0	0	0	0	3
February	2	1	0	0	0	0	2	11	0	8
March	0	0	1	1	0	0	1	3	0	0
April	0	0	0	4	0	0	0	0	0	0
May	0	0	0	0	2	0	0	22	0	0
June	0	0	0	0	18	2	0	0	0	0
July	0	0	5	6	5	9	0	0	0	0
August	4	9	10	12	5	1	0	1	1	0
September	2	0	0	1	1	7	0	0	7	0
October	6	5	3	3	1	1	1	0	0	0
November	0	0	24	18	0	4	6	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Total	18	20	43	45	32	24	10	37	8	11

[1] Fish of both sexes were sampled in the North Pacific but only females in the other two areas.

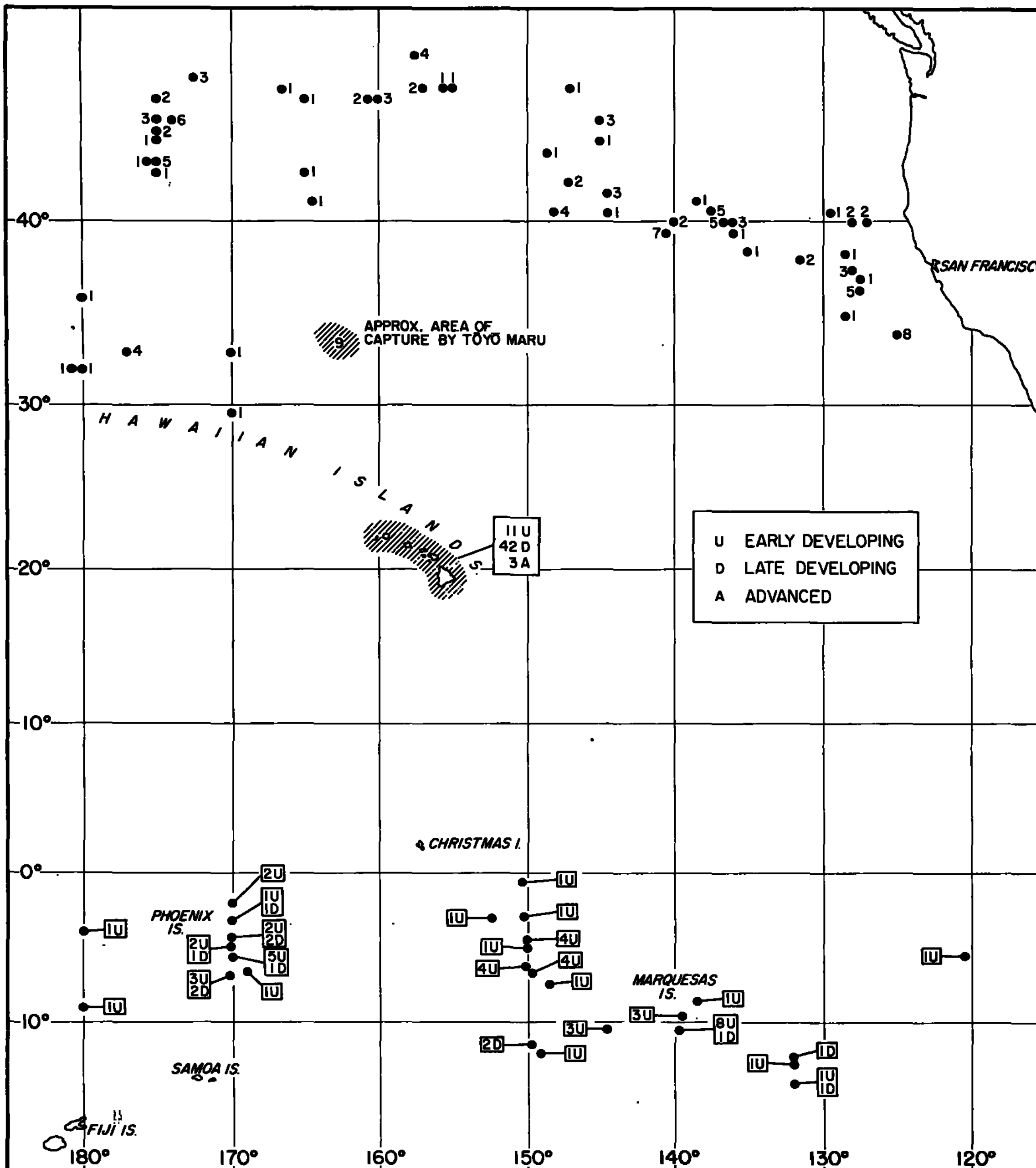

FIGURE 1.—Localities at which albacore gonads were collected. The Hawaiian and central equatorial Pacific samples consisted only of ovaries (stages of development shown); the North Pacific samples included testes and ovaries, all of which were in the early developing stage. (U=early developing, D=late developing, A=advanced stage).

(fig. 2). Immediately after the fish were landed the gonads were removed and preserved in 10-percent formalin. Data recorded were the date and locality of capture, fork length (weight was not always recorded), and the type of fishing gear.

In addition to the albacore taken on POFI vessels, we examined ovaries from a catch of albacore landed in Honolulu by a Japanese longline vessel, the *Tōyō Maru*, in January 1955. This vessel reportedly obtained her catch northwest of the

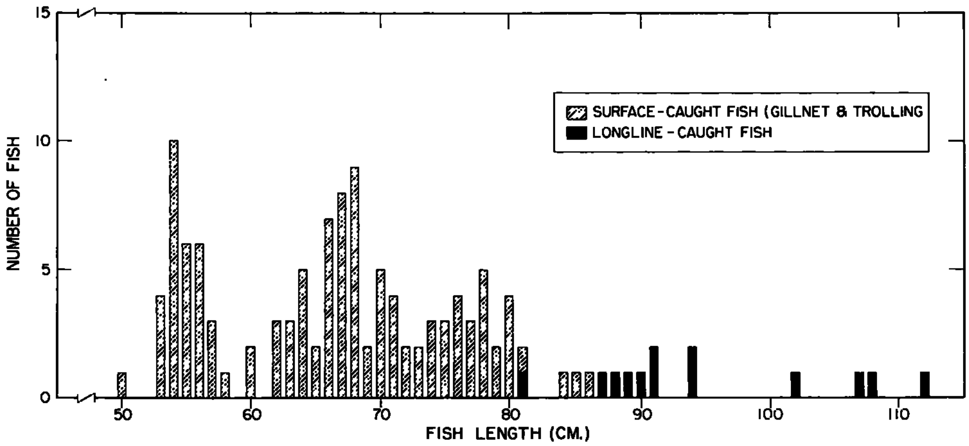

FIGURE 2.—Sizes of albacore sampled in the North Pacific.

Hawaiian Islands in the general area shown in figure 1.

HAWAIIAN ISLANDS

Ovaries from 56 fish ranging in length from 93.1 to 112.4 cm. (weight, 33 to 62 lbs.) were obtained in 1955 and 1956 from landings of the Hawaiian longline fishery (table 1, fig. 1). These fish were captured within 20 miles of the main Hawaiian Islands, mostly during the months of June to September. A detailed description of this fishery is given by June (1950) and Otsu (1954). These albacore and those taken by the *Tōyō Maru* were sampled at the auction markets of the United Fishing Agency, Ltd., and the Hawaii Fishing Co., Ltd., both in Honolulu. The ovaries were preserved in 10-percent formalin. Data obtained for each fish were the date of landing, locality of capture, fork length, and weight.

CENTRAL EQUATORIAL PACIFIC

The bulk of the samples from the central equatorial Pacific was obtained from three areas: (1) between the Equator and 7° S. latitude along 170° W. longitude; (2) between the Equator and 12° S. along 150° W. longitude; and (3) from the general region of the Marquesas Islands, 132° W. to 140° W. longitude (table 1, fig. 1). A total of 66 female albacore, all captured on longline on POFI cruises, was sampled between February 1952 and February 1957; these fish ranged in length from 84.6 to 104.8 cm. (weight, 29 to 54 lbs.). In general, sampling in this area was sporadic both in space and in time. The method of sampling the ovaries was similar to that described for the collection of gonads in the North Pacific.

DESCRIPTION OF THE GONADS

TESTES

The testes are paired, elongate organs suspended by the mesorchium in the body cavity. They are thin and ribbonlike in immature fish but with advance in maturity, they develop into somewhat flattened, whitish-yellow organs which are relatively solid. Their products are collected by a series of small ducts, vasa efferentia, leading posteriorly to a larger duct, the vas deferens, which opens to the exterior through the urogenital orifice.

June (1953) examined both the testes and ovaries in his study of the spawning of yellowfin tuna in Hawaiian waters but found that for this study "the testes were not suitable because no quantitative measure of their sexual products could be found that would provide reasonably accurate estimates of their relative stages of development." We found this to be true for the albacore also, and the testes were therefore merely designated in this report as immature or mature on the basis of their size and the presence or absence of milt.

OVARIES

The ovaries, like the testes, are paired, elongate organs suspended from the dorsal wall of the body cavity by the mesovarium. In immature fish, the ovaries are ribbonlike (fig. 3), may measure as little as 2 or 3 millimeters in diameter, and closely resemble the immature testes in appearance.

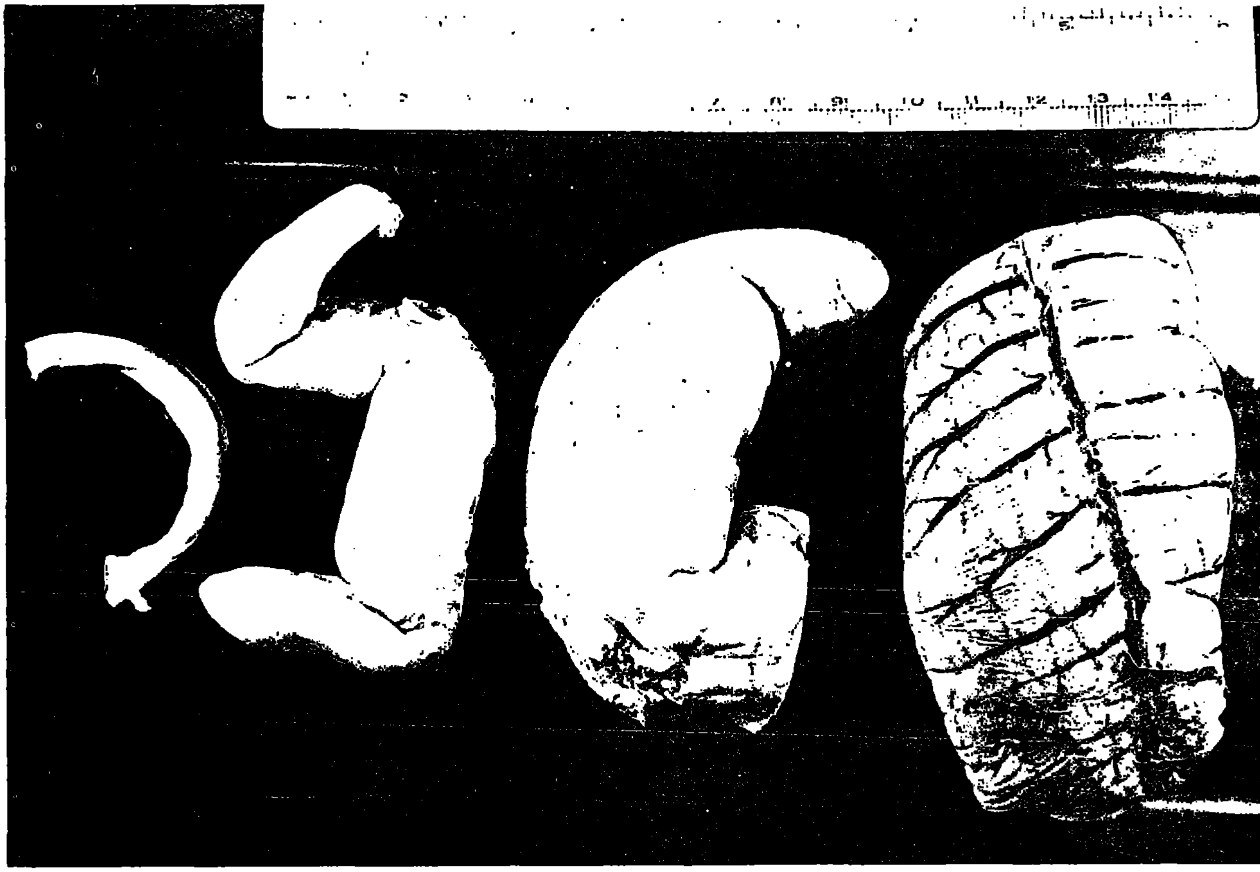

FIGURE 3.—Albacore ovaries in various developmental stages (only part of each ovary is shown). Left to right: a ribbon-like ovary taken from a sexually immature, 75.8-cm. fish (ovary weight 9 grams); an early developing ovary from a 99.2-cm. fish (ovary weight 74 gms.); a late developing ovary from a 98. 5-cm. fish (ovary weight 275 gms.); and an advanced ovary from a 107.6-cm. fish (ovary weight 916 gms.). Photograph by H. Yoshida.

They become progressively enlarged in length and girth as the fish attain sexual maturity, and with the final ripening of the eggs, they may attain a diameter of more than 40 mm. In the more advanced stages, the ovaries are nearly circular in cross section and the right ovary is usually slightly larger than the left. They have a ribbed internal cavity throughout their length and unite posteriorly with a thick-walled oviduct which opens exteriorly through the urogenital orifice.

SUBSAMPLING THE OVARY

An objective method for determining the degree of maturity of an ovary is to measure the diameters of the constituent eggs. In order to reduce the amount of work involved in measuring the tremendous number of eggs within an ovary, it was necessary in our study to resort to subsampling. To subsample an ovary with confidence, however, requires that the distribution of eggs of various sizes throughout an ovary as well as differences between the two ovaries of a pair be determined.

The procedure followed in this study was in general similar to that described by Yuen (1955) who investigated the maturity and fecundity of the bigeye tuna in the Pacific. Eggs from a sample were measured in a Sedgewick-Rafter counting chamber ruled with parallel guide lines. The parallel lines prevented duplicate measurements of the same egg. Measurements were made to the nearest micrometer unit (0.0167 mm.) using an ocular micrometer. Because the formalin-preserved eggs of the albacore are not perfectly spherical, we adopted the method of Clark (1934), June (1953), Yuen (1955), and others of measuring the random diameter parallel to the ruled lines in the counting chamber in whatever axis the egg lies.

DISTRIBUTION OF MATURE EGGS WITHIN AN OVARY

Several tests were conducted to evaluate sampling procedures. First, it was thought necessary to determine whether advanced eggs were evenly distributed within an ovary. For this test, thin cross sections were taken from the anterior, middle, and posterior parts of the right member of one of the most advanced ovaries in the collection (fig. 4a). The cross sections were

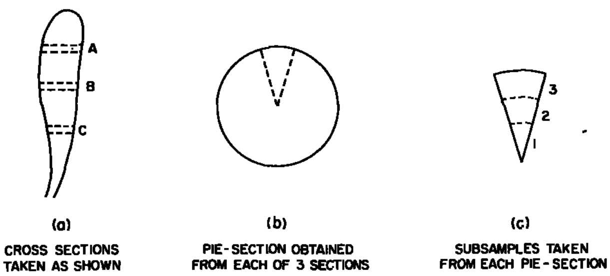

FIGURE 4.—Schematic representation of method used to obtain test samples for determining most efficient sampling procedure.

labeled A, B, and C, respectively. A triangular section was then obtained from each of the three cross sections (fig. 4b). Each triangular section was further subdivided into three subsamples representing, respectively, the center, mid-region, and periphery of the ovary (fig. 4c). Thus, for section A there were positions A_1, A_2, and A_3; for section B, positions B_1, B_2, and B_3; and for section C, positions C_1, C_2, and C_3. These samples were weighed to the nearest 0.001 gram. All of the eggs in the most mature group were then measured. The weights and measurements are given in table 2.

An analysis of variance (table 3) indicated a significant difference ($P<0.05$) between positions in the mean egg diameters but none between sections. The diameter means for sections A, B, and C were 0.842 mm., 0.848 mm., and 0.842 mm., respectively. The results showed that for sections A and B, the mean egg diameter was largest at the periphery of the ovary. The situation was reversed for section C where the mean diameter was least at the periphery and greatest near the central lumen (table 2). It has not been determined whether the differences between positions are real or an artifact of preservation.

The number of eggs in the most advanced group to be expected from 0.1 gram of each sample was

TABLE 2.—*Frequency distributions of diameters of the most advanced group of eggs from the various parts of an ovary (albacore No. 42—Hawaii)*

Diameter (in millimeters)	Sample No.								
	A_1	A_2	A_3	B_1	B_2	B_3	C_1	C_2	C_3
0.668	0	0	0	0	0	0	0	0	1
.685	0	1	0	1	0	0	0	1	1
.701	2	3	2	1	1	0	1	0	2
.718	1	4	4	1	0	1	2	1	2
.735	0	0	4	1	1	0	2	3	4
.752	1	7	3	1	1	1	2	8	9
.768	5	16	5	2	5	1	6	12	12
.785	11	13	10	5	2	1	7	13	10
.802	14	16	15	6	10	7	9	17	13
.818	14	16	15	9	9	4	12	11	14
.835	23	18	23	12	14	6	22	28	22
.852	13	22	13	15	14	7	23	14	19
.868	15	14	16	10	13	16	20	16	17
.885	10	18	9	12	7	5	13	10	12
.902	1	8	13	3	5	1	11	12	5
.918	2	11	8	1	6	3	6	6	6
.935	2	3	7	1	2	4	4	3	6
.952	1	3	5	2	2	2	3	4	0
.969	1	3	6	1	2	0	2	4	3
.985	0	2	1	0	0	1	1	1	3
1.000	0	1	2	0	0	0	1	0	2
Sum	116	179	161	84	94	60	147	164	163
Mean diameter (mm.)	0.833	0.838	0.850	0.842	0.848	0.858	0.850	0.838	0.837
Sample weight (gms.)	.053	.088	.080	.039	.047	.034	.088	.078	.070

then calculated from table 2 and tested by analysis of variance (table 4). The results showed that there was no significant difference ($P>0.05$) in the relative numbers per unit weight of ovary between sections A, B, and C.

A comparison was made of the egg-diameter frequencies of the right and left ovaries (albacore No. 74, Hawaii). A random sample was obtained from the central section of each ovary and all eggs larger than 10-micrometer units (0.167 mm.) were measured (table 5). The comparison resulted in a chi-square of 19.77 ($P=0.9$, 30 *d. f.*[1]) indicating a general similarity in the distributions between the two ovaries.

The results of the various tests suggested that representative samples of an ovary could be obtained anywhere along its length, provided a

TABLE 3.—*Analysis of variance of diameters of the most advanced eggs from different parts of the ovary (albacore No. 42, Hawaii)*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Between sections	2	40.53	20.27
Positions within sections	6	165.85	*27.64
Individuals within positions	1,159	13,770.45	11.88
Total	1,167	13,976.83	

*Indicate significant ($p<0.05$) mean square value.

[1] The last four classes in the frequency distributions were combined because of the low numbers.

random subsample was obtained from the cross section. It was also shown that either of the two ovaries could be used. The procedure routinely used was to measure a random subsample from the mid-section of an ovary.

TABLE 4.—*Analysis of variance of numbers of most advanced eggs from different parts of the ovary (albacore No. 42, Hawaii)*

Source of variation	Degrees of freedom	Sum of squares	Mean square
Between sections	2	156.24	78.12
Positions within sections	6	3,152.96	525.49
Total	8	3,309.20	

TABLE 5.—*Egg diameter frequencies of right and left ovaries from the same fish (albacore No. 74, Hawaii)*

Diameter		Frequency	
Micrometer units[1]	Mm.	Right ovary	Left ovary
10	0.167	259	282
11	.184	137	147
12	.200	124	122
13	.217	117	101
14	.234	107	108
15	.250	115	93
16	.267	82	71
17	.284	72	64
18	.301	75	75
19	.317	69	64
20	.334	51	51
21	.351	48	44
22	.367	54	43
23	.384	56	55
24	.401	45	51
25	.418	59	46
26	.434	40	32
27	.451	39	30
28	.468	47	32
29	.484	29	32
30	.501	32	33
31	.518	16	19
32	.534	15	21
33	.551	26	32
34	.568	27	29
35	.584	27	28
36	.601	18	25
37	.618	20	19
38	.635	19	13
39	.651	10	8
40	.668	6	4
41	.685	2	1
42	.701	3	1
43	.718	1	0
Sum		1,847	1,776

[1] 1 micrometer unit = .0167 mm.

DEVELOPMENTAL STAGES OF THE EGG

Eggs were classified as early developing, late developing, and advanced. The descriptions are based on formalin-preserved material.

Early Developing

This category includes the primitive eggs found in all ovaries and eggs in the beginning stages of development. The primitive eggs vary from about 0.01 to 0.13 mm. in diameter, possess relatively large nuclei, and are transparent. In early development the eggs increase in size and become semi-opaque from deposition of yolk granules. The maximum diameter of eggs in the early developing stage is about 0.4 mm.

Late Developing

In this stage, the eggs are completely opaque from the heavy accumulation of yolk granules. They now range from 0.4 to about 0.8 mm. in diameter.

Advanced

Distinct changes occur in the eggs as they approach ripeness. They lose their opacity and become semitransparent; the nucleus cannot be detected at this stage, and a conspicuous golden-yellow oil globule appears. These advanced but not fully ripe eggs range from about 0.7 to 1.0 mm. in diameter in the most advanced sample available for study.

CLASSIFICATION OF OVARIES

The ovaries were classified into three categories of relative maturity, early developing, late developing, and advanced, according to the stages of development of the largest eggs. In this classification, the early developing category included the thin ribbonlike ovaries from sexually immature fish and ovaries from the larger adult fish which showed no signs of egg development beyond the early stage. The other two categories, on the other hand, included only ovaries from adult fish (fig. 3).

As an example of the classification, a frequency distribution of egg diameters from a fish classed as having late developing ovaries (fig. 5) is shown. In addition to the mode of largest eggs centering at 0.63 mm., other groups of eggs are evident. There are large numbers of early developing eggs less than 0.4 mm. in diameter, and there is evidence of a second group of late developing eggs, one with a mode at 0.43 mm. Both groups of late developing eggs were opaque, characteristic of this stage.

An advanced ovary (fig. 6) has a mode of semitransparent eggs centering at about 0.86 mm. In addition there is one or more groups of late developing eggs between 0.4 and 0.6 mm., possibly a less developed group at about 0.33 mm., as well as the usual large numbers of early developing eggs.

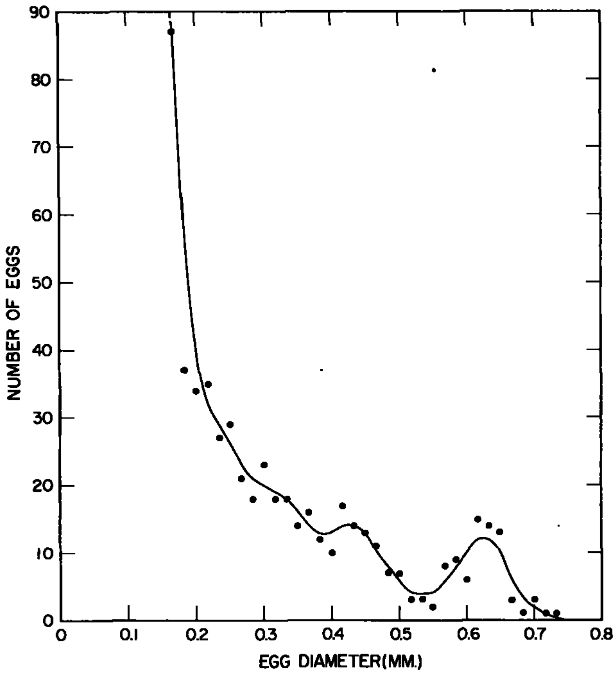

FIGURE 5.—Frequency curve of 550 egg diameters measured from a late developing ovary of a 55-pound albacore taken in Hawaiian waters on June 15, 1955. The curve was derived by smoothing the data twice by a moving average of three.

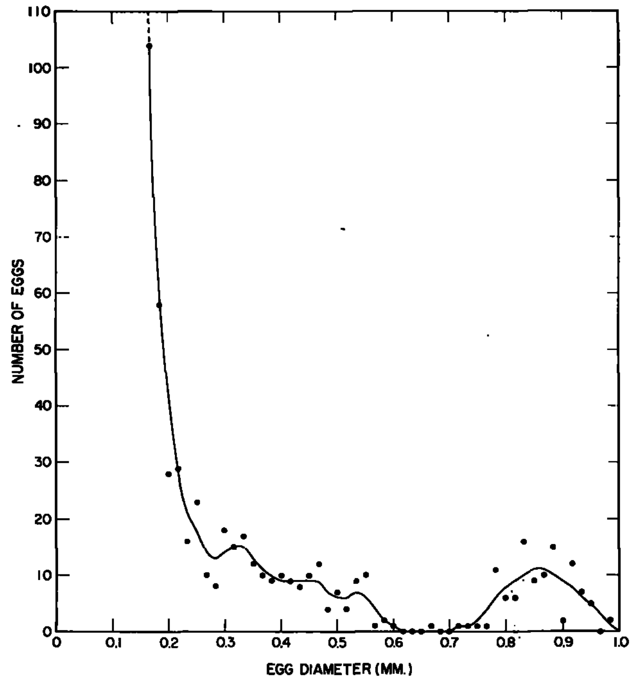

FIGURE 6.—Frequency curve of 550 egg diameters measured from an advanced ovary of a 47-pound albacore taken in Hawaiian waters on June 8, 1955. The curve was derived by smoothing the data twice by a moving average of three.

RESULTS OF GONAD EXAMINATION

NORTH PACIFIC

Since the gonads of albacore in the North Pacific are generally thin and ribbonlike (early developing), the sexes are often difficult to distinguish by gross examination in the field. For this reason, gonads of both sexes were collected and the sex was determined in the laboratory by microscopical examination. Of the gonads of 126 fish examined, 62 were ovaries and 64 were testes.

The ovaries, the bulk of which weighed less than 50 grams, contained only early developing eggs; the maximum egg diameter measured was 0.25 mm. The most enlarged pair of ovaries (131 grams) obtained from the largest female fish sampled (length 108.1 cm., weight 58 lbs.) contained eggs which measured less than 0.13 mm. in diameter. The testes were also immature.

Although large fish (longer than 90 cm.) were not well represented in the sample, field observations of the gonad condition of longline-caught fish gave supplementary evidence that North Pacific fish were either sexually immature juveniles, or adult fish with early developing gonads. Table 6 lists the observations, based strictly on gross inspection, recorded by various members of the POFI staff. Presumably, the gonads of these large fish were sufficiently enlarged so that sex could be determined with some assurance. While the observations recorded as "spent," "spawned-out," and "recovering" might be questioned, there is little doubt that the "immature" fish, corresponding to our early developing category, were correctly designated. The observation dated January 28, 1955 (table 6), for a male albacore of 93.3 cm., is not necessarily indicative of advanced maturity. Male albacore taken in tropical and subtropical waters almost invariably contain some milt in the testes regardless of the size of the gonads. Brock (1943) found that milt could be squeezed from the testes of albacore captured off the coast of Oregon, but the females from this region were judged to be immature.

Our observations indicate that albacore in the central and eastern North Pacific are either sexually immature fish, or are adults which do not show signs of near-spawning. Partlo (1955)

TABLE 6.—*Field observations on sex and maturity of large albacore (over 90 cm.) taken on longline during POFI cruises to the North Pacific* [1]

Date of capture	Position of capture		Fork length, cm.	Sex	Description of gonad condition
	Latitude	Longitude			
Jan. 22, 1954	26°28′ N.	159°39′ W.	107.5	M	Immature.
Jan. 27	33°58′ N.	159°44′ W.	118.3	M	Do.
Do	33°58′ N.	159°44′ W.	112.7	M	Do.
Do	33°58′ N.	159°44′ W.	111.6	M	Do.
Do	33°58′ N.	159°44′ W.	110.7	M	Do.
Do	33°58′ N.	159°44′ W.	109.7	M	Do.
Do	33°58′ N.	159°44′ W.	107.4	M	Do.
Do	33°58′ N.	159°44′ W.	107.4	M	Do.
Do	33°58′ N.	159°44′ W.	106.1	M	Recovering.
Do	33°58′ N.	159°44′ W.	106.1	M	Immature.
Do	33°58′ N.	159°44′ W.	105.7	F	Spawned-out.
Do	33°58′ N.	159°44′ W.	104.5	F	Spent.
Do	33°58′ N.	159°44′ W.	102.5	M	Immature.
Do	33°58′ N.	159°44′ W.	99.4	M	Do.
Jan. 28	35°27′ N.	156°38′ W.	109.1	M	Do.
Oct. 24	38°40′ N.	175°27′ W.	107.6	F	Spent.
Dec. 9	34°23′ N.	159°48′ W.	113.6	M	Immature.
Do	34°23′ N.	159°48′ W.	110.7	M	Do.
Dec. 12	36°14′ N.	159°55′ W.	115.9	M	Do.
Do	36°14′ N.	159°55′ W.	96.8	F	Do.
Dec. 14	35°35′ N.	158°21′ W.	116.1	M	Do.
Do	35°35′ N.	158°21′ W.	114.8	M	Do.
Do	35°35′ N.	158°21′ W.	110.4	M	Do.
Jan. 17, 1955	33°50′ N.	179°44′ W.	104.5	M	Do.
Jan. 18	35°48′ N.	179°49′ W.	116.8	M	Do.
Do	35°48′ N.	179°49′ W.	113.0	M	Do.
Jan. 20	31°25′ N.	178°08′ W.	110.0	M	Do.
Jan. 28	30°42′ N.	175°01′ W.	93.3	M	Some milt in testes.[2]
Do	30°42′ N.	175°01′ W.	90.6	M	No milt in testes.

[1] Includes only those observations in which both sex and gonad condition were recorded.

[2] The presence of milt in the testes does not necessarily indicate advanced maturity, as male albacore taken in tropical and subtropical waters almost invariably contain some milt in testes regardless of the degree of sexual maturity.

who examined histologically a series of male and female gonads, concluded that the British Columbia fishery is dependent on immature fish. Brock (1943) recorded a range in egg diameters of 0.01 to 0.1 mm. in Oregon albacore. He reported that "fish with ripening ova are not present in the Oregon fishery and have never been recorded from the California fishery." Kishinouye (1923) found no fish with maturing reproductive elements in Japanese waters. According to Suda (1954), albacore captured west of Midway Islands, north of the Subtropical Convergence, are all extremely immature, with gonad weights below 50 grams for both males and females. Thus, the albacore resource which furnishes the basis for the spring live-bait fishery in Japanese coastal waters and the Japanese winter longline fishery in midocean, as well as the American west coast fishery in the summer, is composed either of sexually immature fish, or of adult fish which show no signs of gonad development beyond the early developing stage. The implications are, therefore, that albacore do not spawn in the temperate waters of the North Pacific.

HAWAIIAN ISLANDS

Because of the great predominance of males in the landings of albacore in the Hawaiian Islands (fig. 7), coupled with the small numbers taken, we had hoped initially to utilize both male and female gonads in this study. We found, however, that the presence or absence of milt is not a

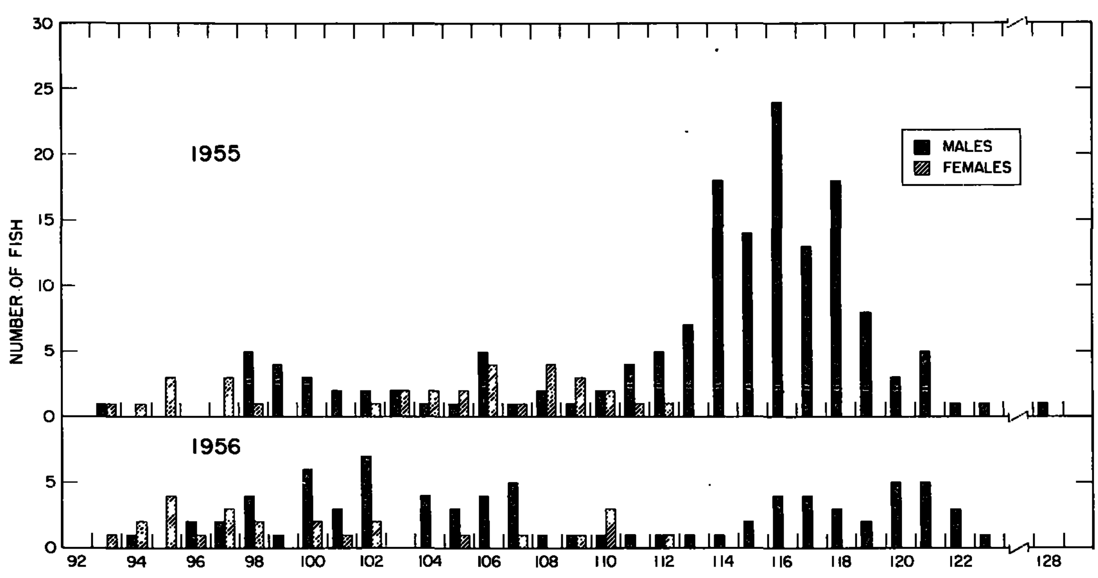

FIGURE 7.—Size and sex distribution of albacore sampled from landings in the Hawaiian Islands, (a) 1955 (b) 1956.

definitive measure of maturity, since regardless of their size, the testes of albacore in Hawaii invariably contain some milt. It was decided, therefore, that only the ovaries would be used for the study of sexual maturity of the Hawaiian and central equatorial Pacific albacore.

Examination of the ovaries from 56 fish revealed varying degrees of maturity from early developing to advanced. Eleven fish ranging in weight from 36 to 59 pounds possessed early developing ovaries; 42 fish, ranging from 33 to 62 pounds, had late developing ovaries; and 3 fish, of 41, 47, and 60 pounds, contained advanced ovaries. The frequency distributions of egg diameters for the 42 late developing and 3 advanced ovaries, and for 4 of the early developing ovaries are presented in table 7. No measurements were made on the remainder of the early developing ovaries with the exception of noting their maximum egg diameters; none exceeded 0.23 mm. The data (table 7) are arranged progressively from the early developing to the most advanced ovaries as determined by the position of the last mode. The modal diameters indicated here were selected by eye after the data had been smoothed twice by a moving average of three. Most of the ovaries showed a distinct second mode which is also indicated.

The modal diameters of the most advanced eggs in each of the 56 ovaries of Hawaiian fish are shown in figure 8 by date of landing. The modal diameters of the 11 early developing ovaries are plotted arbitrarily at 0.167 mm. (10 micrometer units) although the true mode was considerably below this value; only eggs larger than 10 micrometer units were measured.

Of the 36 ovaries sampled in May, June, and July, 3 were advanced and 33 were in the late developing stage; none was in the early developing stage. In August and September, however, of 14 examined, only 7 were in the late developing stage; the remainder were early developing. In October and November, of 6 examined, only 2 were in the late developing stage and 4 were early developing. The above may be an indication that some spawning took place during the summer months. Although the 3 advanced ovaries were not fully ripe, the appearance of the eggs suggested that spawning was not far distant. Clark (1929) examined 21 albacore from Hawaiian waters during the summer of 1929 and reported that all of these fish were "practically mature and ready to spawn." On the other hand, it is possible that albacore have a protracted spawning season, and that the apparent summer spawning season in Hawaii merely reflects seasonality in their occurrence in these waters (table 1).

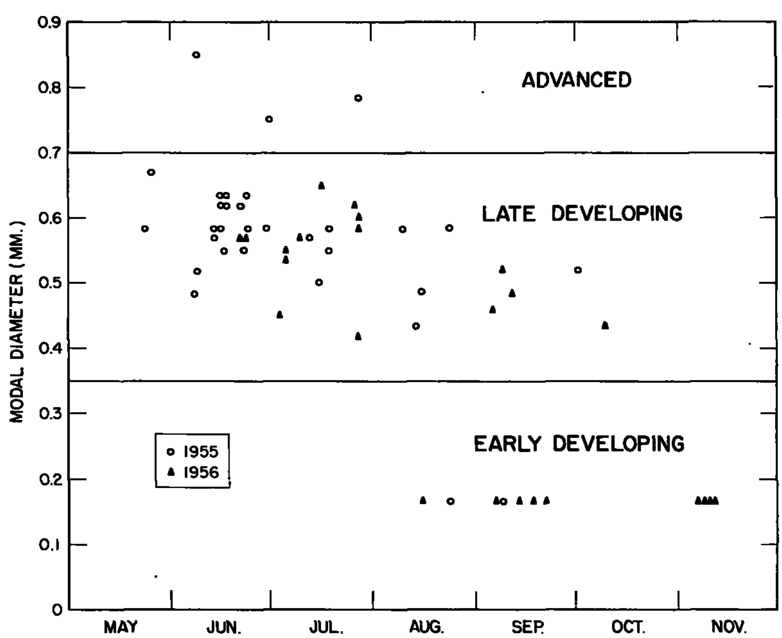

FIGURE 8.—Modal diameter of the most advanced group of eggs shown by date of landing for each of the 56 albacore from Hawaiian waters.

TABLE 7.—*Frequencies of egg diameters, in micrometer units (upper figure)*

[Asterisks mark modal diameters]

Ovary number	10 .167	11 .184	12 .200	13 .217	14 .234	15 .250	16 .267	17 .284	18 .301	19 .317	20 .334	21 .351	22 .367	23 .384	24 .401	25 .418	26 .434	27 .451	28 .468	29 .484	30 .501	31 .518	32 .534
200	175	119	119	65	38	23	5	4	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----
184	142	100	88	65	76	46	21	9	3	----	----	----	----	----	----	----	----	----	----	----	----	----	----
318	57	37	26	27	14	15	8	7	8	1	----	----	----	----	----	----	----	----	----	----	----	----	----
290	60	36	29	15	15	14	8	5	4	8	3	1	1	1	----	----	----	----	----	----	----	----	----
276	125	79	65	52	52	35	24	16	10	10	12	2	2	9	12	*12	5	6	7	6	3	2	2
353	32	15	15	9	4	10	12	7	8	7	3	3	5	5	8	10	*16	11	9	3	4	4	----
179	114	61	46	38	39	31	22	20	19	17	6	6	12	8	12	11	*12	16	10	8	6	5	5
264	105	66	38	39	40	39	24	24	18	29	12	10	13	13	6	8	10	*16	9	7	8	7	5
300	92	53	59	37	32	23	17	12	16	9	8	9	11	16	18	16	19	19	*24	19	18	13	4
32	64	31	25	35	25	30	18	21	16	14	12	11	5	19	11	15	16	21	21	*24	17	23	17
181	75	48	43	50	45	32	23	24	20	22	9	8	11	12	*22	18	14	7	13	*16	14	11	6
314	62	38	28	23	23	15	10	18	*22	14	12	13	12	25	14	16	15	23	34	*24	29	29	20
156	75	59	37	43	48	30	19	20	21	17	6	12	6	8	8	11	15	20	15	12	*24	12	15
41	58	36	31	22	12	14	24	*23	11	16	15	14	14	10	8	10	23	26	24	28	24	*36	29
305	85	48	37	33	33	22	11	13	18	12	8	20	*12	18	9	10	3	5	18	14	16	*24	22
209	43	24	18	15	15	11	19	19	8	12	14	15	9	8	6	17	18	30	31	30	34	*50	38
256	66	35	31	31	27	20	20	12	17	21	16	10	14	13	*13	20	9	13	15	14	16	30	*31
257	57	31	33	38	39	22	18	20	32	16	15	9	10	16	11	8	7	7	11	12	7	11	19
88	46	41	30	25	18	18	17	13	11	14	16	19	*13	24	10	17	11	9	12	9	7	12	30
116	74	59	42	36	28	38	17	15	16	13	15	10	4	15	13	11	10	4	8	9	6	16	19
159	71	45	35	30	31	36	11	25	22	24	18	13	17	20	11	10	5	8	14	7	9	9	18
251	72	42	27	28	27	24	19	18	23	23	14	13	13	*20	19	15	9	12	12	7	8	8	7
246	62	38	25	24	21	26	12	16	24	22	11	7	10	20	*23	20	10	13	16	11	8	11	11
259	62	30	26	21	12	20	19	19	30	17	10	11	14	14	14	*23	13	9	16	11	13	17	15
153	215	151	167	154	161	137	98	88	88	93	82	50	60	69	78	*87	56	67	38	41	25	34	54
74	259	137	124	117	107	115	82	72	75	69	51	48	54	*56	45	59	40	39	47	29	32	16	15
185	77	44	37	30	27	33	22	15	16	15	10	7	11	13	10	14	8	16	8	11	16	10	13
158	35	24	22	23	25	26	18	22	23	19	12	19	16	22	*17	24	9	11	6	4	14	11	15
275	87	43	39	30	36	29	14	17	16	15	13	9	13	12	*22	15	17	13	10	1	10	4	4
130	86	54	40	35	30	21	21	17	16	10	12	11	11	8	*13	14	8	10	7	8	7	5	10
79	76	55	42	36	36	29	22	12	17	21	12	9	9	14	*14	12	8	8	8	7	9	8	13
75	87	57	46	37	29	26	21	18	22	13	8	9	13	*14	9	11	9	8	7	5	2	8	10
80	105	51	34	38	39	40	27	29	27	17	13	13	15	14	*22	15	15	8	8	8	10	4	7
122	53	33	22	21	33	19	15	19	19	18	15	10	14	19	*21	22	11	16	10	7	7	4	9
174	61	37	23	26	22	40	20	17	19	23	17	13	19	9	15	*22	9	21	11	10	10	4	5
15	81	30	32	27	18	36	15	15	30	13	21	10	12	16	13	*22	13	9	17	6	6	1	8
277	102	54	40	40	34	29	15	17	15	15	12	13	6	12	10	*14	6	9	15	7	10	7	6
274	82	44	36	29	23	23	18	17	16	14	12	6	6	9	8	14	*7	8	13	8	9	7	6
110	61	30	36	18	27	40	14	23	13	17	21	16	14	11	15	*21	14	8	16	9	9	4	5
91	49	28	32	25	22	31	20	22	23	18	16	14	15	18	20	*15	6	17	14	13	15	5	10
82	87	37	34	35	27	29	21	18	23	18	18	14	16	12	10	*17	14	13	11	7	7	3	3
123	67	35	31	31	24	21	19	14	18	17	12	9	12	18	9	19	*13	14	22	7	3	1	3
84	72	40	33	25	22	24	17	15	25	13	12	9	13	17	20	*20	16	13	20	11	9	11	4
90	44	32	25	32	27	27	25	14	19	11	17	8	10	21	*16	21	8	16	19	12	12	4	4
269	32	22	24	25	11	17	21	21	12	11	16	7	12	19	15	*33	24	15	13	13	1	6	5
18	61	41	28	29	31	27	11	24	20	11	12	9	5	13	15	*16	12	16	13	4	10	0	1
145	189	94	83	85	74	93	52	61	66	46	44	36	38	47	40	49	42	*53	47	24	13	4	6
165	86	63	54	41	44	37	31	28	29	26	15	4	12	13	13	*15	10	12	12	8	6	6	3
42	104	58	28	29	16	23	10	8	18	15	17	12	10	9	10	9	8	10	12	4	7	4	*9

[1] No measurements were made on 7 of the 11 early developing ovaries with the exception of noting the maximum egg diameters; none exceeded 0.23 mm.

CENTRAL EQUATORIAL PACIFIC

While the vast region of the tropical Pacific is here treated as a single unit because of the small amount of data available, it is realized that a more detailed study of smaller units of area would be desirable.

The albacore caught in the equatorial Pacific (fig. 9) were intermediate in size between those from the North Pacific and those from Hawaii. If only the female fish are considered, however, their sizes were not much smaller than the female fish sampled from Hawaiian waters. One notable difference was in the sex ratio, which in this region was nearly 1:1, while in Hawaiian waters the males predominated (fig. 7).

Ovaries from 66 fish were examined. Of this total, 54 were in the early developing and 12 were in the late developing stage (table 8). In figure 10 the maximum egg diameter of each of the 66 ovaries is shown by date of capture of the fish. Maximum egg diameter was used, because no other measurements were made on most of the early developing ovaries. Most of the samples were collected during February and November 1952, in February and May 1953, September 1956, and January and February 1957. Some late developing ovaries were found during all of these periods with the exception of February 1952. The areas from which late developing ovaries were obtained are also indicated in figure 1. They appear to be randomly scattered. It is evident that no conclusions can be drawn from the amount of data available regarding the spawning time and locality.

and mm. (lower figure), for ovaries from the Hawaiian Islands [1]

[Asterisks mark modal diameters]

33 .551	34 .568	35 .584	36 .601	37 .618	38 .635	39 .651	40 .668	41 .685	42 .701	43 .718	44 .735	45 .752	46 .768	47 .785	48 .802	49 .818	50 .835	51 .852	52 .868	53 .885	54 .902	55 .918	56 .935	57 .952	58 .969	59 .985	Sum
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	200
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	200
0	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	200
2	4	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	531
3	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
3	0	2	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
18	8	13	7	8	2	1	0	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
3	1	2	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
16	8	5	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
8	6	1	1	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
22	6	5	4	3	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
19	15	12	4	4	4	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
27	12	12	9	4	1	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
22	12	15	4	0	3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
*30	26	19	11	10	3	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
*29	28	25	16	9	10	6	2	3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
*24	17	19	5	4	1	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
*8	13	16	7	6	6	3	1	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
18	*16	16	7	10	11	6	4	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
25	*25	25	18	8	5	2	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
27	*17	23	20	10	8	3	2	1	1	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
74	*69	67	53	21	9	4	0	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2, 391
26	*27	27	18	20	19	10	6	2	3	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1, 847
13	*17	16	12	10	10	4	4	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
28	*27	33	17	12	8	5	2	0	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
10	9	*19	12	14	6	5	4	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
10	13	*21	13	17	9	7	3	1	1	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
12	10	*10	15	11	4	4	4	1	1	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
14	15	*21	12	9	4	3	2	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
9	15	*14	10	6	9	7	2	2	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	634
14	20	*25	21	21	17	8	4	3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
8	13	*24	14	15	8	6	6	3	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
16	13	*24	16	14	6	4	2	3	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
6	3	10	*7	8	8	5	6	3	1	3	0	1	0	1	----	----	----	----	----	----	----	----	----	----	----	----	550
12	8	15	21	*25	21	13	8	6	4	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
2	9	11	10	*25	7	11	11	7	7	6	0	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
12	9	9	8	*19	11	8	13	5	6	1	0	0	0	1	----	----	----	----	----	----	----	----	----	----	----	----	550
2	8	9	6	*15	14	13	3	1	3	1	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
6	10	15	17	17	*26	14	14	6	4	2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
5	2	1	9	7	*12	6	8	8	9	10	4	1	3	1	1	2	----	----	----	----	----	----	----	----	----	----	550
5	8	11	12	14	*22	9	21	11	7	3	1	1	0	1	----	----	----	----	----	----	----	----	----	----	----	----	550
6	10	10	20	16	27	*31	19	17	10	5	1	2	1	----	----	----	----	----	----	----	----	----	----	----	----	----	550
5	2	2	4	11	18	15	*21	15	11	15	7	10	0	3	1	1	----	----	----	----	----	----	----	----	----	----	550
2	4	7	3	11	11	13	15	11	16	23	24	*30	24	28	22	11	10	4	5	2	3	1	1	0	1	----	1, 568
3	2	0	1	0	1	1	1	2	6	5	5	5	7	*9	6	5	5	5	6	4	3	2	1	2	----	----	656
10	1	2	1	0	0	0	1	0	0	1	1	1	1	11	6	6	16	*9	10	15	2	12	7	5	0	2	550

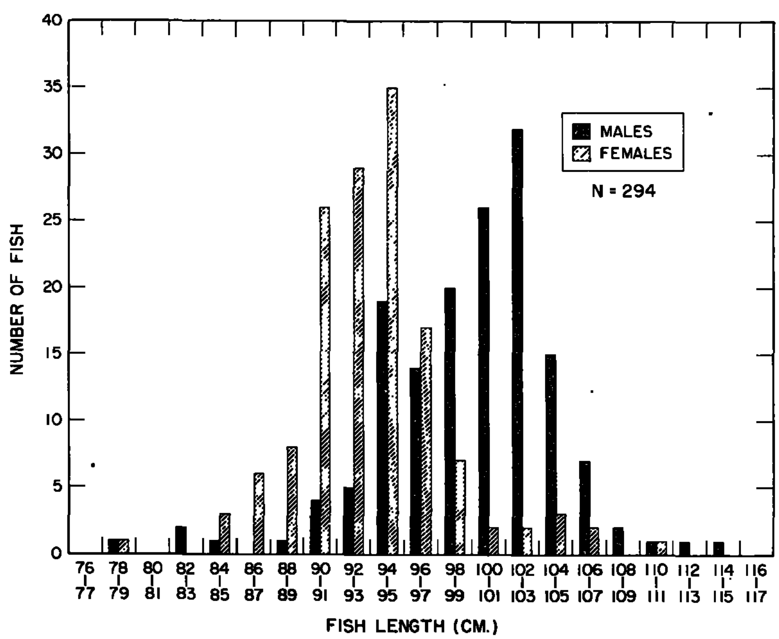

FIGURE 9.—Size distribution, by sex, of central equatorial Pacific albacore captured during the years 1952 to 1957, and for which sex and size data were recorded.

TABLE 8.—*Frequencies of egg diameters, in micrometer units (upper figure) and mm. (lower figure), for ovaries from the central equatorial Pacific Ocean* [1]

[Asterisks mark modal diameters]

Ovary number	10 .167	11 .184	12 .200	13 .217	14 .234	15 .250	16 .267	17 .284	18 .301	19 .317	20 .334	21 .351	22 .367	23 .384	24 .401	25 .418	26 .434	27 .451	28 .468	29 .484	30 .501	31 .518	32 .534	33 .551	34 .568	35 .584	36 .601	37 .618	38 .635	39 .651	40 .668	41 .685	42 .701	Sum
C-16	126	82	72	53	36	37	27	31	28	17	13	13	10	2	2	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	550
C-49	39	23	16	20	18	7	18	13	5	5	*11	4	3	5	3	2	3	1	0	3	1	----	----	----	----	----	----	----	----	----	----	----	----	200
C-48	26	13	11	9	8	17	13	13	3	3	15	*10	10	7	8	8	10	4	5	4	3	----	----	----	----	----	----	----	----	----	----	----	----	200
C-3	57	42	35	22	28	33	30	14	18	16	14	18	19	20	22	*28	27	18	15	14	12	12	9	10	5	6	1	3	2	----	----	----	----	550
C-42	94	48	41	33	27	30	22	21	17	20	20	23	24	19	18	*24	27	12	15	5	4	3	0	0	2	0	1	----	----	----	----	----	----	550
C-20	67	39	38	22	23	19	16	*30	24	20	17	16	20	22	12	32	*21	27	27	10	18	14	7	6	2	1	----	----	----	----	----	----	----	550
C-31	126	77	57	31	19	20	13	8	10	3	6	12	9	12	12	13	20	*22	22	12	10	13	12	6	0	2	3	----	----	----	----	----	----	550
C-10	119	75	58	54	36	31	11	22	16	11	12	5	14	15	8	9	10	11	*16	7	2	3	2	2	1	----	----	----	----	----	----	----	----	550
C-61	61	35	30	29	32	30	25	23	24	15	22	20	19	19	13	18	23	22	*23	26	20	10	8	2	1	----	----	----	----	----	----	----	----	550
C-37	72	44	44	36	17	23	23	24	19	17	12	9	15	15	7	16	21	21	*20	20	16	8	9	9	12	8	3	3	3	3	0	0	1	550
C-1	58	28	25	19	15	14	14	15	14	20	20	16	16	17	22	15	20	22	16	18	26	*23	22	24	18	15	9	5	3	0	1	----	----	550
C-13	117	86	81	49	34	21	21	20	14	12	8	8	4	2	0	3	7	5	9	6	9	*13	3	4	5	5	1	1	1	0	0	0	1	550
C-2	96	56	36	25	23	20	11	20	12	10	15	11	10	11	9	12	17	16	19	11	16	*19	15	13	11	9	8	6	7	2	1	2	1	550

[1] Eggs from only one early developing ovary (albacore No. C-16) were measured.

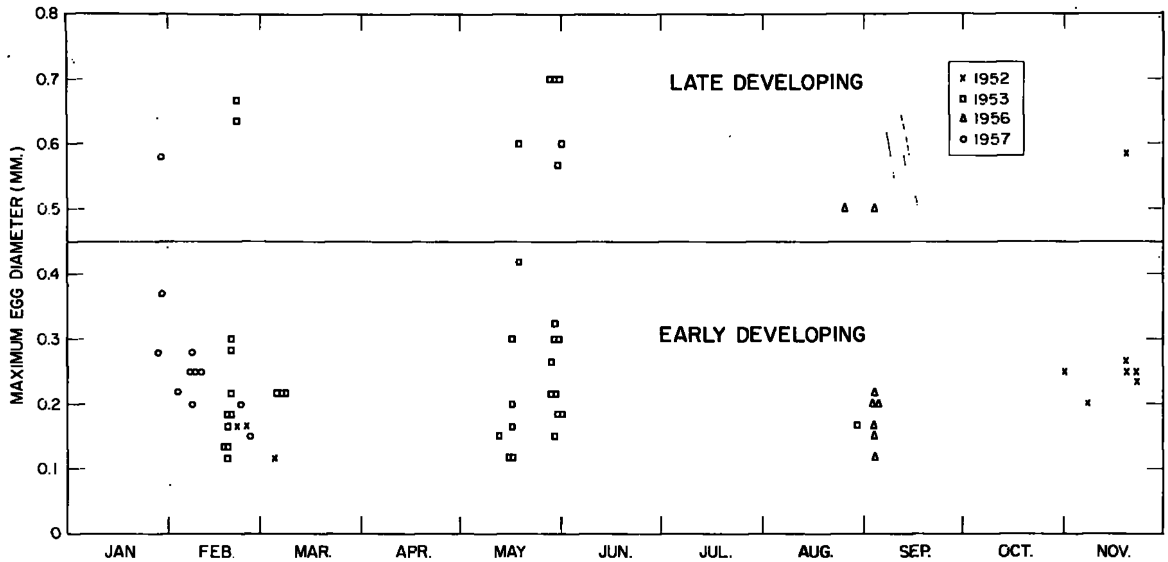

FIGURE 10.—Maximum egg diameter for each of the 66 central equatorial Pacific albacore by date of capture. (Since only the maximum egg diameter was recorded for most of the early developing ovaries, this measurement rather than the modal diameter is used.)

EVIDENCE OF SPAWNING

The spawned-out or spent stage is recognized by the presence of remnants of ripe eggs (residual eggs in the process of resorption) in the lumen of the ovary (Schaefer and Orange, 1956; Yuen and June, 1957). A fresh, unpreserved spent ovary is generally hollow and flaccid. In preserved specimens, however, it may resemble any of the other stages of maturity, even the early developing ovary, depending upon how recently spawning has occurred. Egg remnants were actually found in ovaries in all stages of maturity from early developing through advanced.

In this study we classified the ovaries into developmental stages without regard to the presence or absence of egg remnants. In figure 11 the maximum egg diameter for each of the Hawaiian and central equatorial Pacific albacore is shown by fish size, and the ovaries which contained egg remnants are indicated. No distinction was made of the quantity of remnants in the ovaries, nor of their stage of resorption. While the absence of egg remants may not be accepted as proof that the fish has never spawned, their presence constitutes good evidence that spawning has occurred (June 1953; Yuen 1955; Schaefer and Orange, 1956; Yuen and June, 1957). Of a total of 56 Hawaii samples, 47 contained egg remnants, indicating that these fish had spawned. Similarly of 66 central equatorial Pacific ovaries examined,

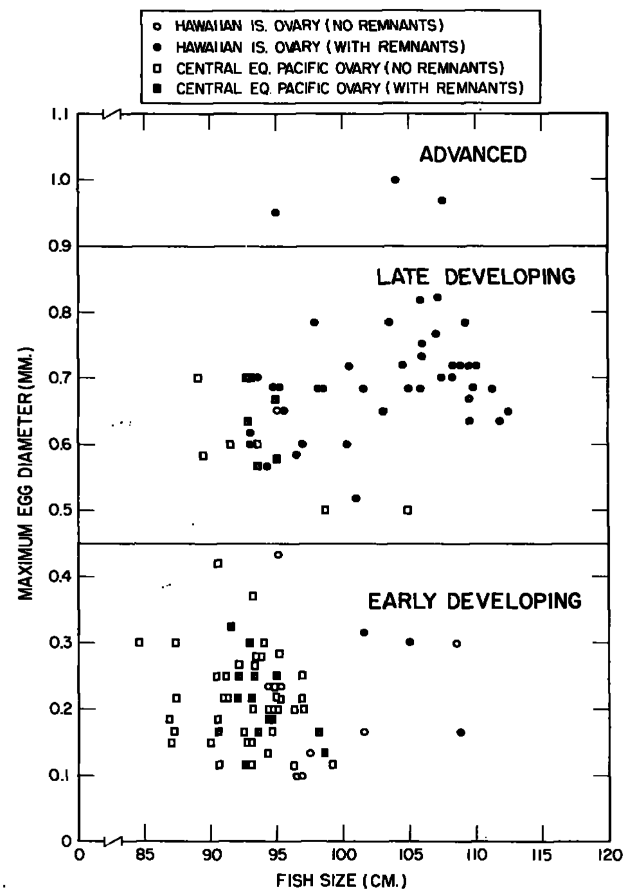

FIGURE 11.—Relation between fish size and maximum egg diameter. Ovaries with egg remnants are indicated.

20 contained egg remnants. None were found in the North Pacific ovaries, thus giving added weight to the conclusion that spawning does not occur in the North Pacific.

MINIMUM SIZE OF SPAWNING FISH

Ueyanagi (1955) has inferred from his studies that the albacore attains sexual maturity and may spawn at about 90 centimeters in length. Our observations are in agreement with this.

The 12 central equatorial Pacific ovaries in the late developing stage were obtained from fish ranging in length from 89.1 cm. to 104.8 cm. (weight, 33 to 54 lbs.); the 45 late developing and advanced ovaries from the Hawaiian area were taken from fish larger than 93.1 cm. (33 lbs.). Additional evidence regarding the minimum size at spawning can be found in figure 11. Although egg remnants were present in ovaries at all stages of maturity, none were found in fish less than 90 cm. in length. Therefore, our data suggest that the albacore attains sexual maturity at a size of about 90 cm. (33 lbs.), which coincides with Ueyanagi's findings.

FREQUENCY OF SPAWNING

The frequency distributions of egg diameters (figs. 5 and 6, tables 7 and 8) show clearly two or more modes which, depending on the growth rate of the egg, may represent eggs that will be spawned in a single season or in succeeding seasons. As the data do not permit determination of the growth rate of eggs, reference is again made to figure 11. The fact that the three advanced ovaries as well as most of the late developing ovaries contained egg remnants strongly indicates that the albacore undergoes multiple spawning. The lack of remnants in large, sexually inactive adults taken during late winter in the North Pacific suggests that remnants are not carried over from one year to the next, though in the absence of any knowledge regarding the rate of resorption of the unspawned eggs, no definite conclusions can be drawn. The presence of egg remnants together with a group of eggs approaching ripeness suggest, however, that albacore may spawn at least twice during a single spawning season.

FECUNDITY

Fecundity calculations were based on the assumption that all of the eggs comprising the most advanced group within an ovary were released in a single spawning. Eight Hawaiian fish of varying sizes were selected for this study. From each pair of ovaries, a random sample was obtained; this was weighed to the nearest 0.001 gram. All of the eggs comprising the most advanced group within the sample were then counted. The total number of such eggs in the pair of ovaries was estimated by multiplying the number in the sample by the ratio of ovary-weight to sample-weight. The results are shown in table 9. The data are arranged in the order of increasing fish size from 36 to 62 pounds. In addition, two calculations made by Ueyanagi (1955) are included.

TABLE 9.—*Estimations of the number of eggs in the most advanced group in the ovaries*

Albacore No.	Body wt. (lbs.)	Ovary wt. (gms.)	Sample wt. (gms.)	Number of mature eggs in sample	Estimated number of mature eggs in ovaries (millions)
158	36	183	0.1215	579	0.9
75	39	271	.1862	882	1.3
275	41	319	.1435	418	.9
42	47	538	.2367	482	1.1
74	54	513	.0560	513	1.6
84	57	552	.1983	582	1.6
145	60	916	.1197	238	1.8
153	62	194	.0811	411	1.0
A [1]	50	365	.2		2.1
B [1]	53	613	.2		1.8–1.9

[1] From Ueyanagi (1955).

There appears to be a slight tendency for larger fish to have more eggs per spawning but it is not as definite as that found for the yellowfin (June 1953) and bigeye tuna (Yuen 1955). The estimated total numbers of eggs in the most advanced group were remarkably uniform, ranging between 0.9 and 1.8 million eggs per individual female. Including Ueyanagi's estimates, the range is from 0.9 to 2.1 million eggs.

OVARY SIZE AS INDEX OF MATURITY

While the state of maturity of an ovary can be determined reliably by means of egg diameter measurements, a more simple and yet objective method for making rapid field determinations is desirable. The size of the ovaries, if directly related to maturity, should provide a reasonable criterion. Our data show that all of the early developing ovaries from the central equatorial Pacific weighed less than 100 grams, and that late developing ovaries ranged from 104 to 363 grams. The early developing ovaries from the Hawaiian area, however, ranged in weight from 54 to 179 grams, the late developing ovaries from 123 to 805 grams, and the three advanced ovaries weighed 181, 538, and 916 grams, respectively. Thus, while the ovaries from the central equatorial Pacific fall conveniently into two stages of maturity according to their weights, there is considerable overlap in the Hawaiian samples. It appears, therefore, that ovary size is actually a poor criterion to follow in assessing the state of maturity of an ovary.

Recently, the relative ovary weight (ovary weight $\times$ 10^3/fish weight) has been found to be a fairly reliable measure of maturity for Hawaiian yellowfin (June 1953) and central Pacific bigeye tuna (Yuen 1955). This relation was therefore tested for the albacore ovaries. In figure 12 the relative ovary weight of each of the Hawaiian and central equatorial Pacific albacore is plotted against the maximum egg diameter. Here again, the data do not permit the use of modal diameters, for these were not determined for most of the early developing ovaries. The data presented in tables 7 and 8 indicate an acceptable correlation between modal and maximum diameters which justifies the use of the latter. The early developing ovaries, with only one exception, have relative ovary weights of less than 6, while all but three of the late developing ovaries have relative ovary weights greater than 6. Thus, with a reasonable amount of confidence, a relative ovary weight of 6 may be considered as the value which separates the early developing from late developing ovaries.

The late developing ovaries ranged in relative ovary weight from 6 to 30 with a general tendency for the ratio to increase with progressing maturity. The three advanced ovaries, however, failed to conform to any pattern and varied in relative ovary weights from 10 to 34. Despite the large variation exhibited by the three ovaries in the advanced stage, the data in general point to a definite relation between relative ovary weight and the state of gonad development.

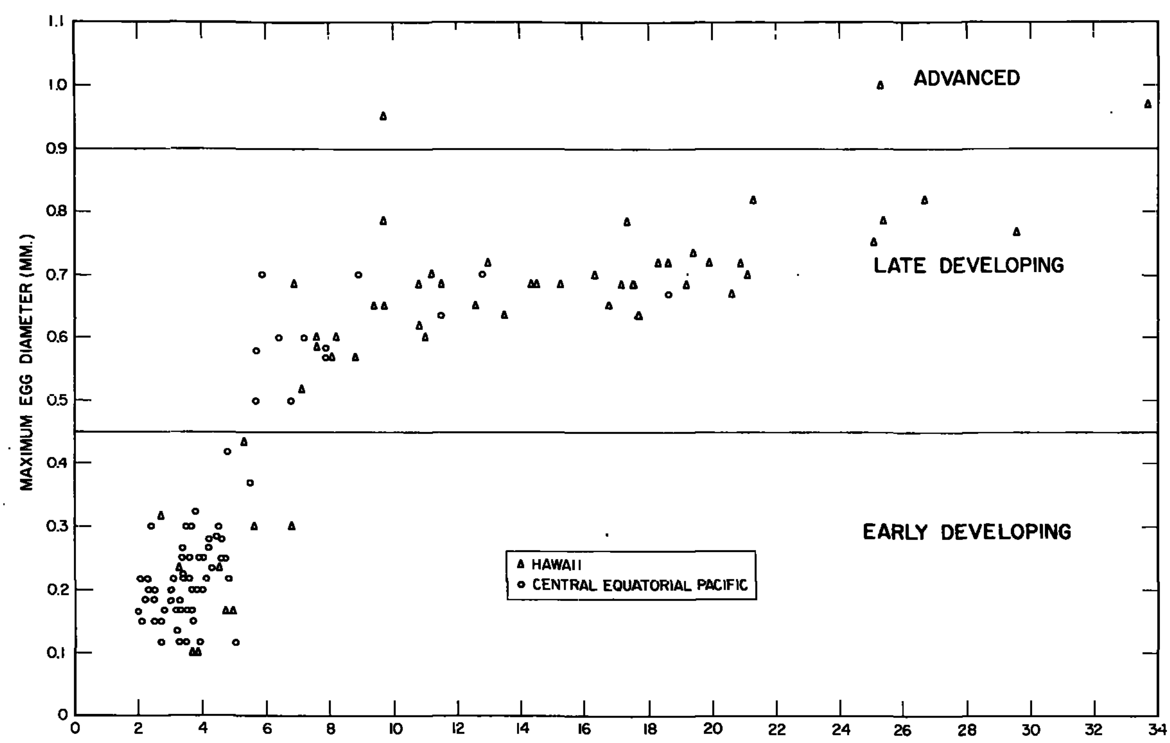

FIGURE 12.—Relation between relative ovary weight and state of maturity.

DISCUSSION

Our samples did not include any ovaries that were fully ripe. Three ovaries were classified as "advanced" on the basis of the appearance of the eggs. Although they were advanced in maturity, and presumably close to spawning, it has not been possible to determine the time required for these ovaries to attain a fully ripe stage. Because these advanced ovaries were collected during the summer months, and since a large percentage of ovaries collected in the fall were in the early developing stage (fig. 8), it was postulated that some spawning occurs during the summer in the vicinity of the Hawaiian Islands.

Fully ripe fish apparently are not available to the fishery. June (1953), working with Hawaiian yellowfin, concluded that this species spawns in Hawaiian waters. He found only one fully ripe ovary among his samples, however, and stated that "fish that are actually spawning either do not take the hook or migrate into deeper water outside the longlining grounds." Similarly, Schaefer and Orange (1956) stated that "apparently, when the yellowfin tuna imminently approach spawning, they become unavailable to the fishery." This behavior was noted earlier by Schaefer (1948) for yellowfin tuna and skipjack off Central America. Brock (1954) also found that fully ripe skipjack are not commonly available to the Hawaiian skipjack fishery. Thus, the possibility that fully ripe tunas are generally unavailable to the fishery may be one reason for the small number of advanced ovaries and the complete absence of ripe ovaries in our collections.

Most of the ovaries examined from the central equatorial Pacific were in the early developing stage, but a few late developing ovaries were present as well as those that contained relics of past spawning. Absence of advanced stages may mean that these fish do not spawn in this region. Unfortunately, not much is known of the maturity of the albacore taken in other regions of the tropical Pacific. Some field observations on the gonads of albacore landed by the Japanese tuna mothership expeditions between April and September of 1951 are available for the western equatorial Pacific between the Equator and 6° N. latitude and between 144° E. and 174° E. longitude (general vicinity of the Caroline and Marshall Islands). Descriptions of these expeditions are given by Shimada (1951), Ego and Otsu (1952), and Van Campen (1952). Of a total of 41 observations made by observers from POFI during this period, 33 were recorded as immature, 6 as spent, and only 2 as mature. Judging from these records, it may be assumed that the maturity of the western Pacific albacore during this period more nearly resembled that of the central equatorial Pacific albacore than that of the Hawaiian fish.

Ishii and Inoue (1956) postulated that the Coral Sea and adjacent New Caledonia area were spawning areas for the albacore. Their study was based on only two ovaries which, according to their descriptions, corresponded to our early developing and late developing stages. On the basis of these data, it is surmised that the maturity of the fish in this area is much like that found throughout the central and western equatorial Pacific. It is interesting to note that Ueyanagi (1955) reported on two well-advanced ovaries obtained in February 1953 from the southern waters of Sunda Islands (Indian Ocean); one of the ovaries he referred to as "ripe" and the other as "nearly ripe".[2] He has hypothesized that the albacore which occur in the Indian Ocean spawn in February, at least, in part. He believes that the area from south of the Sunda Chain to northwest of Australia may be the spawning grounds of the Indian Ocean albacore, since the fish taken there are generally large. Ueyanagi's size-frequency data of the Indian Ocean albacore (fig. 13)

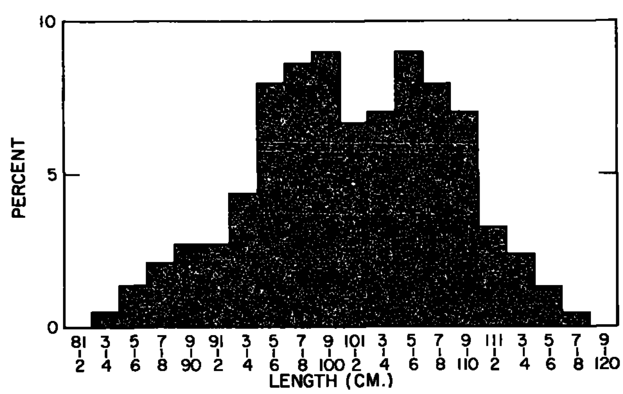

FIGURE 13.—Length composition of Indian Ocean albacore (reproduced from Ueyanagi 1955, fig. 2).

[2] Ueyanagi very kindly sent us samples taken from these two ovaries. The sample he referred to as "nearly ripe" corresponds in maturity to late developing ovaries, and the "ripe" to one of the advanced ovaries in the present study.

closely resemble that of the central equatorial Pacific albacore (fig. 9).

The best indications of albacore spawning are therefore available from two widely separated localities, the Hawaiian Islands in the central Pacific and Sunda Islands in the Indian Ocean, the former during the northern summer and the latter during the southern summer.

It is not known whether the albacore appearing in various parts of the Pacific Ocean belong to a single intermingling population or whether there are discrete populations in the various areas. Suda (1956) is of the belief that the albacore occurring in the North Pacific Current area are a "feeding group" and that there is a corresponding "spawning group" in the North Equatorial Current area. Furthermore, he postulates that the albacore of the Indian Ocean as well as the tropical South Pacific comprise the spawning group of another feeding group located in South Pacific temperate waters. If this is indeed the case, it may be that the Hawaiian Islands represent a portion of the spawning grounds of the northern population, and that the Sunda Islands, that of the southern population.

Our data suggest that albacore attain sexual maturity at about 90 centimeters in length (weight, 33 lbs.). This signifies that the fish exploited during the spring and summer by the Japanese and the Americans in the temperate waters of the North Pacific are largely sexually immature fish (Suda 1955, Brock 1943). The Japanese winter longline fishery in the North Pacific, on the other hand, exploits both juvenile and adult fish (Suda 1954). The gonads of these adult fish do not show any development, however. This situation is in contrast to that in the Hawaiian Islands where the catch is wholly of adult fish (fig. 7). Many of these have gonads showing considerable development. In the central equatorial Pacific, the fish are also generally large and most are adults with gonad development intermediate between North Pacific and Hawaiian Islands fish. It appears possible that the Hawaiian and central equatorial Pacific albacore are a segment of the population which, after attaining a certain size in temperate waters of the North Pacific, moves south into tropical and subtropical waters to reproduce.

SUMMARY

1. This study is based on examination of gonads of albacore taken from three general areas: the North Pacific (north of 30° N. latitude, between 180° longitude and the west coast of the United States), the Hawaiian Islands, and the central equatorial Pacific (Equator to 12° S. latitude, between 180° and 150° W. longitude, with scattered samples collected from as far east as 120° W.). Although the three areas are treated separately throughout this report, this does not infer that the fish belonged to separate stocks, or populations.

2. Gonads of both sexes were used in the study of the maturity of North Pacific albacore. Only the ovaries were used for the other two areas and the degree of maturity was determined largely from egg diameter measurements.

3. The several tests made to determine the most efficient sampling procedure indicated that mature eggs were randomly distributed throughout the length of an ovary but there were some differences in the transverse distribution. There were no differences in the distribution between the two ovaries of a pair. The adopted method of sampling was to take a random sample from the mid-section of an ovary.

4. The ovaries were classified in three stages of relative maturity: early developing, late developing, and advanced, on the basis of the most advanced eggs present. The advanced ovaries were not in a fully ripe condition.

5. The North Pacific albacore were either juveniles or sexually dormant adults with early developing gonads.

6. The Hawaiian albacore evinced varying degrees of maturity from early developing to advanced, with the bulk of the ovaries in the late developing stage. Although the samples were somewhat inadequate for a conclusive study, there was indication that spawning may occur during the summer months in the vicinity of the Hawaiian Islands. The data also indicated the possibility of a somewhat protracted spawning season.

7. The ovaries from central equatorial Pacific fish were in the early developing and late developing stages, with the early developing stage predominating.

8. The presence of egg remnants in the ovaries indicated that most of the Hawaiian fish had spawned previously. None of the ovaries from the North Pacific contained egg remnants. Of 66 central equatorial Pacific ovaries, 20 contained egg remnants. Remnants of eggs were present in ovaries in all stages of maturity from early developing through advanced.

9. The minimum size at which albacore attain sexual maturity and participate in spawning appears to be about 90 cm. (weight, 33 lbs.).

10. The size distribution of eggs within an ovary, as well as the frequent occurrences of egg remnants in advanced and late developing ovaries, indicate that albacore may undergo at least two spawnings during a spawning season.

11. Assuming that all of the eggs comprising the most advanced group within an ovary are extruded in a single spawning, the number released per spawning is about 1 to 2 million eggs per individual female albacore.

12. Ovary size is not a reliable criterion to follow in assessing the degree of maturity of an ovary. Relative ovary weight (ovary weight $\times$ 10^3/virgule fish weight) is shown to be the more reliable index, particularly for segregating early developing from late developing ovaries.

13. This study shows that albacore caught by POFI vessels north of Hawaii, as well as those taken by the Japanese spring live-bait and winter longline fisheries, and those supporting the American west coast summer fishery are non-spawning fish that are either juveniles or adult fish whose gonads give no signs of incipient or past spawning. Albacore apparently do not spawn in the temperate waters of the North Pacific.

14. It appears possible that the albacore in region of the Hawaiian Islands and in the central equatorial Pacific represent a segment of the population which, after attaining a certain size in temperate waters of the North Pacific, moves south into tropical and subtropical waters to reproduce.

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U. S. GOVERNMENT PRINTING OFFICE: 1959 O - 485320