Japanese Albacore and Bigeye Tuna Size Composition Studies

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JAPANESE ALBACORE AND BIGEYE TUNA SIZE COMPOSITION STUDIES

Translated from the Japanese language by

W. G. Van Campen, Translator
Pacific Oceanic Fishery Investigations
U. S. Fish and Wildlife Service
Honolulu, T. H.

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WASHINGTON: June 1956

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Size Composition of Albacore and Bigeye Tuna of the North Pacific Fishing Grounds*

By

Hiroshi Nakamura, Tadao Kamimura, and Yōichi Yabuta
Nankai Regional Fisheries Research Laboratory

/English title and summary/

Size Composition of the Albacore and Big-eyed Tuna Caught in the North Pacific Area

1) The data upon which this report is based have been obtained during the two periods, viz., Nov. '48-March '49, and Oct. '49-March '50. The fishes measured were taken exclusively by the longline. The length given in this paper is the so-called fork length. The North Pacific Area, in this paper, is the seas north of 26°N., between 130°E.-170°W.

2) As shown in fig. 1, the most dominating size of the albacore is from 60 cm. to 110 cm. in length; the min. is 41 cm. and the max. is 119 cm. in both periods, while the dominating size of the fish taken by rod and line is between 70 cm. and 90 cm., as shown in fig. 2 (after Uno).

Such large-sized ones as those taken by long-line are more variable in length than those taken by rod and line. The difference in size composition of both catches is thought to be due to the difference in the fishing methods, seasons and grounds.

3) It is recognized clearly that there is a remarkable difference in the size composition of both periods, namely, the mode C in the former period is perfectly in discord with the mode B and D of the latter period; and the mode E and F, which appear clearly in the former period, are quite indistinct in the latter.

4) We explain the phenomenon mentioned above as follows:

a) The difference in length is caused by the annual difference of the growth.

If it is assumed that the fishes migrating in a certain sea in a certain season are always composed of the definite age groups, then the mode A and C are composed of the X-age and (X + 1)-age group respectively. On this supposition, the fish forming the mode B must be the remarkably well-grown group of the X-age, or the quite undergrown group of the (X + 1)-age. It is known in some cases of the fresh water fishes that their annual growth is greatly affected by the environmental conditions. If this holds true with such pelagic fish as albacore, it may be said to be an interesting phenomenon.

b) The difference in length is caused by the difference in the annual propagation.

On this supposition, modes A, B, C,·····F are thought to be formed by the X, (X + 1), (X + 2),·····(X + 5)-age group respectively. The reason why the modes are, or are not, formed for respective years, may be considered to be due to the difference in the propagation from year to year.

c) The difference in length is caused in the difference of the course of the migration.

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*Contribution No. 12 of the Nankai Regional Fisheries Research Laboratory, published in 1953 in Contributions of Nankai Regional Fisheries Research Laboratory, No. 1.

Translator's note: The literature citations for the six papers in this collection have been combined and amplified and will be found at the end of this report.

This supposition means that the course of the migration differs annually, even in the case of the definite age group, and they do, or do not, migrate to the North Pacific Area.

5) If these sizes corresponding to the modes indicate the age groups respectively, there is a close relation between the present data and the growth-rate given by Aikawa and Kato.

6) Fig. 3 shows that the tendency of the variation of the curves of the length composition of the big-eyed tuna is quite similar to that of the albacore. Therefore, the hypotheses mentioned above are considered to be equally established as tenable for the big-eyed tuna.

7) These phenomena may be explained in more detail by further research, but it is thought to be sure that the phenomena will contain many important problems relevant to ecology or studies of the stocks of these fishes.

/end of English summary/

The size composition of pole-and-line-caught albacore landed at the Misaki Fish Market has already been reported upon by Uno (1936a, b), but nothing has been reported on the longline catch. The present paper is a report of measurements by the authors of albacore and bigeye tuna taken on longlines in the North Pacific fishing grounds in the autumn and winter.

1. Materials

The data were collected in two periods, the first from November 1948 to March 1949 and the second from October 1949 to March 1950. The numbers of vessels covered and the numbers of fish measured by months are shown in table 1.

When the operations of a vessel have extended into two months, they have been classified under the month in which the majority of the fish were taken, as based on their reports of their fishing. The measurement taken was the so-called fork length, and the measurements were grouped by classes of 2 cm. in the case of the albacore and 4 cm. for bigeye. No definite rule was set up for the selection of vessels or of fish, but as many measurements were made as conditions permitted. The North Pacific fishing grounds referred to in this paper include the area north of 26°N. latitude between 130°E. and 170°W. longitude.

2. Size composition by species

A. Albacore, Thunnus germo (Lacépède)

In figure 1 the size compositions for the two periods referred to above, November 1948 to March 1949, and October 1949 to March 1950, are shown as percentages. As is clear from the figure, the size ranges in the landings are in very good agreement, both groups being principally composed of fish from 60 to 110 cm. in length. To

Table 1.--Number of ships and fish sampled by month

Year	Month	T. germo		P. mebachi	
		Ships	Fish	Ships	Fish
1948	11	5	131	-	-
	12	22	2,055	39	1,492
1949	1	26	10,454	29	1,337
	2	13	3,136	3	88
	3	6	2,454	7	462
Total		72	18,230	78	3,379
1949	10	14	1,673	16	1,170
	11	17	2,407	12	881
	12	21	3,204	21	1,151
1950	1	35	7,551	20	716
	2	23	4,190	19	610
	3	13	2,102	10	446
Total		123	21,127	98	4,974

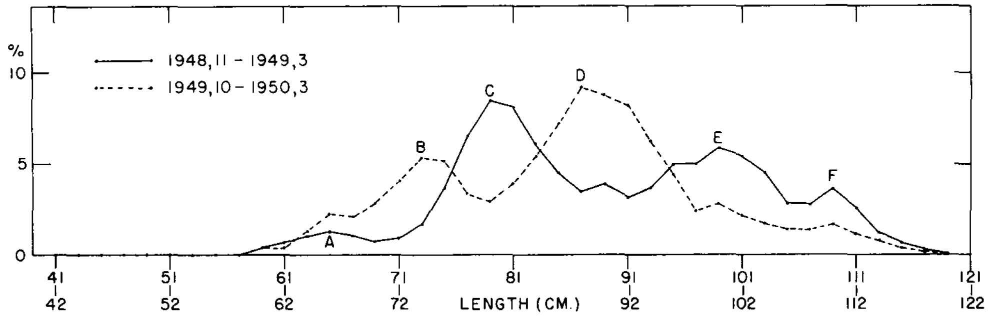

Figure 1.--Length composition of the albacore.

show the makeup of the smallest and largest size groups, in 1948-49 and 1949-50 the smallest class at 41 cm. included one fish in each of the two periods, the largest class of 119 cm. comprised two and four fish respectively. Kishinouye (1923) states that for this species, fish of 25 kg. are considered large, and in Japanese and Hawaiian waters fish of 45 kg. probably represent the maximum size. The aforementioned specimens 119 cm. in length are estimated to be about 35 kg. in weight and thus are not of the size which Kishinouye presumed to be the maximum.

Figure 2 shows the size composition of pole-and-line-caught albacore examined in the Misaki Fish Market by Uno (1936a) in May and June of 1935.

The composition is shown by the actual numbers of fish at 1 cm. intervals. If this is compared with the size composition of longline-caught fish in figure 1, a marked difference between the two can be detected. Whereas in figure 1 the aforementioned 60 to 110 cm. group is predominant, in figure 2 the fish between 70 and 90 cm. predominate. That is, the former is made up of a broad range of small, medium, and large sizes, whereas the latter is made up of medium and small fish and includes hardly any large ones. The causes of this difference can be thought to be (a) the difference in fishing method and (b) differences in fishing season and fishing ground. In the case of (a) little can be said because there are no data with which to make a direct comparison, but concerning (b) the following points of difference can be adduced. In longlining the fishing season is from October to March and the fishing grounds extend from waters adjacent to Honshū out to 170°W. longitude. On the other hand, the fish measured by Uno were taken during the season of May and June and within a range of about 250 miles at most from the coast of Honshū. Uda and Tokunaga (1937) have discussed the relationship between albacore fishing conditions and oceanographic conditions in this

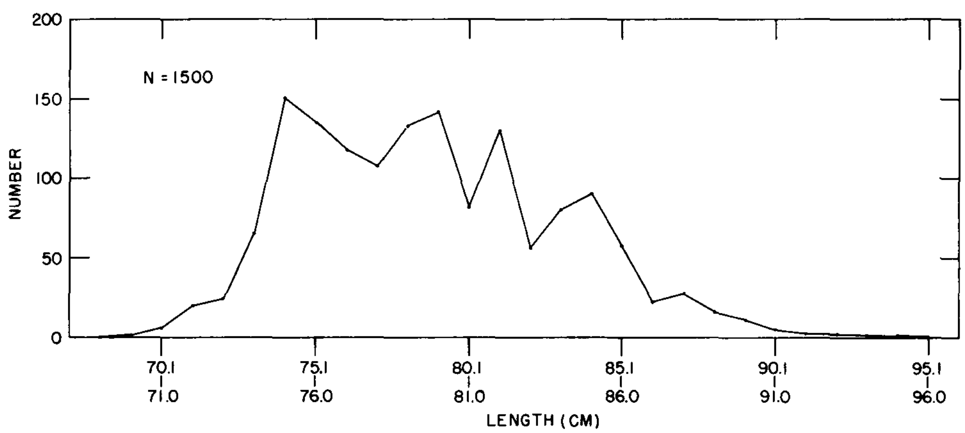

Figure 2.--Length composition of the albacore (after Uno 1936a).

area, and Uda has postulated the existence of an inshore population and an offshore population and further has hypothesized that the offshore population includes two migratory strains. He also reported that as one moves from the coastal waters offshore groups of small, medium, and large fish are found in that order, each of them forming a separate migratory population, and that these groups mingle in the vicinity of 40°N., 165°E. If we follow these hypotheses of Uda, the catch of the longline fishery clearly includes fish from both the inshore and offshore groups, while the catch of the pole-and-line fishery can be thought to be made up principally of fish from the inshore population. Consequently, if we think of the difference in size composition seen in figures 1 and 2 as a difference in the size composition of the inshore and offshore populations, we can consider this to tend to agree with the hypothesis of Uda and Tokunaga. However, there is still room left for examination of the question of whether or not this sort of difference in the size composition is due to a population difference. In investigating problems of this sort it will be extremely important to analyze the makeup of the fishing grounds and the seasonal and regional changes in size composition, but these are questions which must be left to the future.

When we attempt, using figure 1, to compare the size composition for the two periods 1948-49 and 1949-50, we can see a marked difference between the two. For 1948-49 it can be seen that the modes are centered at 65-66 cm. (A), 79-80 cm. (C), 99-100 cm. (E), and 109-110 cm. (F). In 1949-50, on the other hand, we can see an obscure mode corresponding to (A), clear modes centered at 73-74 cm. (B), between (A) and (C), and at 87-88 cm. (D), between (C) and (E), and another extremely obscure mode corresponding to (E) and (F). In other words, the outstanding apparent differences between the two are the complete discrepancy between the positions of (C) in the former and (B) and (D) in the latter and the fact that (E) and (F), which were clearly apparent in the former, have become extremely obscure in the latter. As causes for differences of this sort we can think of shortcomings in the method of collecting the data and of basic natural phenomena. Since there was no great difference in the method of collecting data throughout the two periods, this can hardly be thought to be a cause of the above described discrepancy. If they are considered to be based on natural phenomena, then the following three hypotheses can be advanced.

The first hypothesis is that of annual differences in growth. We will assume that a certain age group migrates into the same area at the same season. Modes (E) and (F) are certainly obscure but since they do appear in both years there is no problem. Now if we assume that the groups making up modes (A), (C), and (E) are respectively X age, X + 1 age, and X + 2 age, the group making up mode (B) can be thought of either as fish of X age which have grown remarkably well in comparison with those of the previous year or as fish of X + 1 age which have grown remarkably poorly. In the same manner the group making up mode (D) must be thought of as either well grown fish of X + 1 age or as poorly grown fish of X + 2 age.

In fishes of ponds and lakes, marked differences in growth from year to year because of environmental factors and because of the amount of reproduction of the fish can be seen, and it is known that in the case of the pond smelt there is good growth and bad growth in alternate years. Assuming that we can detect in the albacore distributed broadly throughout the open sea exactly the same sort of phenomenon we find in such limited water areas, it is thought that this phenomenon may give an important indication for the investigation of the ecology and stocks of this fish.

The second hypothesis is that of annual differences in recruitment. On the basis of this hypothesis, the groups making up the modes (A), (B), (C), (D), (E), and (F) in the figure are thought to belong respectively to ages X, X + 1, X + 2, and so forth, and the fact that fish of the same age group may form a mode in one year and not form one in another is explained as being based on the fact that recruitment fluctuates markedly from year to year. Starting out from this line of thought, it is possible to consider in the case of modes (B), (C), (D), and (E) that from the remarkable differences apparent between the two periods it is to be assumed that the alternation of a year of successful reproduction and a year of unsuccessful reproduction was continued through two cycles. Furthermore, if we consider the modes (A), (B), (C), (D), (E), and (F) each as a separate age group and get their growth rate, we come out in approximate agreement with the estimates of Aikawa and Kato (1938). If this second hypothesis is to stand, we must in the future place the emphasis in our studies of the stocks on finding the period of cyclical changes in reproduction and in investigating their causes. Furthermore, length measurements of the catch may provide a direct clue to finding the growth rate.

The third hypothesis is that there is no great difference in recruitment from year to year, but that the year groups X, X + 1, X + 2, and so forth change their pattern of migration markedly from year to year, sometimes appearing in the North Pacific fishing grounds and sometimes not. However, there is no way of getting evidence to support this theory without carrying on investigations over a wider area of the ocean. It cannot be said at present whether the sudden decline of the large fish above the group making up mode (F) is due to natural attrition or to their making a complete change in their range of occurrence and moving from this sea area into another.

B. Bigeye Tuna, Parathunnus mebachi (Kishinouye)

Figure 3 shows phenomena very similar to those seen in the case of the albacore. For the period from November 1948 to March 1949 the composition shows clear modes centered at 85-88 cm., 121-124 cm., and 149-152 cm. Another obscure mode can be seen centered at 73-76 cm. In contrast to this, in the period from October 1949 to March 1950 the composition shows highly predominant modes centered at 93-96 cm. and 137-140 cm., with an obscure mode centered at 105-108 cm. The size compositions in the two periods show marked discrepancies in the position at which the modes appear and the form in which they appear. Accordingly, as causes for this sort of difference, we can consider the establishment of exactly the same sort of hypotheses that were brought forward in the case of the albacore.

At the present time we do not know whether the above-described phenomena, which are shared by the albacore and the bigeye, are due to any one of the three hypotheses just set forth, or to some completely different reason, or to a complex mixture of these. We believe that these questions will be gradually clarified in the future, and assume that they will have an extremely important significance for the investigation of tuna resources.

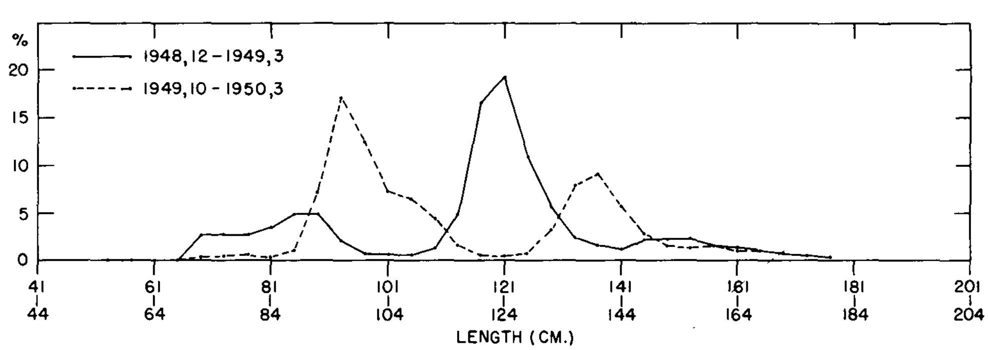

Figure 3.--Length composition of the bigeye tuna.

Albacore Studies. I. Size Composition of Albacore Taken in the North Pacific During the Period of Southward Movement*

By

Akira Suda
Nankai Regional Fisheries Research Laboratory

/English title and summary/

Studies on the Albacore - I. Size Composition in the North Pacific Ground Between the Period of its Southward Migration

The distribution of the Albacore in the North Western Pacific extends from the Equator area to near the Polar Front Area However the fish distributes in such vast area, the fishing grounds are limited almost in the seas between the Subtropical Convergence and the Polar Front, namely in the waters of the North Pacific Current and the north part of the Kuroshio Current.

This fish is caught mainly by the rod and line with live baits in the season between the Spring and Summer, but it is caught mainly by the long-line in the season between the late Autumn and the early Spring. The fishing grounds in the former season moves from south to north, and on the contrary, the grounds moves southward from nearly 40°N. to as far as 27°-28°N. in the latter, and then seem to turn back.

The present author attempted the analysis of the size composition of the fishes which are caught in the latter season, and obtained the result as following.

1) Six different size groups appear in every year. When these six groups are hypothesized to correspond to each other in every year, the modal lengths of the five seasons between 1948 and 1952 are placed with nearly the same intervals as ca. 57cm, 67cm, 78cm, 89cm, 100cm, 110cm.

2) Two groups with the modal lengths 78cm and 98cm, are far more abundant than the others. So far the data obtained, it is clearly recognized that these two dominant groups appear alternately in every other, namely group with the modal length of 78cm are most abundant in the even number years and the other in the uneven number years.

/end of English summary/

Introduction

The distribution of albacore in the northwest Pacific extends over broad areas from the Equator to the Polar Front. However, mass occurrences are limited to the north side of the Subtropical Convergence, a part of the Kuroshio, and the area of the North Pacific Current. In recent years there has been a gradual increase in the landings of albacore in Japan from the southern hemisphere, but the greater part of the landings still come from these areas. The albacore fishing in these areas can be divided into two fishing seasons of different character. One is the pole-and-line fishing season for schools moving north from April to July, and the other is the longline fishing season for southward moving schools from November to April.

With regard to the size composition of the pole-and-line-caught albacore, we already have the reports of Uno (1936a, b). For the size composition of the longline-caught albacore there is the report of Nakamura, Yabuta, and Kamimura (1953), and the aim of the present paper is to take up where they left off and attempt to analyze the albacore size composition of longline catches from the above-mentioned sea areas over the 5-year period from 1948 to 1952. Consequently, pole-and-line-caught fish are completely excluded. From November on, the albacore longline fishing grounds move south from month to month. In March their southern margins reach 27°-28°N., the southward movement stops, and there is a transition to the period of northward migration. In order to limit the material summarized here to albacore of the southward migration, fish taken in March and thereafter are excluded. During this period, at least, little change can be detected from month to month in the positions of the modes in the size composition. Albacore taken in the waters to the west of the Izu and Ogasawara archipelagos have been excluded, and only albacore taken between 140°E. and 180° on the north side of the Subtropical Convergence have been considered in this study.

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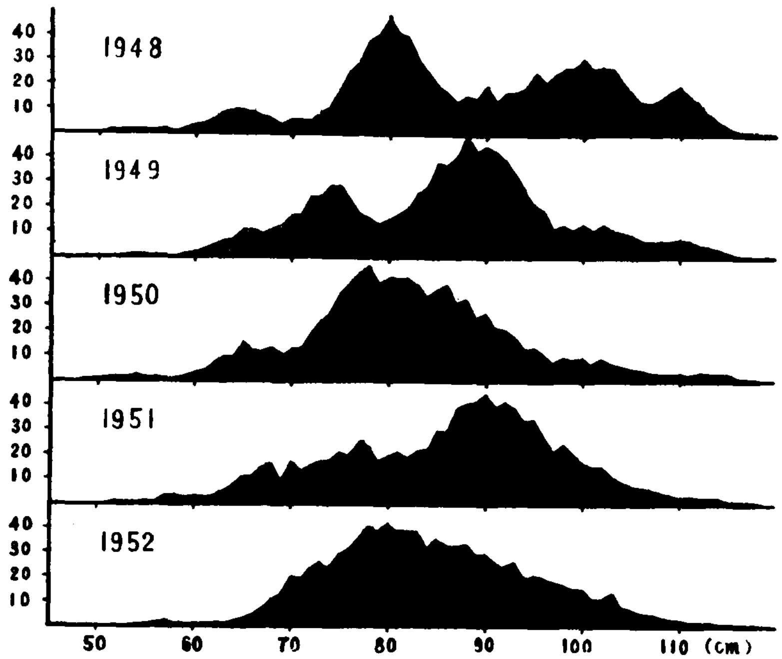

Figure 1.--Length frequency of the albacore caught in the northwestern Pacific during the longline season (indicated by permillage).

The data were gathered by the Nankai Regional Fisheries Research Laboratory[1/] by working on fish landed at markets during the period. From 1948 to 1951 measurements were taken of as many fish as possible from the maximum possible number of boats; in 1952 measurements were taken on a sampling ratio of 0.1 of the fish from 0.5 of the voyages.

Before entering upon the text of the paper, the author wishes to express his gratitude to Director Nakamura and Mr. Yabe for their assistance, to the various personnel of the High Seas Resources Section who collected the data, and to Miss Michiko Momota, who processed the data.

Body Lengths of the Schools of Albacore Migrating Southward in the North Pacific

Figure 1 shows by years from 1948[2/] to 1952 the length composition in permillages of albacore landed from this area. The length used is the fork length. The length range of albacore taken by longlines in these fishing grounds is very broad, extending from about 50 cm. to 120 cm. In the measurements taken over a period of 5 years the smallest specimen was 37 cm. and the largest 121 cm. in length. Fish longer than 120 cm. were extremely rare and in 5 years only 5 were encountered.

The length distribution curve is extremely complex, with either several modes appearing

1/ Measurements taken during this period were as follows:

Year	Location	Number of trips sampled	Number of fish measured
1948	Tokyo	66	15,801
1949	"	106	18,516
1950	"	88	15,131
1951	"	58	16,777
1952	Tokyo, Yaizu	214	40,489

2/ The albacore longline fishing season extends each year from November to March of the following year (this report covers to February). The "year 1948" as used in this report means from November 1948 to March (for the purposes of this report to February) of 1949, and so on for the other years.

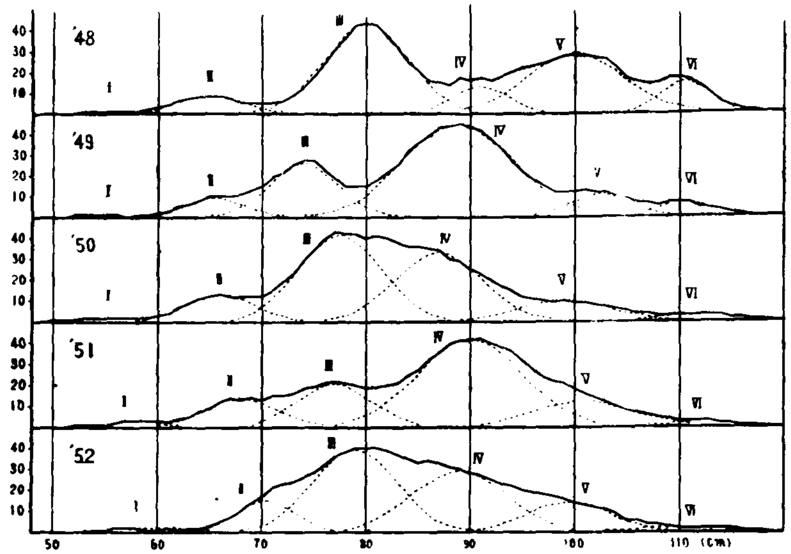

Figure 2.--Length frequency of the albacore caught in the northwestern Pacific during the longline season (indicated by permillage). Solid line - length frequency curve indicated by lapped mean between three length classes. Broken line - length groups estimated by fitting normal curves.

at the same time or appearing to fuse together. Consequently, this is interpreted as the appearance at the same time of a number of different size groups. In figure 2 the solid line shows in permillages the results of smoothing the actual measured values with a moving average of 3 cm. The dotted lines are the result of an attempt to analyze this into a number of normal distributions.[3] According to this, for each year we can detect six size groups. In view of the fact that there is general correspondence among the positions of each size group, we set up the assumption that "six size groups which correspond from year to year appear in the albacore captured in the North Pacific. Some degree of variation in their modal length from year to year can be seen." On the basis of this assumption we shall try to bring out some of the characteristics of these size groups.

Results - I. Positional Relationships of Each Size Group

Table 1 shows the modal lengths for each age group, the groups having been designated as I to VI from the smallest fish to the largest. Tables 2 and 3 show respectively the direct difference of the modal length[4] and the lagged difference [5]. The following statements can be made on the basis of tables 1 to 3:

1. The average modal lengths of each group for the 5 years from 1948 to 1952 are approximately 57 cm. for group I, 67 cm. for group II, 78 cm. for group III, 89 cm. for group IV, 100 cm. for group V, and 111 cm. for group VI.

3/ Normal distributions with various average sizes, standard deviations, and total numbers have been set up, and those whose sums best fit the results of the treatment with a moving average have been taken up. The goodness of the fit for each year has been examined by the chi-square test. With the length classes 2 centimeters, and decreasing the degrees of freedom each year (3 X 6 + 1), each case gave a fit of $P > 0.9$. (1 degree of freedom for each determination of the number of normal distributions, and since 6 normal distributions were fitted each year and for each of them 3 parameters were determined, the degrees of freedom were decreased by 18 or a total of 19.)

4/ Difference in modal length for group N and group N + 1 in the same year.

5/ Difference in modal length between group N for a given year and group N + 1 of the following year.

Table 1.--Modal length of each length group

Year	Group No. I	II	III	IV	V	VI
1948	56.5	65.0	80.0	91.0	100.0	110.5 cm
1949	54.0	65.5	74.0	88.8	102.5	110.5
1950	55.0	66.0	77.5	87.0	99.0	112.0
1951	58.0	68.0	77.0	90.0	100.6	112.5
1952	59.0	70.5	79.0	89.0	99.5	110.5
M ± σ	56.5 ± 1.56	67.0 ± 2.02	77.5 ± 2.05	89.2 ± 1.33	100.3 ± 1.21	111.2 ± 0.87

Table 2.--Direct difference between successive length groups

Year	Group No. II - I	III - II	IV - III	V - IV	VI - V
1948	8.5	15.0	9.0	9.0	10.5 cm
1949	11.5	8.5	14.8	13.7	8.0
1950	11.0	11.5	9.5	12.0	13.0
1951	10.0	9.0	13.0	10.6	11.9
1952	11.5	8.5	10.0	10.5	11.0
M ± σ	10.50 ± 1.14	10.50 ± 2.51	11.26 ± 2.25	11.10 ± 1.59	10.80 ± 1.74

Table 3.--Lagged difference between successive length groups

Year	Group No. II - I n+1 n	III - II n+1 n	IV - III n+1 n	V - IV n+1 n	VI - V n+1 n
1948 (n)-49 (n+1)	9.0	9.0	8.8	11.5	10.5 cm
1949 (n)-50 (n+1)	12.0	12.0	13.0	10.2	10.5
1950 (n)-51 (n+1)	13.0	11.0	12.5	13.6	13.5
1951 (n)-52 (n+1)	12.5	11.0	12.0	9.5	9.9
M ± σ	11.63 ± 1.56	10.75 ± 1.09	11.56 ± 1.64	11.20 ± 1.56	11.10 ± 1.41

2. No conspicuous difference can be seen between the 5-year average values for the two differences and the standard deviation.

3. The intervals for each group for both the direct difference and the lagged difference are 10.5 cm. to 11.5 cm., and the several size groups are spaced at intervals of a little more than 10 cm. The intervals are approximately the same for each size group regardless of whether it consists of large or small fish.

The ranges of body length in each group are as shown in table 4a, b, and c. The breadth of distribution of all groups is rather large, and the two extremes overlap with the adjoining groups. For groups III to V the breadth of the distribution is far greater than the interval between modal lengths, being more than 20 cm. in most cases. However, there is hardly any overlapping between the length ranges which include 80 percent of each group. The average values from 1948 to 1952 of the boundaries of the ranges within which the various length groups are dominant are as follows: groups I-II, 59.8 cm.; groups II-III, 70.7 cm.; groups III-IV, 83.3 cm.; groups IV-V, 96.3 cm.; groups V-VI, 107.7 cm.

Table 4.--Some characteristics of the ranges of the six length groups

a. Extreme ranges of each group

Year	Group No.					
	I	II	III	IV	V	VI
1948	53-60	58-72	69-91	85- 97	88-112	105-116
1949	52-56	59-72	65-83	74-104	96-109	105-116
1950	51-59	58-74	67-88	74- 98	89-109	106-118
1951	54-62	60-76	69-85	77-103	91-111	107-118
1952	53-65	64-77	68-90	78-100	90-109	103-118

b. Range in which each group is dominant

Year	Group No.					
	I	II	III	IV	V	VI
1948	< 58.5	58.5-70.0	70.0-88.0	88.0-93.0	93.0-107.5	107.5 <
1949	< 57.5	57.5-68.0	68.0-79.0	79.0-99.5	99.5-107.0	107.0 <
1950	< 58.5	58.5-70.0	70.0-83.5	83.5-94.5	94.5-107.0	107.0 <
1951	< 60.5	60.5-72.0	72.0-81.5	81.5-98.5	98.5-110.0	110.0 <
1952	< 64.0	64.0-73.5	73.5-84.5	84.5-96.0	96.0-107.0	107.0 <

c. Range of $m \pm 1.28\sigma$ of each group (in this range 80 percent of the individuals of each group are contained)

Year	Group No.					
	I	II	III	IV	V	VI
1948	53.5-59.5	61.0-69.0	75.0-85.0	87.5-94.5	94.0-106.0	109.0-110.5
1949	53.0-55.0	63.0-68.0	71.0-77.0	83.5-94.0	100.0-105.0	108.5-112.5
1950	53.0-57.0	63.0-69.0	73.5-81.5	83.0-91.0	94.5-103.5	109.0-115.0
1951	56.0-60.0	65.0-71.0	74.0-80.0	85.0-95.0	96.0-105.0	110.0-115.0
1952	54.0-64.0	67.0-74.0	74.0-84.0	83.0-95.0	94.5-104.5	104.0-117.0

Results - II. Quantitative Relationships Among the Length Groups

With regard to the quantitative occurrence of each length group, the two central groups of the six, that is group III and group IV, are most outstanding. These two groups form a peak with the occurrences declining as one goes toward both ends of the distribution. The permillage of each group is shown in table 5. For every year, group III and group IV make up more than half. On the average, for the 5-year period group III and group IV together predominate overwhelmingly, forming 70 percent of the whole.

Table 5.--Relative abundance of the six length groups (by permillage)

Year	Group No.					
	I	II	III	IV	V	VI
1948	8	64	429	85	329	86
1949	5	65	214	593	77	46
1950	14	106	405	339	109	27
1951	17	118	180	527	139	20
1952	20	102	401	318	136	24
M	13.8	91.0	325.8	372.4	158.0	40.6

When we look at the proportion occupied by each size group from year to year, we see various different trends. For example, the relative proportion of groups I and II increases from year to year. Group VI on the other hand decreases. Groups III and IV and also V do not show any clear tendency to increase or decrease. Consequently we can see that of the six size groups which appear in this fishing ground the three near the middle do not present any clear tendency to increase or decrease but the smaller size groups show a relative increase while the groups of larger size fish show a relative decrease.

Of the three size groups nearest the middle, in group III and group IV another conspicuous annual change can be seen. This is the alternate year cycle appearing in the quantity of occurrence of these two groups. Group III occurs conspicuously in even-numbered years and is scarce in odd-numbered years. Group IV appears in small numbers in even-numbered years and is outstanding in odd-numbered years. Consequently they alternate every year in predominance.

Discussion of the Results

Basically, in analyzing the size composition into a number of groups with different characteristics, we should take as a standard the characters which they actually possess. If we take as a basis only the form of the size distribution and thus separate them, it is thought that some degree of subjectivity and error will be introduced. Therefore the validity of the size groups separated by this method should be examined by comparing for each character the results of the direct analysis of the size composition with actual phenomena. However, at the present stage we do not have data which would enable us to make such an examination for each character, and furthermore it is thought that of the various /possible/ characters there is the greatest possibility that the groups are based on age. Consequently in what follows we shall try to examine one or two points in terms of age groups.[6/]

a. In Japan, Uno (1936a, b) and Aikawa (1937) and Aikawa and Katō (1938) have studied the age of albacore by means of the vertebrae. The following is the comparison of their results with the spacing of the modal lengths.

a_1 Comparison with the results of Aikawa and Katō:

The absolute values of the differences can not be said to be large. A considerable difference in the trend can be seen. According to Aikawa and Katō's results, the interval between each age group and the next, with the exception of that between age group I and age group II, is 9 cm. Consequently, the five intervals between age groups I to VI are all about 2 cm. larger than the values shown by Aikawa and Katō.

Aikawa and Katō did not separate the size composition directly by the number of rings in the vertebrae, but they used the indirect method of finding

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6/ Differences in size of the fish depending on sex do not appear to participate in the formation of the size groups. Figure 3 shows the results of an examination of the sizes of fish by sex carried out on a research vessel in March 1953. It is unavoidably somewhat rough because it was not possible to carry out an investigation of age at the same time, but at any rate between 70 cm. and 100 cm. no marked difference can be seen between the modal lengths of males and females. Since the intervals between the six size groups are 10 cm. or more, it is not thought that these can be based on differences associated with sex.

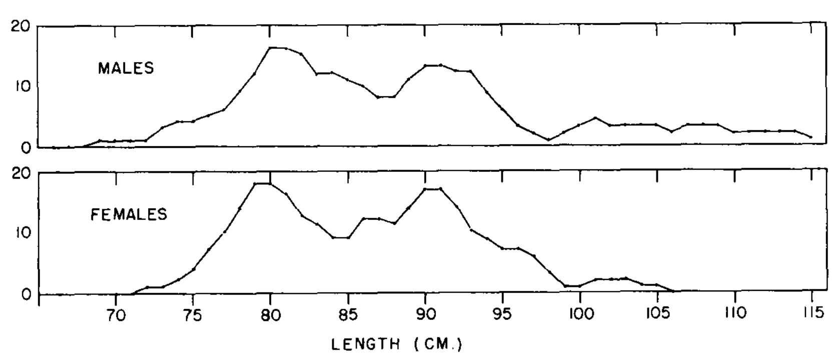

Figure 3.--Length frequencies of males and females.

from the radius of the centrum and the radii of the rings the calculated body length at the time when each ring was formed, so it appears that further examination of these results is necessary.

a_2 Comparison with the results of Uno:

Comparison with Uno's results also shows differences of 1 to 1.5 cm. However, if we take into consideration the great dispersion of the lagged difference (table 3) and the possibility that Uno's results were greatly influenced by annual variations due to the fact that they consisted of only a single value, it is thought that there is a possibility that the two sets of results are in agreement. A rejection test of the two separate results using the t-test was made, and for the interval between the 4th year and 5th year groups (II group and III group) a > 0.3 and for the interval between the 5th year and 6th year groups (III group and IV group) a > 0.6, so that it cannot be said that they do not coincide.[7]

[7] Uno's age group 4, age group 5, and age group 6 are thought to correspond respectively to group II, group III, and group IV.

b. According to tables 1 to 4, the modal lengths of the several groups are located at approximately equal intervals, showing that within this size range the growth of the albacore is in a straight line or follows a curve which is nearly a straight line. However, as already mentioned, in this sea area albacore longer then 120 cm. are very rarely taken. This is not limited only to this sea area, for in other sea areas also we find hardly any fish over 120 cm. in length. Consequently it is assumed that the maximum length which albacore reach is between 120 and 125 cm. For group VI the modal length is in the vicinity of 110 cm. and the upper limit of the size range is at 115-118 cm. Accordingly this means that the growth of albacore which are almost at the maximum size which they can reach proceeds in a straight line. Since the growth of most living organisms is logistic, results of this sort may indicate that it is unreasonable to postulate the various length groups as age groups.

On the other hand, some doubt also arises as to the assumption that the maximum length of albacore is between 120 and 125 cm. If we affirm that almost straight line growth is shown up to the position of the modal length of group VI, it means that the maximum length of albacore that we can anticipate must be much greater than 125 cm. However, on the basis of the data collected up to the present, it is thought that there is rather little room to establish a hypothesis that the length which albacore can reach is greater than 125 cm.

Table 6.--Relation between age and body-length

a. According to Aikawa and Katō

Age	0	1	2	3	4	5	6	7	8
Range of body-length	< 35	35 - 46	46 - 55	55 - 64	64 - 73	73 - 82	82 - 91	91 - 100	100 <

b. According to Uno

Year		1935			1936		
Age		4	5	6	4	5	6
Body-length	M	72.38	79.15	89.55	69.04	81.56	89.70
	S. D.	1.30	3.68	2.25	4.65	3.82	1.98

M and S. D. indicate mean value and standard deviation

c. It is necessary here to reconsider the fitting of the normal distributions. Naturally the numbers of occurrences at both ends of the distribution are few. Furthermore, in the older groups the scatter or dispersion of the lengths is great. Consequently, sampling error is great, especially in the older groups. Furthermore, the difficulty of estimating the modal lengths and the range of distribution of the body lengths is increased, and the length groups overlap each other so that they are difficult to separate. As a result, in the older groups the fitting of normal distributions to the length distribution in itself is unavoidably accompanied by inaccurate results. Actually, if we try taking the coefficient of correlation between the average lengths of group N of a certain year and group N + 1 of the following year8/, the older the age group the smaller the value we get. If we collate these facts with the circumstances set forth in paragraph b, we cannot help thinking that there is a possibility of error in the fitting of normal distributions to the older age groups.

In conclusion, according to paragraph a we cannot find any facts which would deny that at least in the case of the groups II-IV these length groups are age groups. The results can neither be said to agree nor to disagree but the absolute values of the differences are very small. Consequently it appears that there is no great obstacle for the present to treating them as age groups. According to paragraphs b and c, in the fitting of the six normal distributions, a possibility of error is indicated in the fitting to the advanced age groups. On the other hand, if there is no error in the fitting of the normal distributions, a doubt is cast upon the assumption that the six size groups are age groups. With this sort of results, it is thought that if the size groups postulated for the albacore captured by longline in the North Pacific Ocean are handled as five groups consisting of groups I to IV and an advanced age group above that, there is no obstacle to considering them as age groups. Figure 4 shows the size composition which appeared in figure 2 as the 5 length groups, I, II, III, IV and the advanced age group.

8/ The coefficients of correlation are as follows:

Group I-II	Group II-III	Group III-IV	Group IV-V	Group V-VI
+ 0.63	+ 0.87	+ 0.64	+ 0.40	- 0.01

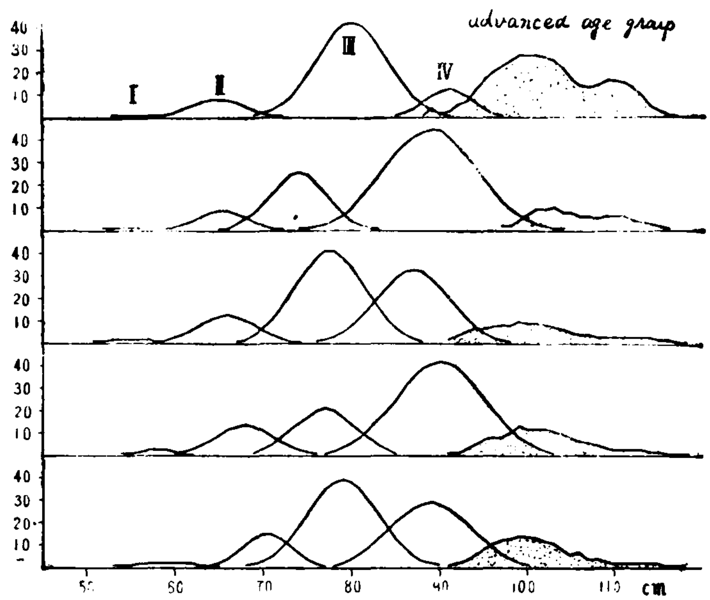

Figure 4.--Length groups of the albacore caught in the northwestern Pacific during the longline season.

Summary

The albacore longline fishing grounds which are formed in the North Pacific Ocean every year in November continue moving southward until March of the next year. The author has attempted to analyze the size composition of albacore landed from these fishing grounds by fitting normal distributions to the size composition. The results are shown in figure 2. These may be summarized as follows:

1. Six size groups appear each year. If we postulate that there are mutual correspondences among the six groups, the positions of the modes are approximately 57 cm., 67 cm., 78 cm., 89 cm., 100 cm., and 111 cm., with approximately equal intervals between the size groups.

2. The size groups which appear in the greatest numbers are those which have their modal length in the vicinity of 78 cm. and 89 cm., these two groups alternating in predominance every other year.

Through an examination of these results the following may be said:

1. A comparison was made with the results of age determinations made by Uno, and for groups II-IV it can neither be denied nor affirmed that there is agreement between the two sets of results. However, the absolute values of the discrepancies are very small.

2. It is pointed out that there is a possibility that the separation of the advanced age group is erroneous. Consequently, it is thought that if the division into groups of the albacore taken by longlines in the North Pacific is carried out as shown in figure 4, there is no great obstacle to handling them as age groups.

Albacore Studies. II. Size Composition of the Albacore Taken in the North Pacific During the Period of Northward Movement*

By

Akira Suda
Nankai Regional Fisheries Research Laboratory

/English title and summary/

Studies on the Albacore - II. Size Composition in the North Pacific Ground during the Period of it's Northward Migration

The area of the Kuroshio current or the North Pacific current is known as the quite excellent fishing ground of the Albacore. Albacore in this ground migrates southward during Autumn and early Spring, and is mainly caught by long-line. From Spring to Summer it migrates northward and is caught by rod and line with live bait. As to the former catch the author already reported it's size-composition (Suda 1954a). In the present, the author reports the analysis of the size-composition of the latter. The principal informations obtained by this work are as follows.

(1) Though the range of the size is confined within the limit between 50 to 100 cm during the seasons of 1951 and 1954, there are the remarkable annual fluctuations.

(2) The number of length-groups are not fixed by the seasons. 3 or 5 length-groups appear in each season from 1951 to 1954.

(3) The modal length of each length-group shows remarkable annual fluctuation. (Table 1)

(4) The relative abundance of each length-group is very unstable as shown in Table 2. In most cases, the most dominant length-group occupies the overwhelming proportion.

Such a size-composition of the northward migrating Albacore differs from that of southward migrating one as follows.

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(1) Such advanced age groups* as seen in the southward migrating fishes do not appear in these which migrate northward.

(2) Size-composition of the northward migrating ones shows the remarkable annual fluctuation, therefore it is able to say that it is much more unstable than that of the southward migrating.

(3) The dispersion of the length frequency of the northward migrating ones is much more small than that of the southward migrating ones.

Then differences between the two groups seen to be based on ecological differences of them other than the difference of fishing method. In spite of these differences, the author hypothesized that there will be some relations between these two groups on a basis that the body-length of the most dominant size-groups are less than 100 cm in both migrating groups.

*Age is not determined; larger than 90 cm. (Suda 1954a).

[end of English summary]

The albacore exploited by the longline fishery, which move southward in the autumn and winter between 140°E. and 180°, cease their southward movement each year around March north of the Subtropical Convergence in the vicinity of 28°N., and in April, while showing some signs of northward movement, they suddenly disappear. As if to take their place, the pole-and-line albacore fishery begins, with its main fishing season from May to June. During this period the fishery moves northward between 140°E. and 160°E. The author has attempted to analyze the size composition of these northward-moving albacore and also to compare it with the size composition of the southward-moving albacore which are taken on longlines (Suda 1954a). The data employed resulted from the studies of landings made by the Nankai Regional Fisheries Research Laboratory at the Tokyo and Yaizu fish markets1/.

Size of the Northward-moving Albacore

According to the data for the period of 1951 to 1954, the length range of the northward-moving albacore taken by pole and line is approximately 50-100 cm.2/ There were almost no specimens over 100 cm. long (solid line in fig. 1). However, within this range the lengths show conspicuous changes from year to year. These variations are particularly marked in the fish between 50 cm. and 70 cm. long, which in some years appear prominently and make up an important element in the albacore catch but in other years hardly appear at all. Fish in the 70 cm. to 100 cm. length range appear every year and are the most stabilized portion of the northward-moving albacore. It is noted that the upper limit of length coincides for all years at about 95-100 cm.

The broken line in figure 1 shows the results of fitting suitable normal distributions to the length frequency curve of the northward-moving albacore3/. Conspicuous variations are shown from year to year in the modal lengths of the several length groups, and it is difficult to determine which groups are analogous. In order to make this determination, the size composition by months for the period from November 1950 to July 1954 was obtained and an attempt was made to follow the transition of the modes. Figure 2 is the size composition by months of not only the northward-moving albacore but also including the southward-moving fish. In most cases the positions of the modes are not clear for the fish over 90 cm. long, so they have been omitted. As can be seen from figure 2, length data for the

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1/ Measurements were made as follows:

Year	Voyage sampling ratio	Voyages surveyed	Fish sampling ratio	Fish measured
1951	as many as possible	40	as many as possible	9,043
1952	0.25	80	0.20	54,893
1953	0.50	127	0.10	25,200
1954	1.00	105	0.10	13,230

2/ In June 1951 some fish 30-37 cm. long were measured, but there was only one large catch of albacore of this size. Their average length (139 fish measured) was 34.6 cm., with a standard deviation of 1.25 cm.

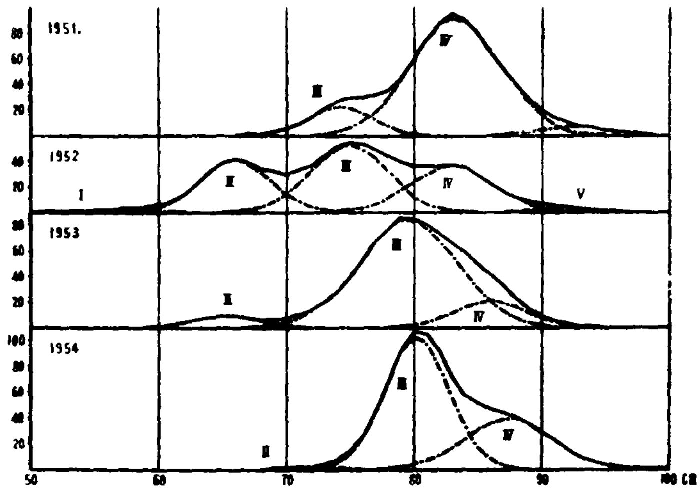

Figure 1.--Size composition of northward-moving albacore. The solid line represents the length frequency curve (shown by permillage), and the estimated length groups are shown by the broken line.

period from summer to autumn are completely lacking, and it is impossible to get a definite grasp of the process of growth. Several growth patterns can be postulated, but the assumption that "the series of modes to which the same number has been given shows the growth of a certain age group" gives a value for 1 year's growth that is nearest to the intervals between length groups. This hypothesis is thought to be the most adequate, provided that adjacent length groups are considered to be 1 year apart in age.4/ In this case, the growth of the albacore is not uniform throughout the year, and the rate of growth from summer to autumn turns out to be markedly lower. However, it cannot be denied that there is a possibility that a certain age group which has grown as indicated by a certain numbered modal series may in the following longline season (November-December) follow the growth shown by the mode with the next lower number. There is need of some method for ascertaining this. In this case, 1 year's growth would always be considerably greater than the interval between length groups, in fact, it would be nearer to twice that interval. Consequently, there would be very little possibility of adjacent length groups being age groups 1 year apart. If we postulate that growth takes place as indicated by following the series of modes to which the same

3/ For the method see my "Size composition of the albacore taken in the North Pacific during the period of southward movement," Bull. Jap. Soc. Sci. Fish. 20(6), 1954. The results of chi-square tests of the fitting of normal distributions to the length frequency curve for northward-moving albacore are as follows:

Season	Degrees of freedom available	Degrees of freedom lost	Degrees of freedom left	Chi-square
1951	13	10	3	27.90
1952	19	16	3	128.47
1953	14	10	4	30.90
1954	11	10	1	28.91

4/ See my paper previously cited. From the results of separating a number of length groups by the fitting of normal distributions on the length frequency curve for longline-caught fish, it appears that there is no obstacle to considering adjacent length groups as having a 1-year age difference.

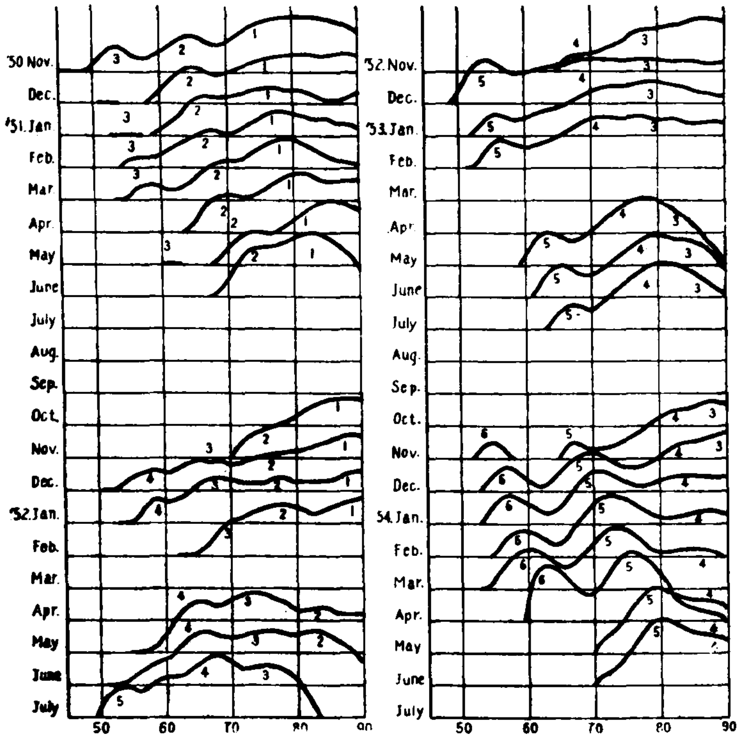

Figure 2.--Size frequency of the albacore caught on the North Pacific ground, by months (northward- and southward-moving albacore combined). The series of figures represents the transition of the modes. The ordinate represents the frequency in logarithms.

number has been attached in figure 2, and make the various length groups correspond as shown below, each vertical column can be considered as representing a single age group.

1951 2 1
1952 5 4 3 2
1953 5 4 3
1954 6 5 4

I II III IV

The various groups are made to correspond in this way, and then they are numbered in order beginning with the smallest, Group I, Group II, etc. (Group V, which has a modal length over 90 cm., is not shown in figure 2.) According to figure 2, these length groups correspond respectively to Group I, Group II, . . . Group V of the southward-moving albacore which are taken on longlines from autumn of one year through into the next year. Table 1 shows the modal length of each length group, and table 2 the proportion of each length group.

Table 1.--Modal length of each length group

Season	I	II	III	IV	V
1951			74.2	83.3	92.5
1952	55.5	66.0	74.9	83.8	91.5
1953		65.4	79.5	86.0	
1954		72.0	80.2	87.3	
M ± S. D.	55.5	67.8 ± 2.98	77.2 ± 2.67	85.1 ± 1.63	92.0 ± 0.50

Table 2.--Proportion of each length group (shown by permillage)

Season	I	II	III	IV	V
1951			139	819	43
1952	14	283	393	294	14
1953		57	802	139	
1954		10	652	337	
M ± S. D.	3.5 ± 6.1	87.5 ± 114.9	496.5 ± 253.0	397.3 ± 254.3	14.3 ± 17.5

In the following paragraphs some characteristics of the length groups making up the northward-moving albacore will be examined:

(1) The length groups appearing in the northward-moving albacore number three to five, the number varying from year to year. The only length groups which appear consistently throughout the 4 years are Group III and Group IV. In terms of the proportion they occupy, all of the groups show wide variations from year to year, the average magnitudes being greater than 50 percent. The fluctuation is particularly conspicuous in Group II, which in some years is an important element and in others does not appear at all.

(2) The 4-year averages of the modal lengths of each group are respectively 55.5 cm., 68 cm., 77 cm., 85 cm., and 92 cm., but the fluctuations in the values from year to year are great, and the spread between the largest and the smallest extremes is as much as one-half the interval between length groups for all of the groups. The intervals between the several length groups, with the exception of groups I and II, are about 2 cm. smaller than in the case of the southward-moving albacore (Suda 1954a). The values of the modal lengths themselves are in approximate agreement with those of the southward-moving albacore. These facts seem to be ascribable in large part to the characteristics of the growth and also to the marked variations from year to year. The upper limit of the length range of the pole-and-line albacore coincides each year at 95-100 cm., but this position is sometimes the upper limit of Group IV and sometimes the upper limit of Group V. It is thought that this is determined rather mechanically and without relation to such things as the positions of the length groups and the range of the distribution, since it is believed that the upper limit of size of fish which can be taken in large numbers by pole-and-line fishing may be in this region. In this case, we must consider the possibility that only the comparatively small fish of Group V may appear in the catch.

(3) There is no consistent trend of predominance of any group throughout the 4 years. Cases of predominance of Group III are most numerous, but there are also examples of predominance of Group IV. In most cases the predominant group is overwhelmingly so, but there are also cases in which it does not rise greatly above the others. There are no signs of the alternation of dominant groups every other year, as seen in the southward-moving albacore.

When we consider, over a number of consecutive years, the length groups which make up the northward-moving albacore, it is difficult to detect any regularity or resemblances in the composition of the length groups from year to year, except for the fact that Groups III and IV appear every year. It is thought that there is a deep connection between these phenomena and the conspicuous fluctuations in the annual catch of the northward-moving albacore.5/

Comparison of the Size Compositions of the Southward-moving (Longline) Albacore and the Northward-moving (Pole-and-Line) Albacore

As stated in the preceding section, the size composition of the northward-moving albacore shows violent annual fluctuations. When it is compared with that of the southward-moving albacore, some conspicuous points of difference

5/ According to the data of the Statistics and Survey Division of the Ministry of Agriculture and Forestry, the albacore landings for the period of May to July of each year were as follows: 1951 - 1,876,000 kan /7,757.26 tons/, 1952 - 11,556,000 kan /47,784.06 tons/, 1953-8,428,000 kan /34,849.78 tons/, 1954-5,841,000 kan /24,152.54 tons/.

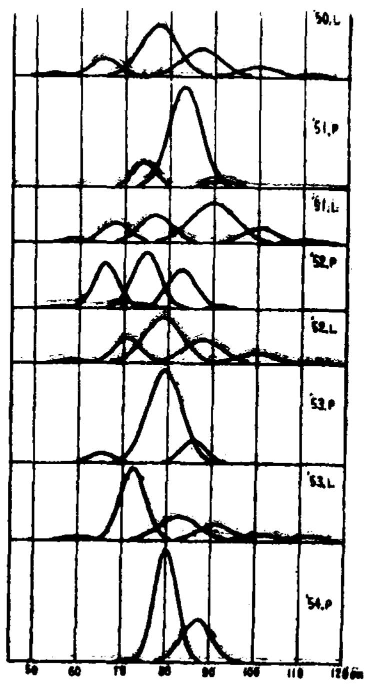

Figure 3.--Comparison of the size composition of the northward- and southward-moving albacore. The curves represent the length groups. Those marked "L" are the longline-caught (southward-moving) fish; those marked "P" are the northward-moving fish taken on pole and line.

are indicated. Figure 3 shows the size of the albacore taken at 140°E. to 160°E., divided according to the periods of northward and southward movement. According to this figure,

(1) The length range of the southward-moving albacore is 50 cm. - 120 cm., while that of the northward-moving fish is 50 cm. - 100 cm., or about 20 cm. narrower (see Suda 1954a). Consequently, Group VI does not appear at all in the northward-moving albacore, and even Group V barely appears in some years. The group of large fish of 100 cm. - 120 cm. (Group V and Group VI) which is seen in the southward-moving albacore is almost absent from the northward-moving fish.6/

(2) Even when Groups V and VI are omitted and only the fish under 100 cm. in length are considered, we see rather fundamental differences between the two. Whereas in the southward-moving albacore there are four length groups appearing repeatedly year after year, with a strong tendency for Group III and Group IV to increase and decrease alternately every other year, in the northward-moving albacore the number of length groups appearing varies randomly (2-4 groups)7/. The difference between the two can be expressed as "stability of the southward-moving albacore as contrasted with instability of the northward-moving albacore."

(3) The concentration of sizes is much more marked in the northward-moving fish. For the period of 1951-1954, with the exception of 1953, almost all of the catch was concentrated within a range of about 30 cm. In the southward-moving fish we see no single length group which makes up a majority of the whole, but in the northward-moving fish, in most years, we see groups which overwhelmingly predominate over the others.

When we consider the relationship between these two groups of albacore, it is thought that some of these points of difference may be of important significance in marking a separation between them. However, even though some points of separation may exist in the size composition of the two groups, the fact that in both the southward- and northward-moving albacore the

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6/ Uda and Tokunaga (1937), dealing with the size of the albacore taken in the winter longline fishery, have reported that those caught in areas closer to Japan are smaller and those taken farther off shore are larger. It is conceivable that the fact that the pole-and-line fishing grounds are limited to waters comparatively close to Japan may be the reason for the size difference between the fish taken while moving northward and those taken while they are moving southward. However, figure 3 shows a comparison of the sizes of these two groups of fish taken between 140°E. and 160°E. longitude, and the difference between them is still clear even when the area is limited in this way.

7/ If we do not limit the area considered to 140°E.-160°E., but broaden it to cover 140°E.-180°, the regularity which we see in the composition of the southward-moving albacore is even further heightened. That is, Group III and Group IV each increase on a 2-year cycle. Group III in even-numbered years and Group IV in odd-numbered years, with the result that the two groups alternate in predominance every other year. The fact that this rule breaks down and becomes less clear as the consideration is limited to areas closer to the Japanese coasts was reported at the Tokyo meeting of the Japanese Soceity of Scientific Fisheries in April 1954.

fish under 100 cm. long make up the overwhelming proportion is an outstanding point that they have in common. Furthermore, when we take into consideration the fact that, despite differences of season and fishing method, the fishing grounds for the two are formed in the same sea areas, it is probably correct to think that a considerable portion of the northward-moving albacore are a legacy from the southward-moving fish.

The tendency for pole-and-line fishing vessels to concentrate on certain particularly productive grounds is very strongly marked. Consequently, the tendency for the peculiarities of the catch of certain grounds to extend an influence over the whole is thought to be especially strong in the case of the pole-and-line catch. Also, as was remarked earlier, the upper limit of the size of fish that can be taken in large numbers by pole-and-line fishing is thought to be in the neighborhood of 100 cm.8/

We cannot deny that such peculiarities of the pole-and-line fishing method may be a cause of the difference in the size composition of the two groups. On the other hand, if we consider that around April and May large albacore of 90-120 cm. break off from the northward-moving group and cross the Subtropical Convergence to the southward (Suda 1954b), it also cannot be denied that the cause of the extraordinary scarcity of this large size-group in the catch of northward-moving albacore may be a decrease in the numbers of the group itself.9/ Furthermore, with regard to the point that the size composition of the northward-moving albacore shows highly irregular changes from year to year, we might also consider the fact that the pole-and-line fishing grounds are formed within the limits of a comparatively small sea area. However, if we take into consideration the point that the size composition of the southward-moving group captured within the same area is quite stabilized, it is believed to be important to think of this phenomenon in relation to seasonal changes in the population.

8/ There may be a possibility that large size-groups are included among the northward-moving albacore but that they are not captured.

9/ Fish of the 90-120 cm. size range are also seen among the albacore taken by long-line during the period of northward movement, however, they are far fewer than during the period of southward movement, and indeed vestigial.

Finally, it cannot be denied that in the differences of size composition seen between the northward- and southward-moving albacore there may be a factor of seasonal changes in the population itself, in addition to such causes as the peculiarities of the fishing method.

In conclusion, the author wishes to express his thanks to all of the staff members of the Nankai Regional Fisheries Research Laboratory, who gathered the data, to Miss Michiko Momota, who made the drawings, and to Director Nakamura and Section Chief Yabe, for their constant guidance.

Bigeye Studies. I. Size Composition of the Bigeye on the North Pacific Fishing Grounds (and Especially on the Alternate-year Cycle in the Size Composition)*

By

Tadao Kamimura and Misao Honma
Nankai Regional Fisheries Research Laboratory

/English title and summary/

Biology of the Big-Eyed Tuna, Parathunnus mebachi (Kishinouye) - I. Length Frequency of the Big-Eyed Tuna Caught in the North Pacific with Special Reference to Biennial Frequency

The present paper deals with analysis of length frequency of the big-eyed tuna, Parathunnus mebachi (Kishinouye), in the light of various hypotheses on the basis of data obtained from length determination conducted at several landing places and from information furnished by tuna fishing boats. Number of the samples used for the study were caught in several parts of the North Pacific, extending north of latitude 26°N., and between longitudes 130°E. and 165°W. in five successive seasons from October to March during a period of 1948 through 1953 (Table 1). For determination of the length, the distance from the tip of the snout to the median part of the caudal fork was used.

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1. The following has been revealed in comparison of the length frequency by fishing area and season.

A. As far as the samples caught in the same season are concerned, modes of the length frequency are, as a rule, found in an agreement with each other, almost regardless of fishing areas (Fig. 1).

B. When the modes formed in different seasons are compared, variance in their presentation is remarkable depending on fishing areas. However, it has been observed that characteristic features prevailing throughout the period under study indicate dominant modes, some formed by smaller fish caught in the western areas, and the other by larger fish in the east.

This can be interpreted in other words that the small sized fish were as abundant in the western part just as the large fish in the east (Fig. 2). Judging from the facts stated above, it is hardly possible to consider that the population of the big-eyed tuna migrating to the fishing grounds under discussion would consist of more than two groups belonging to entirely independent races.

C. In regard to annual discrepancy in the modes, attention has been drawn to the fact the modes tend to form with frequency occuring every other year (Fig. 3).

2. As probable causes of the annual fluctuation in the modes three hypotheses have previously been established by Nakamura, Kamimura and Yabuta 1):

(i) Difference in annual propagation;

(ii) Difference in annual growth rate;

(iii) Difference in annual course of migration.

In the examination of hypothesis (i), a series of assumption (A, B, C) have been introduced in connection with successive transformation of the modes which is likely involved in the course of growth. The assumption has been derived from length frequency by season (Fig. 4) as tabulated below:

Fishing Season

Assumption	1948	1949	1950	1951	1952
(A)	a_1A_1 →	A'b' →	B_2 →	C'' →	D_3
(B)	B_1 →	C' →	D_2		
(C)			a_2A_2 →	A''b'' →	B_3

As the result we have reached the conclusion that hypothesis (i) is more reliable than the others so far as progression of the modes in the way assumed above appears reasonable. Whereas, hypothesis (ii) can not be, at least, a decisive factor influencing the mode progression. Because it is difficult to draw rational interpretation of the phenomenon from this hypothesis. On the other hand, there is some room where hypothesis (iii) may be accepted as reasonable one, provided that the fish should take the same migratory route every two years.

3. On the basis of the above assumption, as it seems to be most feasible for the present study, ecological mechanism influencing the biennial frequency has been considered. In consequence, notable fluctuation taken place in abundance of age groups every second year is found to be likely a major factor supporting this particular phenomenon. At the same time, it has been pointed out that there is more or less disagreement between the modes formed in different seasons when examined in the light of age-group, which might likely be ascribable to the ecological mechanism as well.

4. For the purpose of proceeding the study further on the basis of the assumption (A, B, C), consideration has been paid on two factors: one being the stage from which the biennial frequency might have developed; the other, ecological mechanism involved therein. It is almost certain that the initial stage for the frequency would have occurred before the fish developed to age groups a_{1-3}. However, an alternate question that remains to be solved lies in whether the biennial frequency was resulted from:

a) causes accumulated in the course of growth;

b) or a cause which had a decisive effect on the fish at a certain stage of the development.

Judging from general circumstances for marine life, the latter cause (b) is more likely to take place than the former. In addition, there are sufficient reasons to assume that the initial factor would come in effect at an earlier stage of the fish under development. This assumption appears in an agreement with hypothesis (i). Even if the frequency would start once at an early developmental stage, however, the ecological mechanism accountable for the phenomenon must have been of complex rather than simple one. For this reason, when propagation of the fish is to be discussed as a component of the mechanism influencing the frequency, it is necessary to take into consideration such various environmental factors as to be supplied into different parts of the fishing regions, i.e., the northern hemisphere of the Pacific, its counterpart in the south, and the Indian Ocean.

5. So far as the present study goes, it is premature to decide whether or not the biennial frequency will continue to make an appearance in the future. But if it does, knowledge and data we obtained so far will certainly serve as an important suggestion from which advancement of study on the big-eyed tuna is expected.

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Nakamura, Kamimura, and Yabuta (1953) have already made a comparison of the length frequency composition of the catch of bigeye tuna from the North Pacific fishing grounds in the two periods of December 1948-March 1949 and October 1949-March 1950, and they have pointed out clearly discrepancies in the positions at which the modes appeared in these two seasons and in the manner of their appearance, the former having modes centered at 85-88 cm., 121-124 cm., and 149-152 cm., while the latter had conspicuous modes centered at 93-96 cm. and 137-140 cm., with another somewhat obscure mode centered at 105-108 cm. They have considered the following three possible causes of these discrepancies:

1) Differences from year to year in growth rates

2) Differences from year to year in recruitment

3) Differences from year to year in migrational phenomena

The present authors have made a comparison of the length measurement data for the three periods of October 1950-March 1951, October 1951-March 1952, and October 1952-March 1953, together with the older data mentioned above, and have found some extremely interesting phenomena, which they report here.

Collection of the data used in this study was all planned and executed by the High Seas Resources Section of the Nankai Regional Fisheries Research Laboratory. The term "North Pacific fishing ground" used in this paper means the area from 130°E. longitude to 165°W. longitude and north of 26°N. latitude. The authors herewith express their thanks to Dr. Nakamura, director of this laboratory, and to Dr. Yabe, chief of the High Seas Resources Section, for their guidance in this study.

Data

The measurements, taken with wooden calipers, are the shortest distance from the tip of the snout to the bottom of the fork of the tail. Measurements were read to the nearest centimeter, units below 1 cm. being dropped. In this study the data were arranged in 4 cm. groups. As far as sampling is concerned, the first unit of selection was the vessel and the second unit of selection was the fish. The percentage of selection at the first level did not follow any particular standard, the greatest number of boats possible under the circumstances being sampled. At the second unit of selection the original objective was to measure all fish, but where this was not possible the percentage of selection was modified to suit the circumstances.

Table 1 shows the numbers of fish measured by month and area:

I. Length Composition

Figure 1 shows the length composition by years* and by sea area. The most striking features of this figure are the appearance in each year of what clearly can be considered modes, and the fact that a tendency can be detected for the positions at which the modes appear to coincide generally in the different sea areas. The positions of the modes were: in 1948, 69-80 cm., 81-96 cm., 113-132 cm., and 145-164 cm.; in 1949, 89-100 cm., 101-116 cm., and 132-148 cm.; in 1950, 85-100 cm., 109-128 cm., and 141-164 cm.; in 1951, 89-104 cm., 105-124 cm., and 129-152 cm.; and in 1952, 89-104 cm., 113-136 cm., and 141-160 cm. As for

*Hereafter the periods of measurement will be referred to as "years".

Table 1.--Number of ships and fish sampled by month and by area. Figures enclosed in parentheses show the number of ships

*: No data available.

1948-'49 (1948 season)

Year and month		130° to 140° E.	140° to 150° E.	150° to 165° E.	165° to 180° E.	East of 180° E.	Total	Landing place
1948	12	-*	234(9)	951(25)	307(5)	-	1,492(39)	
1949	1	-	282(11)	588(11)	467(7)	-	1,337(29)	Tokyo
	2	-	88(3)	-	-	-	88(3)	
	3	-	15(2)	90(2)	357(3)	-	462(7)	
Total		-	619(25)	1,629(38)	1,131(15)	-	3,379(78)	

1949-'50 (1949 season)

Year and month		130° to 140° E.	140° to 150° E.	150° to 165° E.	165° to 180° E.	East of 180° E.	Total	Landing place
1949	10	-	-	901(11)	269(5)	-	1,170(16)	
	11	-	237(1)	198(5)	250(5)	196(1)	881(12)	
	12	-	537(11)	-	614(10)	-	1,151(21)	Tokyo
1950	1	-	365(8)	17(1)	334(11)	-	716(20)	
	2	-	278(11)	36(2)	227(5)	69(1)	610(19)	
	3	-	190(5)	-	156(3)	100(2)	446(10)	
Total		-	1,607(36)	1,152(19)	1,850(39)	365(4)	4,974(98)	

1950-'51 (1950 season)

Year and month		130° to 140° E.	140° to 150° E.	150° to 165° E.	165° to 180° E.	East of 180° E.	Total	Landing place
1950	10	-	42(1)	1,052(6)	65(1)	299(2)	1,458(10)	
	11	58(1)	809(8)	3,597(17)	-	72(1)	4,536(27)	
	12	-	1,122(7)	370(3)	450(2)	-	1,942(12)	Tokyo
1951	1	-	907(12)	260(5)	624(3)	-	1,791(20)	
	2	308(3)	1,285(22)	234(4)	252(2)	-	2,079(31)	
	3	230(3)	636(11)	-	-	-	866(14)	
Total		596(7)	4,801(61)	5,513(35)	1,391(8)	371(3)	12,672(114)	

Table 1.--Number of ships and fish sampled by month and by area. Figures enclosed in parentheses show the number of ships (cont'd)

1951-'52 (1951 season)

Year and month		130° to 140° E.	140° to 150° E.	150° to 165° E.	165° to 180° E.	East of 180° E.	Total	Landing place
1951	10	-	-	237(3)	-	-	237(3)	
	11	-	-	1,794(13)	-	-	1,794(13)	Tokyo
	12	-	161(4)	1,005(8)	106(2)	-	1,272(14)	Yaizu
1952	1	309(4)	966(21)	412(10)	919(7)	-	2,606(42)	
	2	116(3)	128(4)	107(2)	127(1)		478(10)	
	3	-	-	-	270(1)	-	270(1)	
Total		425(7)	1,255(29)	3,555(36)	1,422(11)	-	6,657(83)	

1952-'53 (1952 season)

Year and month		130° to 140° E.	140° to 150° E.	150° to 165° E.	165° to 180° E.	East of 180° E.	Total	Landing place
1952	10	40(2)	-	2,252(14)	1,392(7)	-	3,684(23)	
	11	306(36)	-	4,742(29)	314(3)	-	5,362(68)	Tokyo
	12	2,156(47)	68(6)	1,491(17)	500(5)	-	4,215(75)	Yaizu
1953	1	1,832(32)	1,078(25)	832(24)	904(10)	1,294(6)	5,940(97)	Katsuura
	2	1,162(26)	416(12)	536(12)	311(5)	731(6)	3,156(61)	
	3	373(15)	-	-	-	-	373(15)	
Total		5,869(158)	1,562(43)	9,853(96)	3,421(30)	2,025(12)	22,730(339)	

the manner in which these modes appear, it is clear from the figure that this differs markedly from area to area. If we follow individual modes through the various sea areas, we can recognize various degrees from clear existence to almost no indication of existence. This sort of variation arises from differences among the sea areas in the relative abundance of large and small fish.

In order to compare differences of this sort, figure 2 has been prepared, showing the yearly length composition by sea areas. According to the figure, the modes made up of groups of smaller fish predominate in the more westerly areas, while the modes made up of larger fish are more predominant in the easterly areas. This sort of relationship is even more clearly recognizable when the data are separated by areas and by years. In other words, the proportion of the smaller size groups is greater in the more western sea areas, and that of the larger size groups is greater in the more eastern sea areas.

Cases can also be seen in which there are slight displacements in the positions of the modes as between sea areas. To cite conspicuous examples of this sort in figure 1, there are the modes at 109-128 cm. in 1950, 89-104 cm. and 129-152 cm. in 1951, and 113-136 cm. in 1952. In particular, for the mode at 113-136 cm. in 1952 there is a pronounced displacement as between the area of 150°-165°E. and the area east of 180°. If we examine this situation in view of the monthly distribution of the measurements as shown in table 1, we see that the measurements for the former were taken mostly in the first half of the measuring period, whereas the measurements for the latter were taken entirely within the last half of the period. It is presumed that this discrepancy in the time of measurement is part of the reason for the displacement of the mode. However, a rather

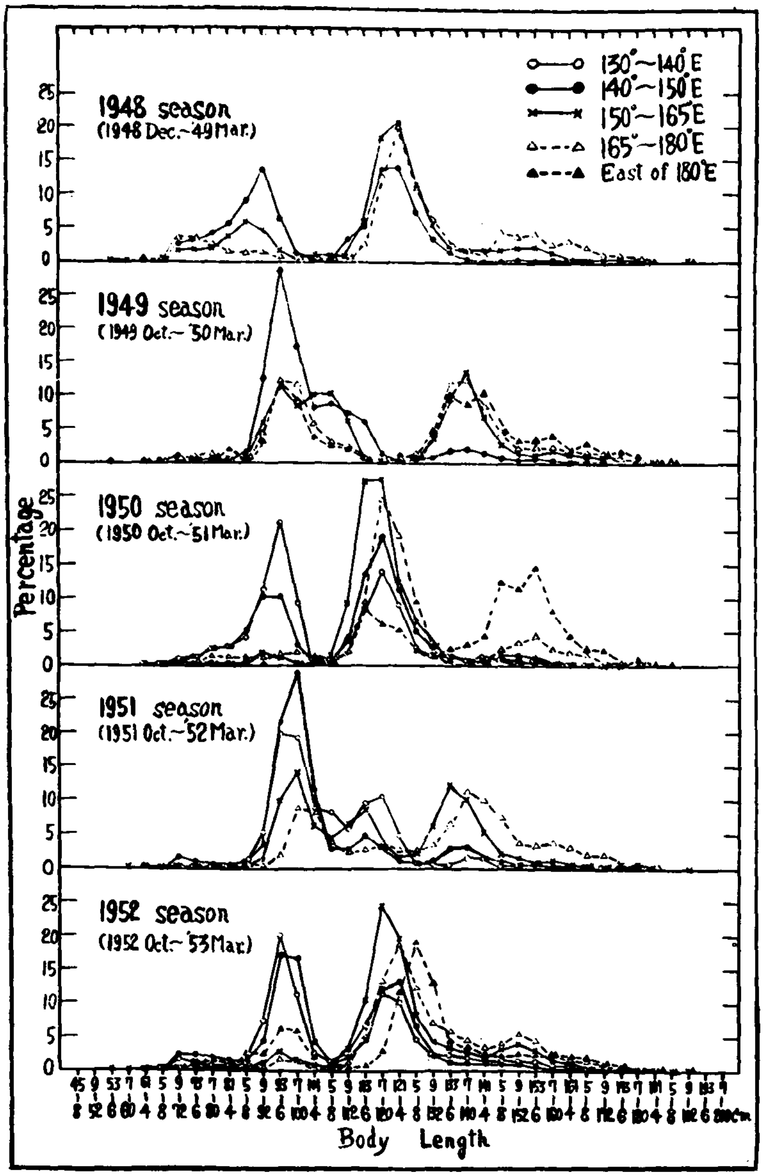


Figure 1.--Length frequency by fishing season.

pronounced displacement can be seen in the same mode as between the area of 140°-150°E. and the area east of 180°, and here there was almost no difference in the period at which the measurements were taken. Looking at it in this way, it is not possible to ascribe all the displacements of the modes for the different sea areas to differences in the periods at which the measurements were taken. If we consider the four examples of displacement of the modes in different sea areas already cited above, we can see that in general there is a tendency for the mode to be displaced to the right in the areas east of 165°E. and to the left in the areas west of that longitude. This phenomenon is probably worthy of note in that it suggests the existence of minute differences in the modes depending on the sea area. However, the displacements of this type are extremely small by comparison with those between the modes in different years, as will be set forth next.

Figure 3 shows the length composition by years, the even-numbered years being represented by solid lines and the odd-numbered years by broken lines. As is clear from the figure, there is a considerable degree of similarity

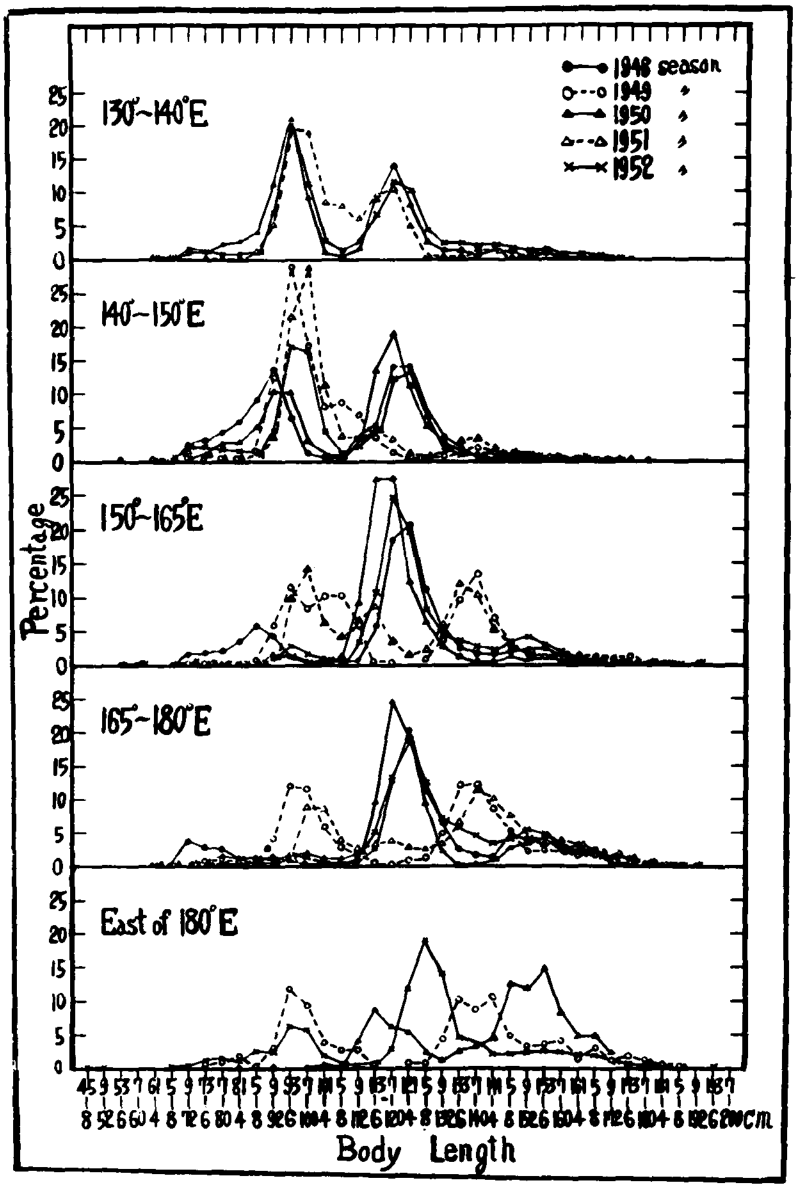


Figure 2.--Length frequency by fishing area.

among the years of each group, but there are conspicuous discrepancies between the two groups. To state it concretely, it is probably possible to point out the existence of biennial cyclical phenomena in the positions at which the modes appear and in the degree to which they appear. If we try to examine these phenomena in figure 2, where the data are presented separately by sea areas, they are unclear in the area of 130°-140°E. and east of 180°, where data are scarce, but they are clearly discernible in all of the areas for which there is much data, 140°-150°E., 150°-165°E., and 165°E.-180°. There are many points which should be examined from various angles with regard to the existence of a biennial cycle, and these points will be taken up below.

The matters pointed out above are all phenomena which appeared from the data, and it is thought that such things as the general correspondence of the positions of the modes as between the several sea areas, and the evidence of common tendencies in different years as regards the relative strength with which the modes appear in different sea areas can hardly be thought to be accidental agreements arising from defects in the data, and can be considered

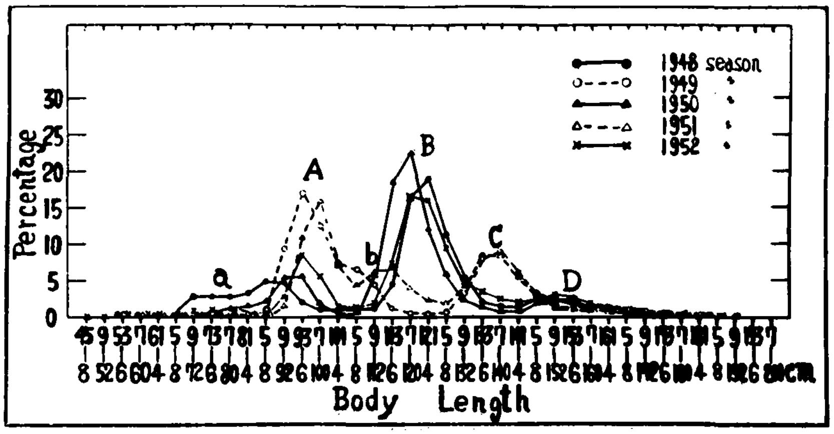


Figure 3. --Aggregated length frequency by fishing season

to reflect the actual composition of the schools that occur in the various sea areas. It can probably be concluded, if there are no errors in this hypothesis, that there is a strong possibility that the population of bigeye inhabiting the North Pacific area is composed of schools belonging to a single stock. At least, it seems that there is very little possibility that they are made up of two or more sharply differentiated racial strains. However, there are examples where small discrepancies can be detected in the positions at which the modes appear in the different sea areas, and it is thought that there is room for further study of various points concerned with the finer internal organization. These points the author would like to take up when the data have been amplified.

II. Observations on the Shifting of the Modes from Year to Year

Nakamura, Kamimura, and Yabuta (1953) have already advanced the three hypotheses mentioned above in connection with the phenomenon of the conspicuous discrepancies from year to year in the positions at which the modes appear and in the degree of their appearance. These hypotheses are:

1. Differences from year to year in the growth rate
2. Differences from year to year in recruitment
3. Differences from year to year in migrational phenomena

We will continue our examination of this subject by taking up these hypotheses one at a time in the order 2, 1, and 3.

Hypothesis 1 - Differences from year to year in the amount of recruitment

If it is postulated that a difference from year to year in the amount of recruitment is the main factor in the shifting of the modes, it should be possible to detect through the variations in the modes phenomena connected with growth. Contrariwise, if it is possible to ascertain the existence of phenomena related to growth from the group of phenomena related to the shifting of the modes from year to year, it can be concluded that the validity of the above-mentioned hypothesis will be strengthened. At least it can probably be said that it will be impossible to discard this hypothesis. We will attempt to examine the data directly from this point of view.

Figure 4 shows the body length composition split up by years. Assuming first of all that the schools which made up the modes a_1A_1 in 1949 have returned to the fishing grounds year after year, if we try to relate the discrepancies in the modes to growth which has taken place during this period, it is thought most natural to try to establish the following sort of postulate from the inter-relationships among the positions at which the modes appear: a_1A_1 (1948) ⟶ A'b' (1949) ⟶ B_2 (1950) ⟶ C'' (1951) ⟶ D_3 (1952).... (A)

The main difficulty with this assumption is in the form of the modes or in other words in the degree to which they appear, for incompatible relationships can be seen between a_1A_1 and A'b' and between A'b' and B_2.

If we try for modes B_1 and a_2A_2 the same sort of postulation as for (A),

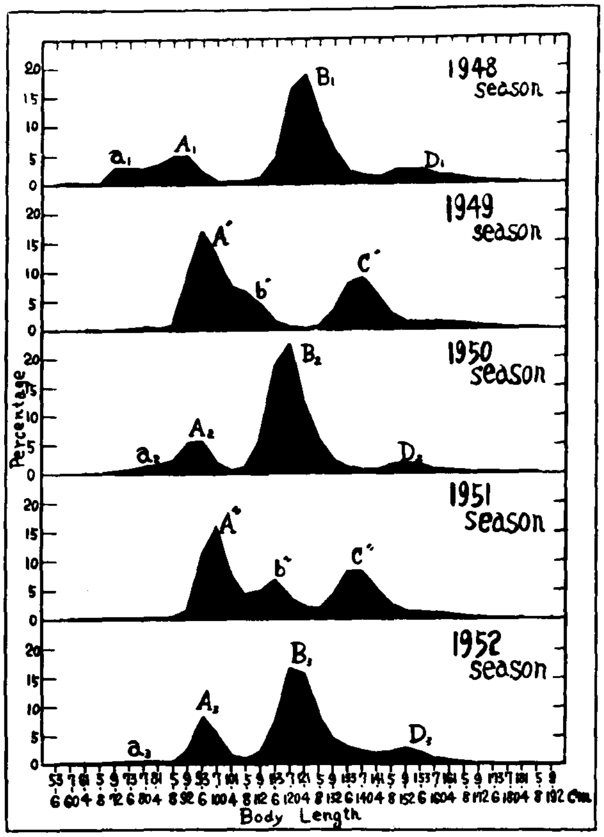


Figure 4.--Length frequency by season with noted modes.

B_1 (1948) $\longrightarrow$ C' (1949) $\longrightarrow$ D_2 (1950) .... (B)

a_2A_2 (1950) $\longrightarrow$ A''b'' (1951) $\longrightarrow$ B_3 (1952).... (C)

These relationships can be established. However, the same difficulty exists with regard to (c) as for (A). We shall investigate further to try to find out whether the difficulties pointed out for assumptions (A) and (C) are of a nature such as to overthrow these assumptions completely or whether they are of such a nature that a reasonable explanation can be given for them provided certain conditions are fulfilled. For convenience in the explanation the problems will be divided into two: (a) $a_1A_1 \longrightarrow$ A'b' and $a_2A_2 \longrightarrow$ A''b'' (b) A'b' $\longrightarrow B_2$ and A''b'' $\longrightarrow B_3$

On problem (a):

A'b' is thought to be compounded of two groups shown by A' and b'. In the same manner a_1A_1 can hardly be thought, in view of the form, to be a single mode, and it is probably valid to think of it as being compounded of two groups shown by a_1 and A_1. If we take it that this assumption is correct, a_1A_1 and A'b' will be understood to have no particular inconsistent relationship in their essential composition. The same sort of assumption is established with regard to the relationship between a_2A_2 and A''b''. The point that needs to be noticed here in the comparison between A'b' and A''b'' is that whereas the displacement between A' and b' in the former is small, that between A'' and b'' in the latter is relatively great. However, this sort of difference is not fundamentally in opposition to the point that they are made up of two groups as stated above. Consequently, it can probably be thought that the elements which prevent the rational establishment of the assumptions $a_1A_1 \longrightarrow$ A'b' and $a_2A_2 \longrightarrow$ A''b'' arise chiefly from differences in the relative abundance between the two different groups.

Table 2 shows the relative abundance between the two groups mentioned above. As far as the division into two groups is concerned, there is no particular problem in the case of

Table 2.--Relative abundance between two groups

*: No data available

Mode	Group \ Area	130° to 140°E.	140° to 150°E.	150° to 165°E.	165° to 180°E.	East of 180°E.	Total area
a_1A_1	a_1	-*(%)	27.7	35.6	69.5	-	40.2
	A_1	-	72.3	64.4	30.5	-	59.8
a_2A_2	a_2	11.9	16.5	19.9	28.9	0	17.0
	A_2	88.1	83.5	80.1	71.1	100.0	83.0
A'b'	A'	-	72.2	59.3	78.1	76.8	71.2
	b'	-	27.8	40.7	21.9	23.2	28.8
A''b''	A''	61.9	82.0	60.0	59.6	-	66.0
	b''	38.1	18.0	40.0	40.4	-	34.0

A''b'', but in the others no clear-cut basis for making the division could be discerned so the division was performed mechanically in the following manner. For A'b', when the length group at 101 to 104 cm. was taken at the center, a point at which the curve of the line changed was observed and this was taken as the boundary of the groups. The length group of 101 to 104 cm. was split into two parts, which were added respectively to A' and b'. In the case of a_1A_1 and a_2A_2, the length class standing midway between them was taken as the boundary and the length group at that boundary was divided into two, which were added respectively to the group of large fish and the group of smaller fish. According to the table, for all sea areas totaled, in a_1A_1 and a_2A_2 the proportion of a_1 and a_2 was less and the proportion of A_1 and A_2 was greater. In contrast to this, for A'b' and A''b'', A' and A'' were in greater proportion and b' and b'' in the lesser proportion. Comparing these results with those which were obtained for each sea area separately, the only example in which the two sets of results were in disagreement was at a_1A_1 for the area of 165°E. to 180°. In all other cases the relationships were found to be in agreement. To sum up, in general for a_1A_1 and a_2A_2 the proportion of the group of smaller fish was less and that of the group of larger fish was greater, whereas for A'b' and A''b'' the proportion of the group of smaller fish was larger and the proportion of the group of larger fish was smaller. Where one would think of linking these relationships directly to phenomena accompanying growth, this phenomenon is clearly incompatible. However, considered in the following manner it will be realized that the aforedescribed relationship is not necessarily contradictory. If we try comparing for separate years the relative manner in which the length groups appear which correspond respectively to a_1, a_2 and A_1, A_2, we can see throughout the data for the last 5 years that in both cases the former is small and the latter is large. From the point of view of age, the length groups corresponding to a_1 and a_2 are clearly younger than those corresponding to A_1 and A_2, and the fact that the modes for the younger groups of fish are always smaller than those of the older groups of fish can probably be ascribed to the problem of availability. Specifically, it is postulated that the main reasons are probably that the length groups corresponding to a_1 and a_2 come into the fishing ground in lesser volume or that they are subject to the operation of too low a catching efficiency because of the selectivity of the gear. It is not possible to offer a quantitative hypothesis in regard to what the degree of the effect of availability may be, but that it appears to be rather well marked can be assumed by analogy from the differences detected in the relative manner of appearance of length groups corresponding to a_1 and a_2 and A_1 and A_2, as seen in figure 4.

It is clear from the foregoing observations that the establishment of the assumption ($a_1A_1 \longrightarrow$ A'b', $a_2A_2 \longrightarrow$ A''b'') can be understood to involve no particular contradictions.

Concerning problem (b):

A difficulty lies in the fact that whereas A'b' and A''b'' are each composed of two different groups, B_2 and B_3, which are assumed to be the result of the growth of the same fish, cannot be judged to be necessarily composed of two groups. In other words, the former are of the bimodal type while the latter are of the unimodal type. With regard to this point the following considerations may perhaps be brought forward.

First, looking at the form of B_2 and B_3, they can hardly be considered bilaterally symmetrical, for in each case they are skewed to the right. Furthermore, when we try comparing A'b' and A''b'', we see that in the former the displacements of A' and b' are small, while in the latter the displacements of A'' and b'' are large, and it is possible to point out an analogous relationship in the comparison between B_2 and B_3. That is, in B_2 the degree of skewness on the right is small whereas in B_3 it appears relatively large. The same sort of relationship can be indicated by making comparisons for each sea area separately (see fig. 1). Second, let us consider what changes in the course of their growth will affect two groups which differ in the time at which they were produced. When we examine the successive stages of existence of two groups defined in terms of length composition, it may be thought that perhaps with the passage of time they may tend more and more to overlap. It is thought that this is mainly due to the fact that with the passage of time there is a relatively greater increase in the growth rate differential as between the individuals than in the growth rate differential based on the difference in the time of production, and it is imagined that this effect also operates to some degree in problem (b).

If we think about the analogies pointed out under consideration 1, taking account of the effect of the process of growth as set forth under consideration 2, there is probably no obstacle to deciding that there is a fairly strong relatedness between A'b' and B_2 and A''b'' and B_3.

With regard to the assumptions ($B_2 \longrightarrow C'' \longrightarrow D_3$) and ($B_1 \longrightarrow C' \longrightarrow D_2$), no points of essential disagreement can be detected by a direct inspection of the form of the modes. It is thought that the fact that the modes gradually diminish in height is due to the effect of the increasing mortality and the problem of availability.

Figure 5 shows how the displacements of the modes look based on assumptions A, B, and C. As is clear from the figure, the growth rates based on these various assumptions are in very good agreement. This fact may be thought to strongly support the validity of assumptions A, B, and C.

As observed above, it must be said that there is a considerable rational basis for the establishment of assumptions A, B, and C, and consequently it can be judged that there is a strengthening of the validity of the hypothesis that the variations in modes from year to year arise from differences in the amount of reproduction or recruitment from year to year. However, there is still a gap between the establishment of the assumptions A, B, and C and the establishment of this hypothesis, so we shall make a further consideration of this point later.

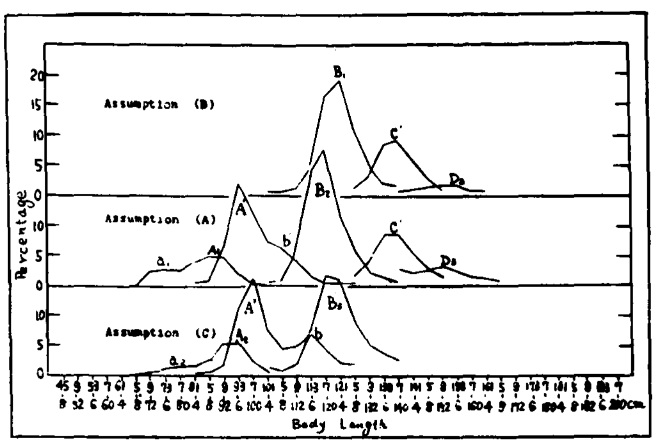


Figure 5.--Mode transformation based on assumptions A, B, and C.

Hypothesis 2 - Differences in the growth rate from year to year

This is a consideration of a case where hypothesis (2) is the controlling factor in the variations in the modes from year to year. In this case: (a) the amount of growth during the year assumed in hypothesis (1) should be taken as the difference between years in the amount of growth; (b) the differences in the amount of growth between years are small by comparison with the amount of growth within the year. These two conditions are postulated in this case. We shall see whether or not it is possible to form a rational postulate to account for the displacement of the modes accompanying growth while satisfying the conditions of hypothesis (2) and conditions (a) and (b). If, on the basis of figure 4, we attempt to form an assumption for the sort of relationship that will satisfy conditions (a) and (b), the following relationships may be thought of.

a_1A_1 (1948) ⟶ C' (1949) .... (D)

A'b' (1949) ⟶ D_2 (1950) .... (E)

a_2A_2 (1950) ⟶ C'' (1951) .... (F)

a''A'' (1951) ⟶ D_3 (1952) .... (G)

However, these assumptions are basically in conflict on the following points. First, when the amount of growth within the year based on the assumptions is made to correspond to assumptions A, B, and C, there exists in all cases between the amounts of growth of the two a discrepancy of approximately 3 : 1, and this relationship stands in opposition to the first proposition, which was that the rate of growth varies from year to year.

Secondly, when the amount of growth in the year based on this assumption and the discrepancies among the length frequency groups appearing in the same year (which are handled as independent units in the assumption) are made to correspond with assumptions A, B, and C and are compared, there is in every case a discrepancy between the two averaging 3 : 2. If this sort of relationship is considered in direct connection with growth, it is thought to be clearly inconsistent.

In conclusion, assumptions (D) to (G) do not satisfy hypothesis (2), and it is also apparent that the assumptions themselves do not satisfy the relationship accompanying growth. In short, as long as we postulate that schools of the same stock return repeatedly into the fishing grounds, we cannot establish any assumptions that would satisfy both hypothesis (2) and conditions (a) and (b) at the same time, and consequently it can be decided that hypothesis (2) cannot at least be the dominant factor in the variations in the modes from year to year.

Hypothesis 3 - Differences in migratory phenomena from year to year

Concretely, this hypothesis is based on the idea that the migrations of the schools as differentiated by length groups differ from year to year. What is meant in this case is that the schools which come into the fishing grounds in a given year and those which come into the fishing grounds in the following year do not have any direct relationship. However, it is anticipated that in order to link up hypothesis (3) rationally with the alternate-year cyclical phenomena already described, we must bring into hypothesis (3) in some form or another a cyclical migrational phenomenon which occurs in units of 2 years. Let us assume a displacement of the modes attendant upon growth based upon this sort of assumption, and examine the validity of the results. If we postulate the existence of migrational phenomena with a period of 2 years, the schools which come into the fishing grounds in a certain year may be thought to return again to the grounds 2 years later, so it is to be expected that any direct relationship will be between the schools in odd-numbered years and between those of even-numbered years and would not exist between those of successive years. Consequently we will assume the following relationships from figure 4.

Even-numbered years:

a_1A_1 (1948) ⟶ B_2 (1950) ⟶ D_3 (1952) .... (H)

B_1 (1948) ⟶ D_2 (1950) .... (I)

a_2A_2 (1950) ⟶ B_3 (1952) .... (J)

Odd-numbered years:

A'b' (1949) ⟶ C'' (1951) .... (K)

If we attempt to examine the validity of these assumptions as seen through the phenomena, it will be understood that as regards their relatedness from the point of view of the internal structure of the several length groups, it can be established under postulates similar to those considered for assumptions A, B, and C, while as far as growth rate is concerned there is general agreement among the several assumptions and there is also agreement with the rate based on assumptions A, B, and C. Looking at the problem in this way, we can come up with the interpretation that assumptions A, B, and C and assumptions H, I, J, and K are analyses of the same phenomena from different starting points and that both are reasonable from their respective standpoints. As for the reality of assumptions A, B, and C and assumptions H, I, J, and K,

(1) Assumptions H, I, J, and K in comparison with assumptions A, B, and C apply to very particular cases, and in view of this fact and in the absence of other concrete facts supporting these assumptions, it may probably be concluded that their reality is very slight.

(2) As is clear from the considerations brought forth under (a) and (b), with regard to the establishment of the relationships ($a_1A_1 \longrightarrow A'b' \longrightarrow B_2$) and ($a_2A_2 \longrightarrow A''b'' \longrightarrow B_3$) for assumptions A and C, the reasonableness of these assumptions was positively promoted by the intervention of A'b' and A''b''. And it may be said that this fact shows a greater validity in assumptions A, B, and C, where the schools which appear respectively in even-numbered and odd-numbered years are considered directly, than in assumptions H, I, J, and K, where these schools are considered indirectly.

In conclusion, if for hypothesis (3) we postulate cyclical migratory phenomena with a 2-year period, it is possible that this can be the dominant factor in the fluctuations of the modes from year to year. However, if we consider the fact that assumptions A, B, and C, which are of a more general nature, also apply to the same identical phenomena, it is thought that it may be decided that in the present stage of studies this hypothesis has very little reality.

From the foregoing considerations, it has been shown that the applicability of hypothesis (1) is strengthened by assumptions A, B, and C, that hypothesis (2) can be judged to be at least not a controlling factor, and that there is room for the application of hypothesis (3) through postulating the existence of an alternate-year cycle in the migratory phenomena. No determination can be made under present conditions as to the problem of whether the elements which essentially control the phenomena are produced in accordance with hypothesis (1) or (2), or whether they arise from entirely different factors, or whether they are the effect produced by a complex intermingling of a number of factors, but in any case they must be said to be extremely interesting phenomena.

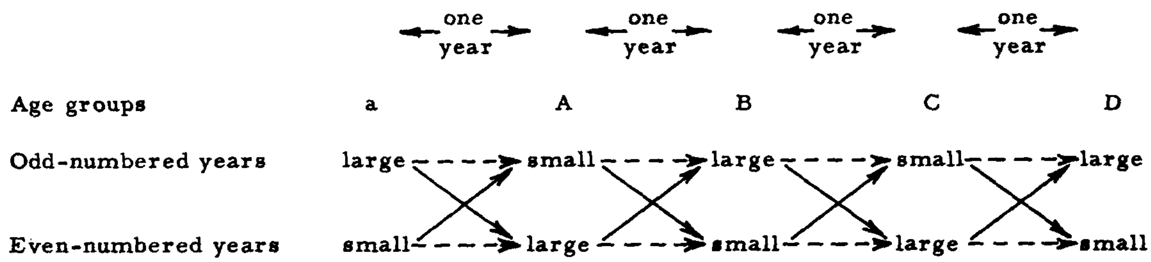
III. A Consideration of the Mechanism of the Alternate-year Cycle

We shall here attempt a consideration of the mechanism of the alternate-year cycle based on assumptions A, B, and C, which are thought to have the strongest reality. If we try to point out the most outstanding points of difference between the even-numbered years and the odd-numbered years as shown in the phenomena, in figure 3, (1) we can detect a tendency for the length group corresponding to a to be numerous in even-numbered years and scarce in odd-numbered years. However, its abundance in the even-numbered year 1952 differed hardly at all from that of odd-numbered years; (2) the length group corresponding to A appears as a conspicuously predominant mode in odd-numbered years but presents no such predominant mode in even-numbered years. A tendency can be seen for the position of this mode to be displaced to the left in even-numbered years and to the right in odd-numbered years; (3) the length group corresponding to B appears as a conspicuously predominant mode in even-numbered years, but in odd-numbered years it appears as an inconspicuous mode somewhat to the left in a position corresponding to b; (4) the length group corresponding to C appears as a mode only in odd-numbered years and in even-numbered years does not form any particular mode; (5) the length group corresponding to D appears as a very small mode only in even-numbered years and no mode appears for this group in odd-numbered years. In all cases the length groups larger than that corresponding to D show very unclear differences between odd and even years.

According to assumptions A, B, and C the length groups a, A, B, C, and D mentioned under (1) to (5) are assumed to be 1 year apart, so hereafter they will be handled as year classes a, A, B, C, and D. As is clear from (1) to (5), the factor contributing to the mechanism of the alternate-year cycle is principally the relative abundance as between years seen as separate ages, and at the same time it can probably be judged that this tendency is to be detected also in the displacement of the modes seen as separate ages.

(a) Concerning relative abundance:

The age groups that appear conspicuously in even-numbered years correspond to a, B,



and D, while to those which appear conspicuously in odd-numbered years A and C correspond. Consequently if we assume relationships attendant upon growth based on assumptions A, B, and C, we can postulate the above diagram of the mechanism.

In this diagram of the mechanism, the words "large" and "small" indicate the relative abundance of each age group as between the different years, the solid lines show the relationship accompanying growth, and the dotted lines indicate the existence of the even-numbered year type and the odd-numbered year type. As is clear from the figure, this mechanism diagram satisfies the existence of the alternate-year cycle from the point of view of relative abundance, and it can be understood that the essential factors are marked variation every other year in the amount of the schools considered as separate age groups, and that the age group a is taken as a starting point. Consequently, if we think that D_1 which appears in 1948 and D_2 which appears in 1950 have come through the same process as D_3 appearing in 1952, we can consider that the elements of the alternate-year cycle for 1948 and 1950 originated 5 years before those years.

(b) Concerning the displacements of the modes:

The only direct comparison which can be made on this point is of age groups A and B, and as already stated in (2) and (3), a tendency can be detected for the mode for age group A to be displaced to the left in even-numbered years and to the right in odd-numbered years, and for age group B contrariwise to the right in even-numbered years and to the left in odd-numbered years (fig. 3). If we consider this to be directly linked to the magnitude of the amount of fish in these groups in the years referred to, it can be said that for both age groups A and B the mode is displaced to the right in years when fish are abundant and to the left in years when they are scarce. However, considerable discrepancies in the location of the modes can be detected among abundant years and among scarce years, and we can also cite the example of age group A, which in 1949, when the fish were plentiful, and in 1952, when the fish were scarce, had its mode appear at almost the same position. Consequently, even though we assume that the displacement of the modes is a factor in the alternate-year cycle, it is obvious that it does not appear as such a clear-cut difference as did factor (a). At the present we cannot decide whether or not it is a factor in the alternate-year cycle, but it can be said that there is a possibility that it is, and in such case we may think that it is organically linked with factor (a) and we may expect that it will give important indications for a consideration of the mechanism giving rise to the alternate-year cycle.

IV. Considerations of the Mechanism by Which the Alternate-year Cycle Arises

In the preceding section it was shown clearly that a controlling factor in the alternate-year cycle is the marked difference in the amount of fish of different ages insofar as assumptions A, B, and C are used as a basis, and it was ascertained that it was possible to explain the mechanism rationally by relating it to the processes accompanying growth. We cannot say definitely whether or not the phenomenon of the alternate-year cycle will continue hereafter. But assuming that it will continue, we shall attempt to consider the mechanism which gives rise to it chiefly from the standpoint of pushing ahead these studies in the future.

From the diagram of this mechanism it is possible to interpret the source of the phenomenon as something which arose in age group a prior to its development. To put it concretely, we are dealing with the fact that the amount of fish in age group a is great in even-numbered years and small in odd-numbered years and that these phenomena are alternately repeated. Consequently, with regard to the mechanism giving rise to phenomena of this sort, it is thought that the following two ideas may be established:

(a) They arise as a result of gradual addition during the process of growth of age group a.

(b) They are determined at a definite time in some certain stage. It is impossible to carry out any consideration based directly on data with regard to (a), but it is thought that there is very little possibility of it unless it can be anticipated that the environmental conditions of this population may vary markedly from year to year during the course of growth of age group a. As for b, probably it is most correct to ascribe it to the problem of recruitment under hypothesis 1.

If we postulate the simplest possible case with regard to the problem of (b), we can assume two cases: (a) either the amount of spawning differs conspicuously every other year, or (b) even though the amount of spawning does not differ greatly there is a conspicuous difference every other year in the amount of attrition of the newly hatched or larval stages.

Before considering this problem we will first summarize what is known about the distribution and spawning habits of the bigeye.

1. Distribution:

According to Nakamura (1949, 1951), in the northern hemisphere in the Pacific Ocean the bigeye is distributed almost everywhere from 0° to 40°N. latitude, and it is further presumed to be broadly distributed in the southern hemisphere waters of the Pacific Ocean and in the Indian Ocean. According to recent records of operations of Japanese long-line vessels, the outstanding grounds where large catches of bigeye are made are first of all in the low latitudes, the main current area of the North Equatorial Current and the Equatorial Countercurrent, the aforementioned sea areas of the North Pacific, the Banda, and Flores seas, and the northeastern parts of the Indian Ocean. In the southern hemisphere waters of the Pacific Ocean at present the operating area is generally limited to N. of 20°S. latitude, but it has been ascertained that the bigeye is apparently rather densely distributed in the southern hemisphere also.

2. Spawning habits:

Nakamura (1949, 1951) has stated as common characteristics of the tunas and spearfishes that the spawning of these fishes takes place in broad areas of the low latitudes over long periods of time. From June to August of 1951 Kikawa (1953) observed in the area of 2°N. to 9°N. latitude, 161°E. to 174°E. longitude large numbers of bigeye having completely ripe, transparent eggs, which were thought to be close to spawning, and he has postulated that the spawning of the bigeye takes place in this sea area. The matters set forth below have not yet been formally reported, but they are the outline of what has become known as a result of the investigations of bigeye spawning at the Nankai Regional Fisheries Research Laboratory.

i) Spawning appears to be carried on principally in the main part of the North Equatorial Current or in the sea areas south of that current.

ii) The minimum size of maturity appears to be about 100 cm.

iii) The spawning season is very long and on the whole appears to extend almost throughout the year.

On the other hand, the results of the examination of gonads of bigeye taken from September to April in the sea areas of the North Pacific has revealed that they are all immature.

From the items given under 1 and 2 above we can deduce two things: that the North Pacific sea area is only a part of the total range of occurrence of the bigeye, and that the North Pacific sea area has no direct relationship to the bigeye spawning grounds, and consequently in the northern hemisphere waters of the Pacific Ocean there must be some direct mixing of the bigeye occurring in the high-latitude waters of the North Pacific and in the low-latitude sea areas through their spawning activity. Setting up these provisos, we will attempt to examine cases (a) and (b).

With regard to the case of (a), if we assume that the minimum size at maturity for bigeye is about 100 cm., it is clear that the age groups contributing to spawning must be at least 2 years or older. Consequently, insofar as no other special consitions exist, it may be thought highly unlikely that the amount of spawning will differ markedly every other year.

As for case (b), judging from the fact that the spawning of the bigeye takes place in low-latitude sea areas with stable environmental conditions and that the spawning is carried out over a long period of time, it may be thought highly unlikely that the rate of attrition will differ markedly every other year. Looking at the matter in this way, it is deduced that the mechanism which produces the alternate-year cycle is not something which appears in a simple form. If we assume that it does not arise in a simple form, it is thought that problems of the following sort will have an extremely important significance judging from the pattern of distribution of the bigeye. This is the problem of in what form and to what extent the groups of bigeye in the North Pacific and the South Pacific and the Indian Ocean are connected through their spawning activity. If, as stated earlier, the principal spawning grounds of the group occurring in the northern hemisphere lie in the low-latitude sea areas, including the equatorial area, the principal spawning grounds of the groups occurring in the southern hemisphere waters of the Pacific and in the Indian Ocean will probably be of the same character as those for the northern hemisphere. In this case it may be thought that the spawning grounds of these three groups will at least in part overlap. If we start off from this idea, it will not be enough in dealing with the amount of recruitment to consider it a problem simply of the total amount, but it will be necessary to give consideration at the same time at least to the mechanism of replenishment in the northern hemisphere and southern hemisphere waters of the Pacific Ocean.

It is not possible at present to go any further into this problem than we have here. At any rate it is hard to believe that the problem of the alternate-year cycle is of such a character that it can be clarified by taking only the sea areas of the North Pacific into consideration. If we think of all the bigeye so broadly distributed throughout the Pacific and Indian Oceans as one great population, it is naturally to be anticipated to be in organic connection at various points with problems related to the internal organization of this mass, and it is thought that there is a necessity to push ahead the study of the problem from this standpoint. To express this in another way, it can also be said that for future studies the alternate-year cyclical phenomena have an important significance as a powerful means for the investigation of the structure of this population.

Summary

1. Length measurement data of bigeye taken in the North Pacific fishing grounds have been examined in various ways. Data were obtained for five periods extending from autumn to winter of the years 1948 to 1953.

2. As a result of comparisons of the length composition in the different sea areas,

   a. It has been observed that the positions at which the modes appear are as a rule in agreement for different sea areas in the same year.

   b. Although the relative heights of the individual modes differ conspicuously from sea area to sea area, as a characteristic which extends to all the years, in the more westerly sea areas the modes formed by the smaller size groups are predominant while in the easterly sea areas the modes formed by the larger size groups predominate. In other words, in the more westerly areas the groups of smaller fish are more abundant, while in the easterly areas the groups of larger fish are more abundant.

   Judging from (a) and (b) it is thought that there is very little possibility that the composition of the groups which come into the fishing grounds results from two or more clearly different racial stocks.

   c. There are conspicuous discrepancies from year to year, particularly in the positions of the modes and in their height, indicating alternate-year cyclical phenomena.

3. With regard to the causes of the annual displacements of the modes we have considered the validity of three hypotheses earlier advanced by Nakamura, Kamimura, and Yabuta (1953):

   (1) Variation from year to year in the amount of recruitment

   (2) Variation from year to year in the growth rate

   (3) Variation from year to year in the migrational phenomena

   As a result, with regard to hypothesis (1), we concluded that its validity is strengthened by the fact that the assumptions A, B, and C that have been made in relation to the processes accompanying growth have a rather fairly rational basis. As for hypothesis (2), since it is difficult to get a rational grasp of the phenomena insofar as this hypothesis is used as a basis, it has been decided that it cannot at least be the controlling factor. In the case of hypothesis (3), it has been shown that there is room to apply it by postulating migratory phenomena on an alternate-year cycle.

4. The mechanism of alternate-year cycles has been examined on the basis of assumptions A, B, and C, which had been thought to have the strongest validity. As a result it has been shown that the majority of the elements forming this mechanism lie in the fact that there is a marked variation every other year in the amount of the schools regarded as age groups, and it also has been pointed out that there is a possibility that the displacements of the modes regarded as age groups are contributory to this mechanism.

5. Based in the same way on assumptions A, B, and C and chiefly from the point of view of the carrying on of future studies, we have considered the time of appearance of the alternate-year cycle and the mechanism which gives rise to it. It has thereby been made clear that the time is anterior to the development of age group a, but it has not been possible to show whether (a) it arises gradually in the course of the process of growth, or (b) whether it is determined at once at one particular stage. However, in a general manner of thinking it should be said that (b) has the greater possibility, and it is also thought correct to ascribe the time to the early stages of life. This is also in agreement with hypothesis (1). Even though we assume that the matter is decided at once in the early stages of life, it is hard to think that the mechanism arises in a simple form, and in handling the matter of recruitment it is thought that there is a necessity for considering the problem of the mechanism for replenishment in at least the North Pacific, South Pacific, and Indian oceans.

6. It cannot be determined whether or not alternate-year cyclical phenomena will continue hereafter, but assuming that they do continue, it is anticipated that in further developing future bigeye studies these phenomena will provide an important starting point and a key to the consideration of various matters.

Bigeye Studies. II. A Consideration of the Size Composition of Bigeye Taken on Pole and Line*

By

Misao Honma and Tadao Kamimura
Nankai Regional Fisheries Research Laboratory

/English title and summary/

Biology of the Big-Eyed Tuna, Parathunnus mebachi (Kishinouye) - II. A Consideration on the Size Composition of the Big-Eyed Tuna Caught by Pole and Line

The present paper deals with analysis of length frequency of the young big-eyed tuna caught by pole and line. Especially a relationship between the fishing localities and the discrepancy in the mean length which was evident in the same modal group has been discussed.

1. Data used for the study are the measurement of body length obtained from numbers of samples and the pertaining information furnished by fishing boats at two ports during the period from June to July 1953.

2. In the length frequency two dominant modes, A and B, were recognized not only throughout the samples (Fig. 2) but also in the mean value of each school from 1 to 17 examined nearly in the same period. These findings have led the writers to an assumption that modal group A may form an independent unit different from group B in regard with length frequency.

3. As no uniformity in the length frequency has been found among the samples belonging to the same group (Table 1), correlation between the mean length of the groups and fishing locality has been examined, substituting the size composition sorted by fishing cruise for that by school of fish, because few data on the latter were available for this purpose.

As a result it was found that the mean length of the fish in both groups A and B was small in the western area of the fishing grounds and tends to become greater as one goes east (Table 2, Fig. 3).

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4. The fact that the survey period fell on the months of June to July when the fish would be migrating northward (Fig. 3) seems to suggest that the easterly increase in the mean length may be attributable to different tendencies of the migrating behavior between the fish in the eastern area and those in the west. In other words, the fish of both groups A and B in the eastern area are supposed generally larger in size than those of the corresponding groups in the west, while all migrating northward.

/end of English summary/

It has been known in the past that in the tuna pole-and-line fishery some young bigeye tuna[1/] are taken incidental to the capture of skipjack, albacore, and small yellowfin, but up to the present time there have been no detailed reports concerning them. In general the fishes on which the pole-and-line fishery operates have a strongly schooling character, and this character is clearly evident in the young bigeye. In taking up problems related to the structure of the population, with fishes of a strong schooling character, it is thought that the weight given the schools, which are the structural units of the populations, is of very great significance. In the present study the size composition of the separate schools is considered from this point of view, note is taken of the discrepancies among schools appearing in the results, and some consideration is given to linking these discrepancies with the provenance of the schools.

The data are mainly fish measurements and information on fishing conditions collected at the Yaizu fish market in June and July 1953.[2/] Some data collected at the Makurazaki fish market are also included; they were supplied by the Oceanic Resources Section of the Tohoku Regional Fisheries Research Laboratory.

Appreciation is here expressed to Director Hiroshi Nakamura of the Nankai Laboratory and to Dr. Yabe, Chief of its High-seas Resources Section, for their advice in connection with this study, and also to the Oceanic Resources Section of the Tohoku Laboratory for its unfailing cooperation and for the valuable data supplied.

Size Composition by Separate Schools

In panels 1 to 17 of figure 1 we have taken those samples which, on the basis of the fishermen's reports, were judged to have clearly been caught from a single school, have chosen only those from which 30 or more fish were measured, and have arranged them in order of average size; the bottom panel shows the average composition of 1 to 17. Figure 2 is a comparison of the average composition of the schools represented in figure 1 (panel a) and of the composition based on all of the measurements taken during approximately the same period (b).

As is clear from figure 2, the positions of the modes in the size compositions represented by (a) and (b) are in very good agreement, and in both of them the presence of two modes, A and B, is clearly apparent. In addition, in the average size composition represented in panel (a) there is a faintly discernible mode C centered at 100.1 - 102.0 cm., but in the composition based on all the fish measured, represented in panel (b), this mode is not clear. As there are very few data on the group making up mode C, it is omitted from further consideration. For convenience in discussion, the groups making up modes A and B will be referred to hereafter as groups A and B.

The presence of groups A and B can also be pointed out in the several schools represented in figure 1. For example, schools 4, 14, and 17 can be cited as having a simple composition, and each of them is composed either of group A or of group B. In the other schools[3/], also, modes appear at locations corresponding to A and B, and we do not, at any rate, see anything that would positively deny the presence of modes A and B. As has been indicated above, groups A and B are interpreted as forming individual units[4/] even when they are in different schools,

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1/ These small bigeye are generally called bachimeji or daruma, whereas the adults are called mebachi.

2/ The length used was the so-called "fork length", measured from the tip of the snout to the deepest part of the fork of the caudal fin.

3/ If we look at the relation of mixed schools to the objects with which they were associated (see notes to fig. 1), we find that they were all with whales, sharks, drift logs, etc. Taking this point into consideration, it may be wondered whether the intervention of such objects of association may not play a significant role in the formation of mixed schools.

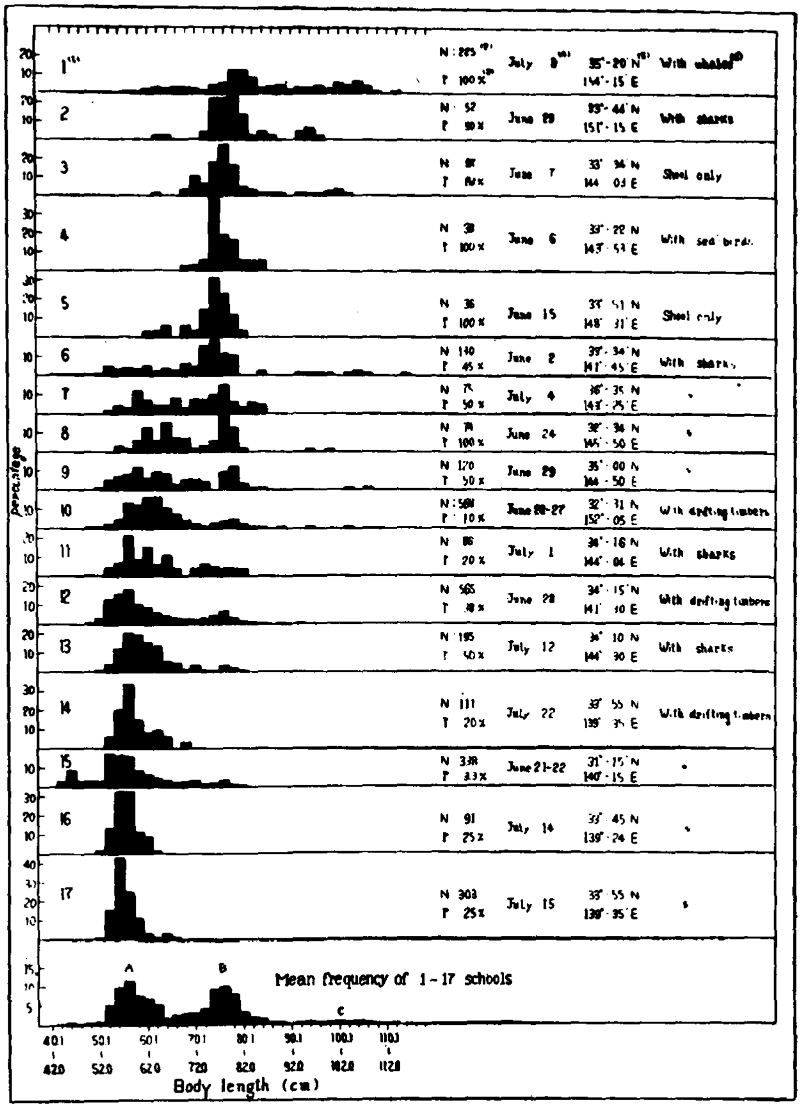

Figure 1.--Length frequency by school. (1): Sample number (2): Size of sample (3): Sampling fraction (4): Date of catch (5): Locality of catch (6): Kinds of associates sighted with the fish.

and it is hypothesized that they are length groups which differ with respect to their early life history.

A point which requires attention here is the fact that for both group A and group B the locations at which the respective modes appear differ slightly from one school to another. This sort of discrepancy is thought to appear more conspicuously in group A than in group B.

Table 1 is a statistical examination of the separate samples, for both group A and group B, in order to see whether or not they were after all homogeneous. For this examination the determination of the size ranges of the two groups was based on the size composition of all measurements (fig. 2, panel b) and they were taken to be 50.1 - 68.0 cm. and 70.1 - 86.0 cm. respectively. For each group only those

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4/ The question of whether or not the two are different age groups will be examined in a subsequent report.

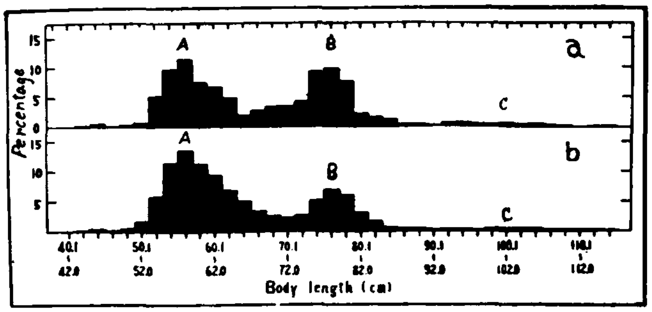

Figure 2.--Comparison of length frequency. Upper (a): Mean frequency of the schools 1-17 shown in Fig. 1. Lower (b): Frequency of the total individuals measured during the same period as the samples of the schools 1-17.

Table 1.--The tests of variance and difference between mean value of body length (5% level)

GROUP A (50.1 - 68.0 cm.)

Sample No. *	Size of sample	Mean	Mean square	No.	1	2	3	4	5	6	7	8	9	10
1	23	63.7	8.6	1										
6	36	58.7	23.6	2	X									
7	32	61.1	17.0	3	X	O								
9•	70	59.7	16.7	4	X	O	O							
11	65	59.6	16.5	5	X	O	O	O						
13	177	59.3	13.3	6	□	X	□	O	O					
14	107	58.0	10.1	7	□	X	X	X	X	X				
15	245	56.9	15.5	8	X	X	□	□	□	□	X			
16	90	56.4	5.8	9	□	X	X	X	X	X	X	X		
17	303	56.2	7.6	10	□	X	X	X	X	X	X	X	X	

GROUP B (70.1 - 86.0 cm.)

Sample No. *	Size of sample	Mean	Mean square	No.	1	2	3	4	5	6	7	8	9	10
1	100	79.5	10.6	1										
2	43	77.7	8.5	2	□									
3	82	76.4	9.7	3	□	□								
4	37	76.8	10.4	4	□	O	O							
5	30	75.8	5.1	5	X	□	X	X						
6	77	75.7	7.2	6	X	□	O	□	O					
7	41	77.0	16.8	7	X	X	X	O	X	X				
9	42	77.0	12.2	8	□	O	O	O	X	X	O			
11	21	75.7	10.8	9	□	□	O	O	X	O	O	O		
15	30	74.7	8.6	10	□	□	□	□	O	O	X	□	O	

X: Significant in variance.

□: Not significant in variance, but significant in difference between mean.

O: Not significant both in variance and in difference between mean.

*: The sample numbers correspond to those of the schools of Fig. 1 respectively.

samples with 20 or more measurements were used.

As is clear from the table, out of 45 comparisons, A has 28 and B has 13 in which the variance shows significant differences; A has 9 cases out of 17 and B has 15 out of 32 in which the difference in variance is not significant but the difference between the means is significant and A has 8 cases and B has 17 in which neither the variance nor the mean differ significantly. These facts show, for both group A and group B, that the samples from individual schools have no common size composition, and therefore in neither group can they all be regarded, on the basis of probability, as samples drawn from the same universe.

Kawasaki (1952), discussing the populations of skipjack migrating into the Northeastern Sea Area, has reported that the size compositions of individual schools separated by age cannot be considered on the basis of probability as samples from a single population. This agrees with the above-described results obtained with bigeye.

Various reasons for the lack of uniformity among the schools, such as the influence of biological characteristics and environment, sampling error, and so forth, can be thought of, but account must also be taken of the possibility that one reason may be a lack of uniformity within the population[5]. If this is the case, it is believed that the lack of uniformity seen among the schools will provide an important clue for deducing the lack of uniformity of the population.

Relation of Nonuniformity of Composition to Locality

In table 2, for the size compositions of the landings of individual vessels the average lengths of groups A and B have been found and their relation to longitude has been shown. A classification by cruise has been used because there were few data available which were recorded by separate schools and the separation by cruise was thought to provide the best approximation. Since the problem here is the local character of the size composition, we have used only data from vessels which operated within areas of 4 degrees of longitude and 2 degrees of latitude. The vessels which operated over more than 2 degrees of longitude were assigned to the area in which the majority of their fish were taken. Furthermore, since the average length of the fish in samples varies widely depending on the amount of data available, only those samples in which 20 or more fish in each group were measured were used.

Of course, the size composition of the catch of an individual vessel is thought to represent the averaged values of the composition of several schools, but it is assumed that in its trend it will reflect the peculiarities of the individual schools in the area in question. It can be clearly seen from the table that for both group A and group B the average length of the fish is smaller in the more western areas and that it tends to increase to the eastward.[6] By comparing, in the lower parts of both tables, the frequency by longitude and by 10-day periods, it is clearly shown that the above-mentioned slope downward from east to west is not due to a difference in growth arising from any lag in the time of capture.[7]

In figure 3 the distribution of average lengths has been indicated, as explained in the legend, by plotting the positions of capture with symbols corresponding to three categories. By referring to the plot, the downward slope from east to west indicated in table 2 can be noted at different latitudes.

Figure 4 presents the size composition of the bigeye measured at the Makurazaki fish market.

Since very few data classified by individual vessels were available, the data from a number of vessels were combined for presentation. The locations of the catches in both June and July were west of 130°E., and when they are compared with the fish measured at the Yaizu market during the same period of time, it can clearly be seen that the fish were captured in more westerly areas (see fig. 3). As for the size composition, all of the modes appearing in

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5/ In this case the "population" indicates the schools migrating into the fishing grounds considered separately by groups.

6/ For group A $r = 0.73$, for group B $r = 0.56$. In both cases the probability that these values could be obtained from a universe in which $r = 0$ is $P < 0.005$.

7/ For group A $r = 0.11$, for group B $r = -0.13$. In both cases the probability that these values could be obtained from a universe in which $r = 0$ is $0.50 > P > 0.25$.

Table 2.--Number of the samples correlated between longitude, mean length, and date of fishing

Upper: Longitude and mean length of catch by fishing cruise

Lower: Longitude and date of fishing.

GROUP A

	°Longitude (E.)	134 to 136	136 to 138	138 to 140	140 to 142	142 to 144	144 to 146	146 to 148	148 to 150	150 to 152	152 to 154	154 to 156	156 to 158	158 to 160
Mean length (cm.)	53.1 - 54.0													
	54.1 - 55.0	1												
	55.1 - 56.0	1		1										
	56.1 - 57.0			2	1									
	57.1 - 58.0			2	1	4	1							
	58.1 - 59.0				1	6	3	1						
	59.1 - 60.0			1	1	2	4	4	1	1	1			
	60.1 - 61.0					2		3	1		1			
	61.1 - 62.0					1								
	62.1 - 63.0						1							1
	63.1 - 64.0											1		
	64.1 - 65.0													
Date of fishing	June, First decade			2	1									
	Second "			1										
	Last "				2	2	4		1	1	1			
	July, First "				1	6	1	8	1		1	1		1
	Second "			2		7	2							
	Last "	2		1			2							

GROUP B

	°Longitude (E.)	134 to 136	136 to 138	138 to 140	140 to 142	142 to 144	144 to 146	146 to 148	148 to 150	150 to 152	152 to 154	154 to 156	156 to 158	158 to 160
Mean length (cm.)	73.1 - 74.0													
	74.1 - 75.0			1	1	1								
	75.1 - 76.0				2	1	1		1					
	76.1 - 77.0				2	6	4	1	1					
	77.1 - 78.0					4		5	3	1	1			1
	78.1 - 79.0						1							
	79.1 - 80.0					1						1		
Date of fishing	June, First decade				2	4	1							
	Second "			1					4					
	Last "				2	1	4		1	2	1			
	July, First "				1	5	1	6	1			1		2
	Second "					3								
	Last "													

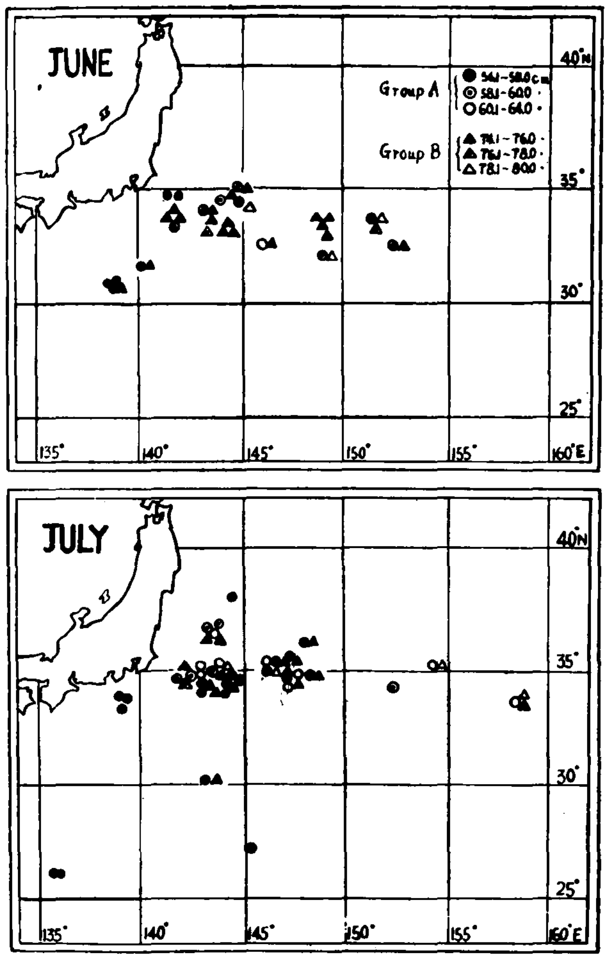

Figure 3. --Distribution of mean length by group and cruise.

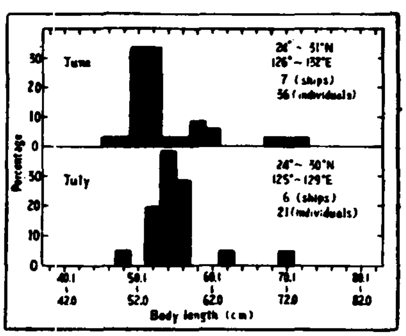

Figure 4. --Length frequency of the samples measured at the Makurazaki fish market.

both June and July correspond to group A; if we try to compare them with the composition of group B, as shown in figure 2, we see that their positions are notably displaced to the left.

A Consideration of the Gradient and the Source of Migration

For a close relationship between nonuniformity of the population and locality, such as was discussed in the preceding section, the usual mechanism that would come to mind would probably be to relate it to the source of the migrations of the schools. As can be seen in figure 3, in June and July the schools clearly show a northward movement. It is thought that these schools probably continue to move north through the spring and summer, so it is assumed that in June and July they are engaged in this northward movement. As they proceed north, the schools in the western areas are thought to be forced by the configuration of the Japanese coast to move gradually eastward with a resultant intensification of their contacts with the schools moving northward in the more easterly areas that would greatly promote the mingling of the two. It is deduced that the internal structure of the population in June and July corresponds to just this stage. Consequently, if the fact that within the same group the proportion of small fish is greater in the more westerly areas, with the proportion of large fish increasing to the eastward, is taken to originate from a difference in the source of the migrations of the schools moving north in the westerly areas and those moving north in the easterly areas, then it is deduced that even though both may be in a stage where their mingling is being brought about, the mingling is not yet complete.

In the first report of this series the authors studied the annual changes in the size composition of the bigeye tuna taken on longlines in the North Pacific area, and in that report too, as the result of a comparison of the size compositions in different localities, it was pointed out that the same sort of phenomenon could be seen in the case of the longline-caught fish. Whether this phenomenon common to the fish in the catches of both fisheries arises through exactly the same mechanism in both cases can neither be affirmed or denied, but the probable presence of a close relationship is hypothesized. If the hypothesis set forth above in regard to the relationship between the east-west gradient and the source of migration were correct, it would be noteworthy as an example of the migratory pattern and mixing process of the bigeye tuna in the North Pacific.

Albacore Studies. III. Size Compositions Seen in the Several Ocean Currents*

By

Akira Suda
Nankai Regional Fisheries Research Laboratory

/English title and summary/

Studies on the Albacore - III. Size Compositions Classified by Ocean Current

The size compositions of albacore distributing in various current areas of the Pacific have been examined. The following have been found with the fish caught in the Western North Pacific areas.

1) The albacore occurring in the North Pacific Current area seem to be remarkably different from those in the North Equatorial Current and in the Equatorial Countercurrent areas in size composition. A greater majority of the fish distributing in the North Pacific Current area consisted of the ones less than 100 cm. in body length. They are supposed to belong to a group of immature fish. However, most of those caught in the areas of the North Equatorial Current and the Equatorial Countercurrent measured more than 90 cm. in length and likely belonged to a mature group (figs. 1 and 2).

2) There is a discrepancy of about 10 cm. between the modal length of albacore caught in the North Equatorial Current and that of the fish in the Equatorial Countercurrent. This phenomenon may have a close relation with the sex ratio of the fish (fig. 2 and table 2).

3) Variance in the size compositions between albacores in the North Pacific Current area and in the other current areas is more conspicuous then the regional difference and seasonal one within the North Pacific Current area (table 3).

The above evidences are indicative of the fact that each of the various ocean currents would present an environment considerably different from the others for tunas, as has been pointed out by Nakamura (1954).

/end of English summary/

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The author has earlier pointed out that the size composition of albacore in the area of the North Pacific Current presents regional (Suda 1954b) and seasonal (Suda 1955) variations. It has frequently been pointed out that different ocean currents represent different environments for the tunas, and that if the current differs, the ecological significance of the tunas distributed there also comes to differ (Nakamura 1949, 1954; Nakamura, Yabuta, and Ueyanagi 1953). From this point of view, the manner in which the size composition of the albacore distributed in the North Pacific Current differs from those of albacore in other current areas--in this case the North Equatorial Current and the Equatorial Countercurrent--is a matter of extraordinary interest.

(1) Sizes of Albacore Distributed in the North Pacific Current, the North Equatorial Current, and the Equatorial Countercurrent

The size compositions for these three current areas are summarized in figure 1. (The fishing method in all cases is the longline.) The size compositions for the North Equatorial Current and the Equatorial Countercurrent differ conspicuously from that for the area of the North Pacific Current (Suda 1954a, 1955). Almost the whole is composed of fish of 90-120 cm., that is the largest sizes attained by albacore. This is markedly different from the albacore of the North Pacific Current area, where the greater part is medium and small fish (under 90 cm.). Consequently the range of the size composition is notably narrow as compared with that found for the North Pacific Current. From the opposite point of view, this can be regarded as an outstanding point shared in common by the albacore of the North Equatorial Current and those of the Equatorial Countercurrent. However, a difference can still be detected between the albacore of the North Equatorial Current and those of the Equatorial Countercurrent, and that is that there is a discrepancy of about 10 cm. in the modal length between the albacore of the two areas. For the albacore of the North Equatorial Current, fish about 110 cm. long are the principal group, while in the area of the Equatorial Countercurrent the principal group is at about 100 cm., which means that the fish in the North Equatorial Current are larger.

Figure 2 shows the size compositions of the albacore distributed in the three current areas schematically using the average values of data obtained in the years 1948-1952. The symbol a represents the period of southward movement in the North Pacific Current (longline fishery), b the period of northward movement in the same area (pole-and-line fishery), c the North Equatorial Current (longline), and d the Equatorial Countercurrent (longline). The size groups are numbered as in Suda (1954a), and the shaded portion represents the size group which the author has treated as the group of fish of advanced age (Suda 1954a). The lower root of the latter is in approximate coincidence with what Ueyanagi (1954a) has hypothesized as

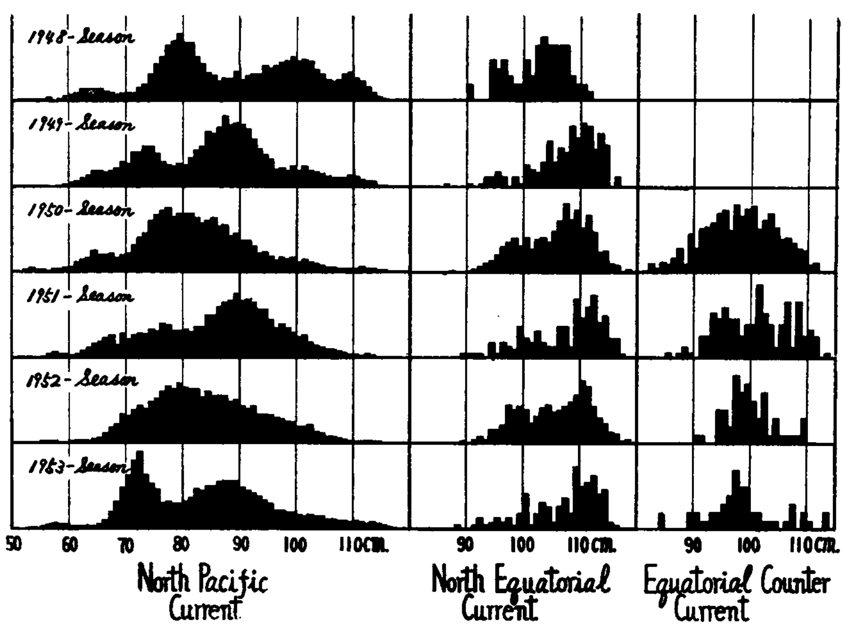

Figure 1.--Size composition classified by the current.

Table 1.--Number of fish measured

Area \ Season	1948	1949	1950	1951	1952	1953
North Pacific Current area	15,801	18,516	15,131	16,777	40,489	35,635
North Equatorial Current area	91	190	1,204	151	530	143
Equatorial Countercurrent area	-	-	530	138	58	52

the smallest size participating in spawning. In a rough approximation the following relationship can be postulated for the size compositions shown in a - d.

a - b ≓ advanced age group ≓ c + d

This is thought to mean that (1) on appearances, at least, the distribution of medium and small albacore is limited to the area of the North Pacific Current, or in other words to the north side of the Subtropical Convergence (the boundary between the North Pacific Current and the North Equatorial Current). (2) The albacore schools distributed south of the Subtropical Convergence are all made up of mature individuals. (Ueyanagi (1954b) considers the albacore distributed in the North Equatorial Current, at least, to be related to spawning.) (3) At the season of the changeover from a to b, that is, the time when the albacore in the North Pacific Current shift from a southward to a northward movement, the advanced age group is recruited from the North Pacific Current area into the waters south of the Subtropical Convergence*. Consequently, we have on the north side of the Convergence, that is, in the North Pacific Current area, an immature group, and on the south side of the Convergence, that is, in the North Equatorial Current and the Countercurrent, a mature group which has come over from the north side, and this indicates a remarkable ecological difference between the albacore on either side of the Convergence. It is thought that the discrepancy between the length distributions shown in c and d may be due to the marked difference in the sex ratios of the albacore in the two current areas. Figure 3 gives the length frequencies separately by sexes for the albacore taken in the

*The shift in fishing method from longline to pole and line can also be thought of as a cause of this, however, it is actually possible to trace the group which crosses the Subtropical Convergence to the southward.

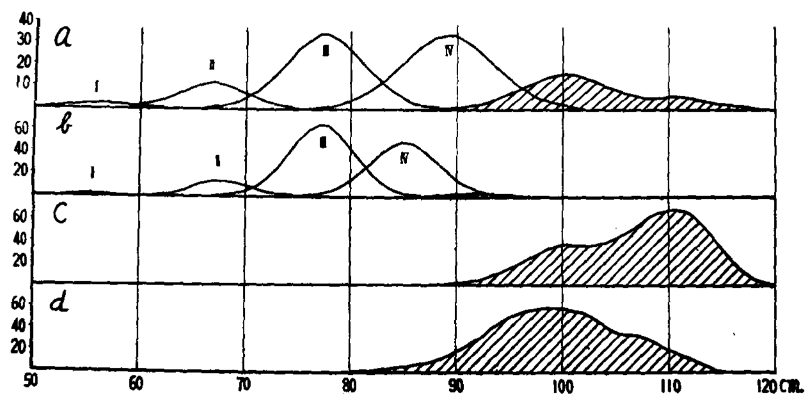

Fig. 2.--Average size composition in each current area. Ordinate represents the permillage.

a: North Pacific Current area (southward migrating season).
b: North Pacific Current area (northward migrating season).
c: North Equatorial Current area.
d: Equatorial Countercurrent area.

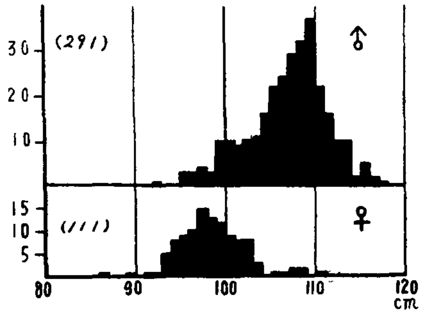

Figure 3.--Length frequency of males and females caught in the North Equatorial Current area.

North Equatorial Current area. The length distribution of the males very closely resembles that for the North Equatorial Current, and that for the females just as closely resembles the size composition for the Equatorial Countercurrent. Since we have no data with sex determinations for the albacore of the Countercurrent area, we cannot immediately conclude that the discrepancy between the sizes in c and d is due to a difference in sex ratios, but at any rate it is certain that there is an extraordinarily high proportion of males in the North Equatorial Current area (table 2). On the other hand, we cannot rule out the possible influence of the albacore of the Southern Hemisphere, so there is a need for further investigation in this field.

(2) Size Differences Within Currents and Size Differences Between Different Currents

The internal differences in size composition seen within a current area are, as has already been pointed out, regional and seasonal. Within the North Pacific Current area there is a marked tendency for the size of albacore taken along the same latitude to increase gradually from west to east (Suda 1954b). This change in the size composition in an east-west direction is not uniform, being extremely gradual in some cases and rather abrupt in others. For example, the change seen in the vicinity of 150°E. is conspicuous. Such regional variations can be regarded as corresponding to internal changes in the character of the North Pacific Current.** It has already been remarked that the seasonal variations*** are thought to rest largely on ecological causes.

Table 3 has been compiled in order to compare the degree of difference between size compositions within currents with that between currents. This table shows the discrepancies between the size group composition for each area (the length frequencies analyzed by normal distributions into 5 groups (Suda 1954a)) and the average size group composition for the North Pacific Current. The reason for using the average values for this area as the base for comparison is that this is the area for which

**For example, east of 150°E. the North Pacific Current flows almost regularly eastward, but west of that longitude is the place where the Kuroshio turns the direction of its flow from northeast to east, and there are many irregular currents.

***Since it is the prevailing rule all over the area of the North Pacific Current that the size of the fish gradually increases from west to east, there is thought to be little possibility of the existence of different stocks (Uda and Tokunaga 1937).

Table 2.--Sex ratio of albacore* in the North Equatorial Current area

Date of investigation	Locality		Male	Female	Ratio (♂/♀)
May 4 -May 23, 1949	18°18'N.-20°59'N.	148°10'E.-152°02'E.	84	40	2.1
June 22 -July 2, 1949	21°56'N.-22°56'N.	148°52'E.-152°54'E.	59	26	2.3
Mar. 5 -Mar. 22, 1949	21°00'N.-24°13'N.	143°32'E.-151°45'E.	14	6	2.3
Feb. 14-Feb. 19, 1950	22°12'N.-24°42'N.	149°52'E.-152°28'E.	17	3	5.7
Mar. 26-Apr. 6, 1950	22°50'N.-24°10'N.	143°15'E.-146°09'E.	56	9	6.2
May 17 -June 14, 1952	13°55'N.-22°54'N.	146°23'E.-153°06'E.	10	12	0.8
July 2 -Aug. 1, 1952	10°08'N.-24°04'N.	150°23'E.-158°43'E.	56	16	3.5
	Total		296	112	2.64

*Includes the individuals whose body length was not measured.

Table 3.--Dissimilarity of size component by locality. As the standard of the comparison, the mean value of four localities in the North Pacific Current area was used

Area	Season	140°E.-150°E.	150°E.-160°E.	160°E.-170°E.	170°E.-180°E.
North Pacific Current area	1948	○	□	□	○
	1949	X	□	□	□
	1950	□	□	□	□
	1951	○	□	□	□
	1952	○	□	□	○
	1948		—		Northward migrating albacore (caught by pole and line)
	1949		—		
	1950		—		
	1951		○		
	1952		□		
North Equatorial Current area	1948	X	X	—	—
	1949	X	X	X	—
	1950	X	X	X	X
	1951	X	—	X	X
	1952	X	—	X	X
Equatorial Counter-current area	1948	—	—	—	—
	1949	—	—	—	—
	1950	X	X	X	—
	1951	X	X	X	—
	1952	X	X	—	X

we have the most data and we can see the internal changes in the size composition more clearly than in other current areas. The discrepancies were shown in the following manner. For each current we found $\sum_{n=1}^{5} \frac{(m_n - M_n)^2}{M_n}$, and where this value was less than 50 we marked it □, when 50-100 ○, and when over 100 X. M_n is the percentage of Group n in the average size group composition for the North Pacific Current, and m_n is the percentage of Group n for each of the localities. On the basis of table 3 it can be said that (1) the differences in the size composition as between different currents is far more conspicuous than the regional differences within the North Pacific Current, and (2) the differences between currents are also more outstanding than the seasonal differences in the size composition within the North Pacific Current. Consequently, for the North Pacific Current, at least, the differences from other currents are much greater than the variations within the current.

Conclusions

(1) The albacore of the North Pacific Current, the North Equatorial Current, and the Equatorial Countercurrent have differing size compositions (fig. 1).

(2) The differences in size composition between the North Pacific Current and the other two currents are much greater than the various kinds of internal differences seen within the North Pacific Current (table 3).

(3) It is thought that there is a connection between such differences in size composition and the fact that the possibilities of spawning and the sex ratios differ as between currents.

The foregoing facts clearly confirm what Nakamura (1954) has indicated about different currents being different biological environments (conclusion 2) and the differences in the ecological significance of the schools which are distributed in different currents (conclusion 3).

In conclusion the author wishes to thank those members of the staff of the Nankai Regional Fisheries Research Laboratory who collected the data, and also Director Nakamura and High Seas Resources Section Chief Yabe for their assistance.

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