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DIVISION OF FISH AND GAME OF CALIFORNIA
FISH BULLETIN No. 31
Studies of the Length Frequencies of the California Sardine (Sardina caerulea)

BY

THE CALIFORNIA STATE FISHERIES LABORATORY

FOREWORD

The two papers herein presented comprise further results from a continuous study of the California sardine. The program of investigation was inaugurated in 1919 and has been carried on by a staff of numerous workers. Fourteen previous publications have been issued by various authors. Since the program is so largely cooperative, any publication of facts derived from the investigation would not be possible were it not for the contributions of past and present members of the staff of the California State Fisheries Laboratory. These people, all of whom can not be enumerated, have given generously of their time in the collection of material and of their counsel in the staff conferences which largely determined the nature of the conclusions here drawn. Special mention, however, should be made of three individuals: Mr. N. B. Scofield, head of the Bureau of Commercial Fisheries, Division of Fish and Game, whose untiring efforts not only established the laboratory but also have made possible the continuation without interruption of its research program for more than eleven years; Dr. W. F. Thompson, director of investigations, International Fisheries Commission (United States and Canada), who formulated the program for the sardine studies and who has continued to advise freely about the many problems which have arisen; and to Mr. W. L. Scofield, present director of the laboratory, who aided materially in interpreting the facts presented by the data and who led the conference discussions which have shaped the recent trends of the investigation.

Frances N. Clark.

CONTENTS

DOMINANT SIZE-GROUPS AND THEIR INFLUENCE IN THE FISHERY FOR THE CALIFORNIA SARDINE
(Sardina caerulea)

By Frances N. Clark

Contribution No. 107 from the California State Fisheries Laboratory, August, 1930. Although the California sardine has recently been assigned to the genus Sardinops by Hubbs (Proc., Calif. Acad. Sci., 18, p. 261–265, 1929), until this name comes into general use we have retained the better known form, Sardina.

CONTENTS

1. INTRODUCTION

During the past eleven years, 1919 to 1930, the California State Fisheries Laboratory has carried on an intensive study of the California sardine. One phase of this work has been a thorough sampling of the commercial catch landed at each of the principal fishing ports. A study of these samples has demonstrated, from season to season, major fluctuations in the size of the fish in the catch. These fluctuations were caused by three different dominant groups which influenced the fishery during the eleven-season interval of the study and a fourth which appeared in the last season, 1929–1930.

These superabundant groups appeared in the catch in three or four year intervals, the fish in each group increased in size from season to season, and the group finally lost its dominance with the entrance of a new and more abundant size-group. This entrance into and passage through the fishery of each dominant group largely determined the average size of fish in the commercial catch. For seasons in which the dominant group was composed of large fish the average size of the fish in the catch was large; when the fish of the superabundant group were small the average was small.

In addition to the dominant groups which appeared in the sardine catch, other size-groups have been characterized by a relative scarcity of fish. These deficient groups showed a similar size progression from season to season and eventually disappeared from the catch as did the superabundant groups. Obviously the available supply of fish to the fishermen is greatly affected by these fluctuations in the numbers of fish of each size-class. A dominant group of small-sized fish accompanied by a subnormal number of large fish produces an apparent scarcity of large fish, while the reverse condition seems to indicate an unusual abundance of the larger sardines. This latter condition prevailed in the fishery at Monterey from 1927 to 1929 and at San Pedro from 1926 to 1928. Any adequate measure of population abundance can be made therefore only with due consideration of the influence of these dominant groups. Thus these dominant size-classes play a significant role in the task of detecting the presence or absence of overfishing for the sardine.

The same superabundant groups occurred simultaneously at both Monterey and San Pedro, and this fact throws further light on the problem: Do sardines intermingle freely along the California coast or is fishing in each locality maintained by a separate population? The answer to this question is of great importance in fishery regulation.

From the known history of the three dominant size-classes which passed through the catch during the interval under observation, the fate during the succeeding two or three years of the fourth group which entered the fishery in 1929–1930 has been forecast. It may be with study of further data that the time of appearance of abundant or deficient groups also can be told in advance.

Since it is evident that these dominant groups affect all phases of the sardine investigation and largely explain the variations in the nature of the catch, this preliminary analysis is here presented.

2. SCOPE OF THE PRESENT WORK

A presentation of the complete analysis of the length frequency data collected during the eleven years which have elapsed since the sardine investigation was inaugurated would delay indefinitely the publication of the preliminary results and would produce too cumbersome and complicated a paper. Consequently this publication deals only with the total length frequency data for each of the fishing seasons from 1919 to 1930 for Monterey and San Pedro and from 1928 to 1930 for San Diego. For the Monterey and San Pedro data, analyses of the component parts of the first four seasons, 1919 to 1923, were made by Scofield, Higgins and Thompson, but in the later years so many data have accumulated that the material will be presented in a series of publications.

Studies of daily average lengths by Andrews (1928) and Clark (1930) showed that consistent size differences between fall and winter fish exist at each fishing locality, and that to secure a true picture of sizes for each fishing season, data collected throughout the entire season must be used. Fall fish of one season can not be compared with winter fish of another season. Because of these findings this study is based on the analysis of the total season's data only, and makes a comparison of the sizes of fish from season to season and from locality to locality. Similar studies are now in progress for separate fall and winter portions of each season. Detailed analysis of the length frequencies of San Diego sardines are presented by Godsil in the second paper of this bulletin.

3. COLLECTION AND TREATMENT OF THE DATA

3.1. COLLECTION OF MATERIAL

The program evolved for the sardine investigation is exceedingly comprehensive, but because of the care and forethought exercised at the instigation of the work, the same methods have been adequate throughout the entire study in spite of changes which have occurred in fishing procedure. The details of these methods were described for San Pedro by Higgins (1926), for Monterey by Scofield (1926) and for San Diego by Godsil in the second paper of this bulletin. At Monterey from 1919 to 1923 and at San Pedro from 1919 to 1921, samples of sardines were taken from five fishing boats daily, and in the following years from five boats semiweekly. The adequacy of semiweekly sampling was demonstrated by Sette (1926). With the exception of the last two seasons, at Monterey each sample consisted of forty fish, while for the last two seasons at Monterey and for the entire eleven years at San Pedro each sample comprised fifty fish. Forty fish made up each sample at San Diego. Thus either 200 or 250 fish were measured on each sampling day.

Each fish was measured on a board designed for that purpose and measurements read to the nearest millimeter. The body or standard length used in all the California sardine studies is from the tip of the mandible to the end of the silvery area exposed on the caudal peduncle when the scales are removed. The seasonal length frequencies each consisted of the summation of the many sample distributions and because each sample comprised an equal number of fish, each sample had the same influence on the seasonal curves as did any other sample. Data for males and females were compiled separately, but this paper deals only with the length distributions for the combined sexes.

Since previous studies on daily average lengths demonstrated decided size differences between fall and winter fish, a true picture of the distribution for a fishing season must be derived from measurements of fish taken over the entire fishing period. Due to various causes, the length of the fishing season has varied greatly from year to year and differs markedly between localities. The Monterey sardine season is the longest and in some instances has extended from June of one year to March of the following year. At San Pedro the maximum seasons have extended from late September to May, but in the earlier years, 1919–1924, no fishing occurred before December and the fall fishery is not represented in the San Pedro data for these seasons. The fishery at San Diego for large, adult sardines takes place from January to April only, and the data from that locality are characteristic of the winter fisheries at the other ports. In 1929 the California Legislature restricted the time in which sardines can be taken for canning purposes, and the season now opens at Monterey on August 1 and closes on February 15. At San Pedro and San Diego the season extends from November 1 to March 31.

Because differently sized fish are taken at different times in a fishing season, an ideal condition would exist if all fishing seasons were of equal length, but this study deals with conditions as they actually exist and the data here presented describe the sizes in the commercial catch of each fishing season regardless of the length of that season. The only serious error resulting from this method becomes apparent when the length frequency curves for San Diego are compared with those for Monterey and San Pedro. Because the San Diego fishery is a winter fishery only, the numbers of large fish for this locality appear disproportionately great when compared with the Monterey and San Pedro data.

3.2. USE OF PERCENTAGES

After the length frequencies for each season had been compiled the frequencies were smoothed twice by a moving average of three, and the resulting numbers at each millimeter of length expressed in percentages of the total. Since the lengths of the fishing seasons, and consequently the number of samples and the number of fish measured, varied greatly from year to year and from locality to locality, this use of percentages was necessary to make directly comparable length frequencies for each season and each locality. Such a use of percentage frequencies

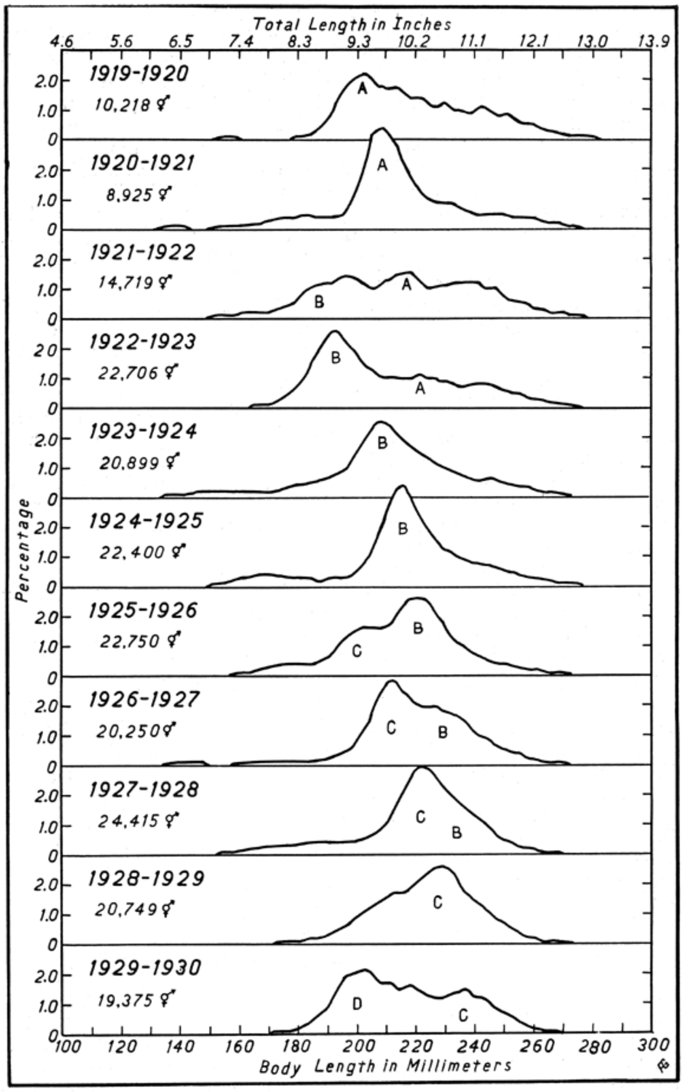

FIG. 1. Seasonal length frequency polygons of the combined measurements of sardines at Monterey and San Pedro expressed in percentages of the season's total.

FIG. 1. Seasonal length frequency polygons of the combined measurements of sardines at Monterey and San Pedro expressed in percentages of the season's total

involves certain statistical errors which have been discussed in detail by Thompson (1926, p. 179).

To secure the seasonal length frequency curves for the combined data for Monterey and San Pedro (see fig. 1), the percentage curves for both localities were summed for each season and the resulting sums divided by two. Thus each locality was equally represented in each seasonal frequency.

3.3. CALCULATION OF THE DEVIATION CURVES

To demonstrate more clearly the dominant size-groups and their progression from season to season, calculations were made of the deviations of each season's frequency from an average season. This average season was determined by summing the percentage length frequencies for the eleven seasons and dividing by eleven the sums resulting at each length unit. The eleven-season average frequency was then subtracted from each individual percentage frequency.

3.4. COMBINED LENGTH FREQUENCIES FOR MONTEREY AND SAN PEDRO

3.4.1. Dominant Groups

To depict the size distribution of sardines taken in the commercial catch at the two chief fishing ports, Monterey and San Pedro, the eleven, seasonal length frequency curves resulting from a combination of the data from these two ports are presented in figure 1. These frequency curves show the size changes which have occurred in the major California sardine catch over the eleven-season period. Three dominant groups, here designated **A, B,** and **C,** have passed through the fishery in the time interval covered by the investigation, and a fourth group, **D,** appeared in the last season, 1929–1930. Group **A** was present in the fishery for the first four years; **B** appeared in 1922–1923 and was evident for the four succeeding seasons. In 1925–1926, **C** first made its appearance.

Since the frequency curves here presented are very complex, an analysis of these dominant groups is difficult. Mathematical formulae and graphical methods were used to separate the superabundant groups from the remainder of the frequency curves, but the results did not prove satisfactory. In many instances the resultant curves were questionable and too largely determined by the personal bias of the worker. If the age of sardines could be ascertained by any of the methods usually employed by fisheries workers, the frequency curves for each age-class could be defined and the entire curves broken up into their various age-groups. But studies of ways of determining the age of the California sardine are not as yet far enough advanced to allow an analysis of the dominant groups by age-classes. The method adopted for handling the present data has been therefore to deal with the seasonal frequency curves in their entirety.

3.4.2. Frequency of Appearance of the Dominant Groups

One of the first problems is to determine the frequency with which the dominant groups enter the commercial catch. Can new dominant groups be expected to appear in the catch at regular intervals or is their appearance merely fortuitous? Since the age of the fish has not been determined, we can only compute the number of seasons which elapsed after one group entered the fishery until a second group was clearly manifest. When sampling began in 1919, group **A** was present in the catch. Whether **A** was evident the previous year is not known, but since **A** in 1919–1920 corresponded roughly in size to the entering sizes of other groups, the assumption has been made that this was the first season of appearance. On this basis, group **B** appeared three years after **A; C**, three years after **B**; and **D**, four years after **C**. In their first season, the modes of **A, C** and **D** fell at approximately 200 mm., but the first mode of **B** occurred only slightly above 190 mm. Did the fish comprising **B** first enter the commercial catch one year younger than the fish of the other three groups, or did **B** represent a slower growing group of fish? If group **B** in the 1922–1923 season was comprised of sardines one year younger than the fish of group **A** in 1919–1920, and of **C** in 1925–1926, we must conclude that groups **A** and **B** are separated as to age by a period of four years, **B** and **C** by two years and **C** and **D** by four years.

Either method of determining the time interval between the dominant groups indicates that these groups have not entered the fishery with any definite periodicity, but that during the eleven seasons covered by the investigation not more than four seasons elapsed after one group made its appearance until a second was manifest.

3.4.3. Size Progression of the Groups

Because of the difficulty of locating the mode of each dominant group, the size progression from season to season of these classes was determined only approximately. The method adopted was to smooth each distribution twice by a moving average of three, and to call the highest point of each group the mode. In figure 2 and table 1, are indicated the progression of each mode thus located. The irregularity in the progression of the modes was due in part at least to the inadequate method of location. The most erratic increase occurred in mode **B**. The increase from 1922–1923 to 1923–1924 was 16 mm., while the increase from 1924–1925 to 1925–1926 was only 2 mm. Group **C** showed a consistently greater increase than **A** or **B**.

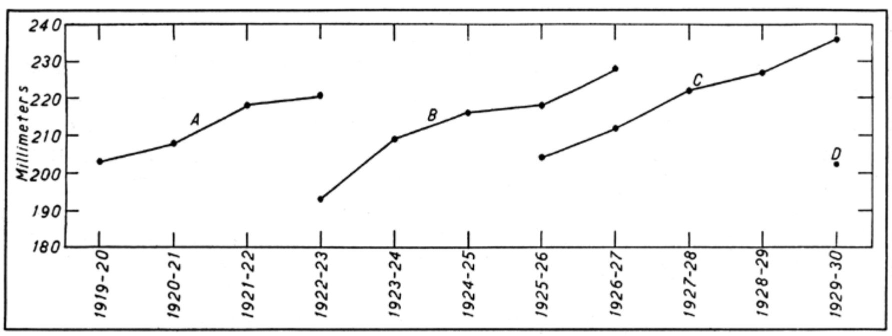

FIG. 2. Seasonal progression of the modes of the dominant groups in the combined Monterey and San Pedro data.

FIG. 2. Seasonal progression of the modes of the dominant groups in the combined Monterey and San Pedro data

TABLE 1

Location of the Modes of Each Dominant Group According to Season in Combined Monterey and San Pedro Data

Season	Mode A mm.	Mode B mm.	Mode C mm.	Mode D mm.
1919–1920	203			
1920–1921	208			
1921–1922	218			
1922–1923	221	193		
1923–1924		209		
1924–1925		216		
1925–1926		218	204	
1926–1927		228	212	
1927–1928			222	
1928–1929			227	
1929–1930			236	202

TABLE 1

Location of the Modes of Each Dominant Group According to Season in Combined Monterey and San Pedro Data

To make more readily comparable the seasonal progression of each mode, the locations of the modes are again shown in figure 3 in accordance with the season in which they appeared in the fishery.

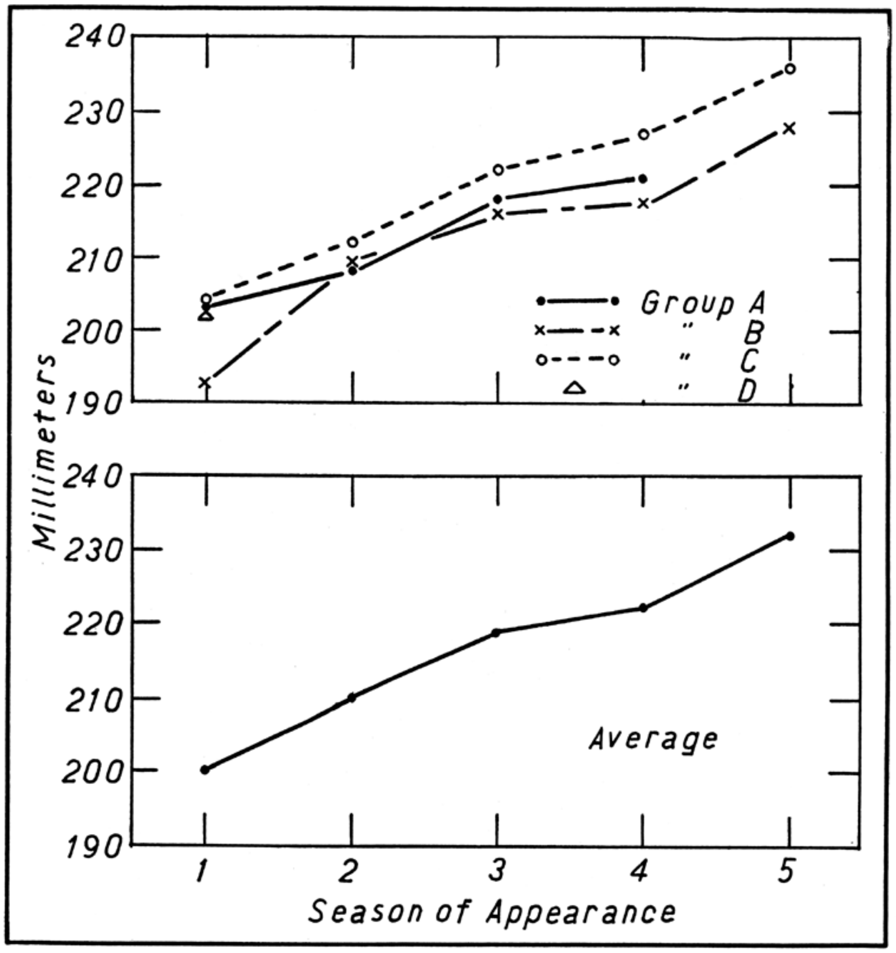

FIG. 3. Progression of the modes according to the season of appearance of the dominant groups. Monterey and San Pedro data combined.

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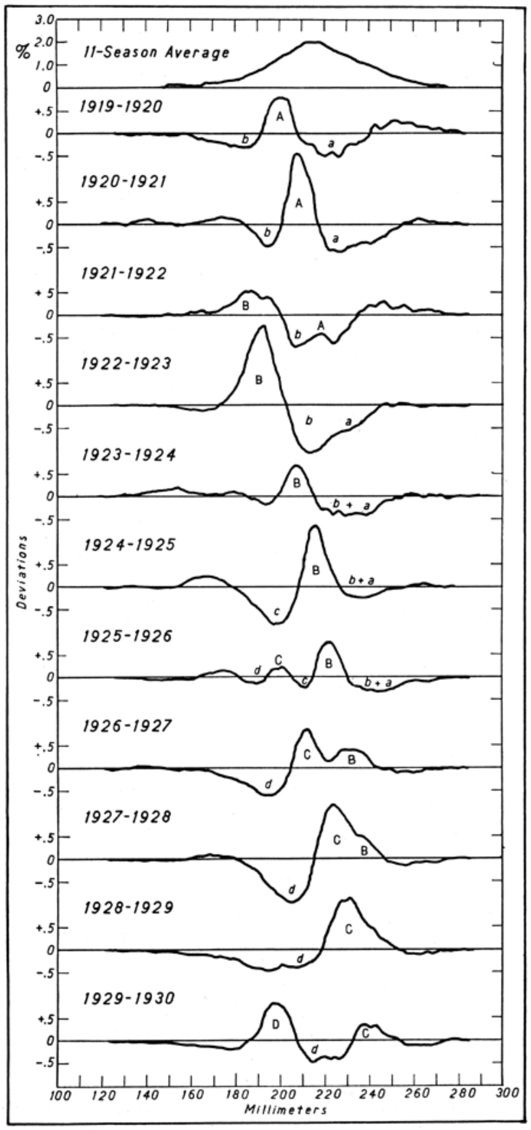

FIG. 4. Seasonal deviations from the eleven-season average frequency polygon of the combined Monterey and San Pedro measurements.

FIG. 4. Seasonal deviations from the eleven-season average frequency polygon of the combined Monterey and San Pedro measurements

Thus in the season of entrance mode **A** fell at 203 mm., in the second year at 208 mm., etc. In the entering season mode **B** occurred practically a centimeter lower than **A, C** or **D**, but in the next three seasons **A** and **B** were very similar in location while **C** was somewhat higher, and in the fifth season both **B** and **C** showed an unexpected progression over the previous year. An explanation of this unusual increase between the fourth and fifth seasons is not clear, but since in the fifth year neither group **B** nor **C** were very dominant, it is probable that the rough method of treating the data fell far short of locating the true modes for these seasons.

The average progressions of the modes for all the groups is indicated in the lower graph of figure 3. Since **B** and **C** alone determined the location of the mode in the fifth season, again the increase between the fourth and fifth season appeared abnormal. The average seasonal increase was 7.9 mm.

3.4.4. Deviations from the Eleven-Season Average Frequency

The four dominant groups which appear in the frequency curves of figure 1 stand out even more strikingly in figure 4. These curves portray the amount that each seasonal frequency curve deviated from the average frequency curve for the eleven seasons. In addition to the dominant groups **A, B, C**, and **D**, there are manifest, in these deviation curves, size-groups characterized by a scarcity of fish. These deficient groups, designated **a, b, c**, and **d**, showed the same types of size progression as did the dominant groups and are recognizable for an even greater number of seasons.

Group **a** was clearly apparent for the first two seasons only, but **b** influenced the fishery for the first seven years. This paucity of sardines of size-classes just greater than those of dominant group **B** was partly responsible undoubtedly for the decided dominance of **B**. Since in the seasons from 1922 to 1926 large sardines were apparently scarce in the fishing areas, the fishery relied chiefly on group **B** and thus brought this group into great prominence. The scarcity of fish of group **c** was manifest for four seasons only, and this group was not marked by as decided a lack of fish as was **b**. Group **d** was evident in the fishery for the last five seasons and will probably persist for one or two more.

After the appearance of dominant group **C** in 1925–1926, the fishery was characterized by a scarcity of numbers in the incoming year-groups which was not interrupted until group **D** entered in 1929–1930. These deficient size-groups exert as great an influence on the fishery as do the dominant groups, and any analysis of sizes of sardines must be based on an understanding of the subabundant as well as of the superabundant groups.

3.5. DOMINANT GROUPS IN EACH FISHING AREA

3.5.1. Monterey

3.5.1.1. Frequency of Appearance

The eleven, seasonal frequency curves for the Monterey data are depicted in figure 5. The same dominant groups which occurred in the combined data also appeared in the Monterey frequencies.

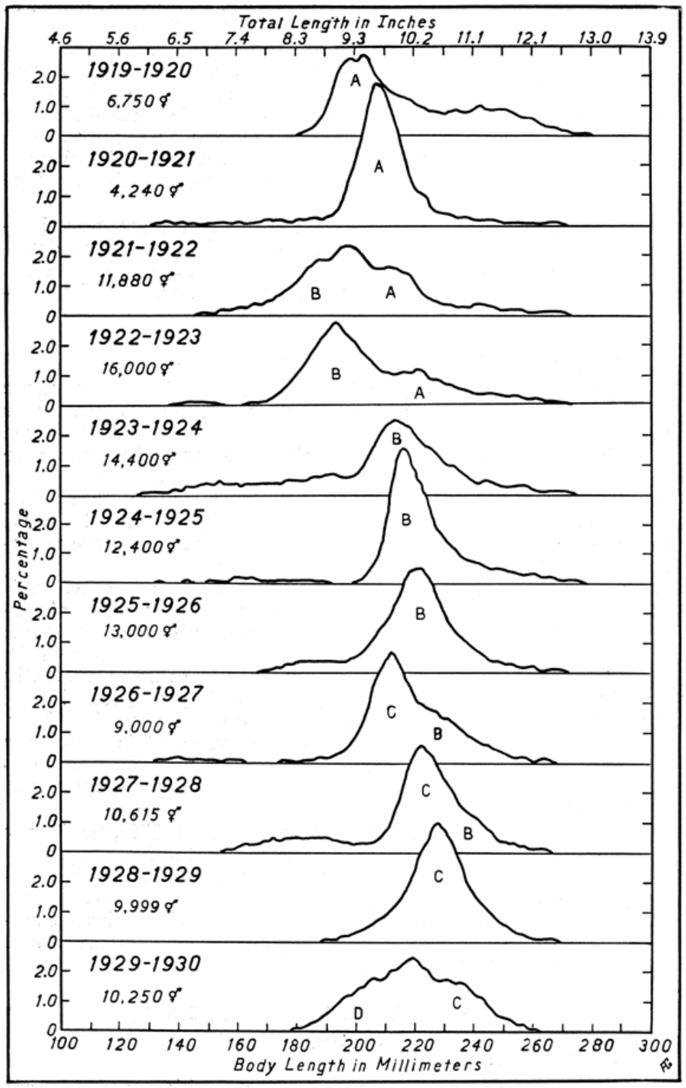

FIG. 5. Seasonal length frequency polygons of sardines measured at Monterey, expressed in percentages of the season's total.

FIG. 5. Seasonal length frequency polygons of sardines measured at Monterey, expressed in percentages of the season's total

Group **A** was manifest from the first to the fourth season, 1922–1923, when group **B** was clearly recognizable. In the previous year, 1921–1922, the height of the curve between 180 and 190 mm. suggested the incoming of group **B**, which was so definitely dominant in the following four seasons. In 1921–1922 the dominance of group **A** greatly diminished, group **B** although probably present was not taken in sufficient numbers to have much effect on the catch, and, as indicated by the abundance of fish from 190 to 205 mm., this season's fishery was largely supported by the size-groups occurring between **A** and **B**. In the next season, 1922–1923, this indication of dominance of sizes just larger than group **B** was not manifest. During the three succeeding seasons, 1923–1924, 1924–1925 and 1925–1926, the fishery chiefly relied on group **B**. By 1926–1927, **B** had disappeared as a dominant class and group **C** entered the fishery. In this and the two following years, 1927–1928 and 1928–1929, the fishery depended almost entirely on group **C**, but by 1929–1930, the dominance of this group was barely discernable. In this last season, possible traces of group **D** were evident between 190 and 200 mm., but the fishery was largely maintained by the size-groups between **D** and **C**. Thus with the exception of 1921–1922 and 1929–1930, the sardine fishery at Monterey has been characterized in any one fishing season by its major dependence on a single dominant group.

The time interval between the appearance of each dominant group in the Monterey fishery was irregular. If the assumption is made that **A** first appeared in 1919–1920, three fishing seasons elapsed between the entrance of **A** and **B**, four seasons later **C** appeared, and three seasons transpired between the origin of **C** and the suggested appearance of group **D**. Whether **D** will be clearly dominant at Monterey in 1930–1931 remains to be seen. If it so enters, an interval of four seasons will have occurred between **C** and **D**. Thus the entrance of the dominant size-groups into the Monterey fishery can not be considered periodic, but during the time of the investigation, not more than four seasons passed between the first occurrence of any two dominant size-groups.

3.5.1.2. Size Progression

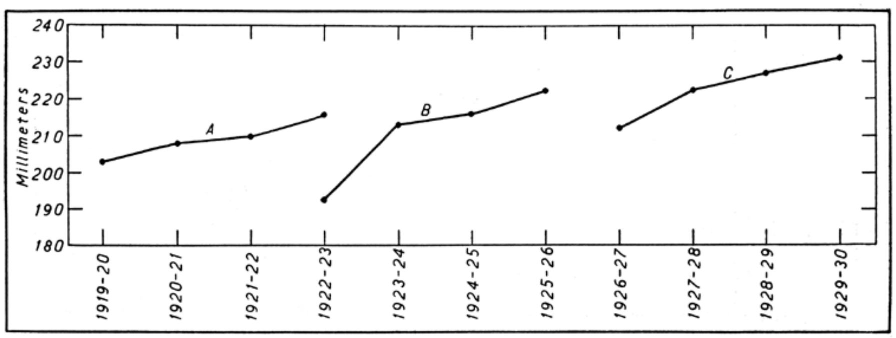

Fig. 6. Seasonal size progression of the modes of each dominant group in the Monterey data.

FIG. 6. Seasonal size progression of the modes of each dominant group in the Monterey data

TABLE 2

Position and Height of the Modes in the Length Frequency Curves of Monterey Sardines

Season	Mode A		Mode B		Mode C	
	Position, mm.	Height, per cent	Position, mm.	Height, per cent	Position, mm.	Height, per cent
1919–1920	203	2.70				
1920–1921	208	4.78				
1921–1922	210	1.61				
1922–1923	216	1.15	193	2.79		
1923–1924			213	2.46		
1924–1925			216	4.62		
1925–1926			222	3.55		
1926–1927					212	3.66
1927–1928					222	3.58
1928–1929					227	4.02
1929–1930					231	1.73

TABLE 2

Position and Height of the Modes in the Length Frequency Curves of Monterey Sardines

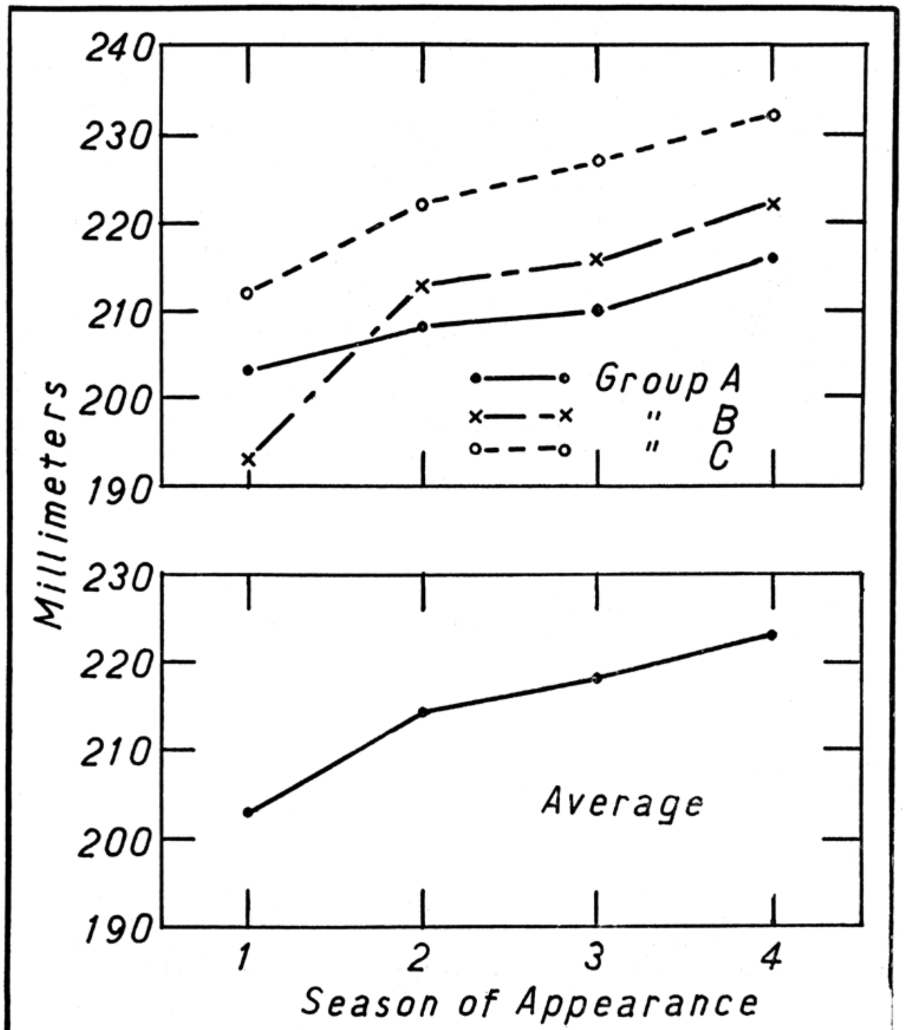

FIG. 7. Progression of modes of the dominant groups according to the season of appearance in the Monterey fishery.

FIG. 7. Progression of modes of the dominant groups according to the season of appearance in the Monterey fishery

The size progression from season to season of the modes of the three dominant groups is shown in figure 6 and table 2. Little similarity existed in the progression of the modes of each group. In the four seasons that each was evident, mode **A** moved 13 mm.; **B**, 29 mm.; and **C**, 19 mm. The seasonal increase of **A** and **C** was relatively constant but **B** varied from 3 to 10 mm.

To compare this size progression of the modes, they are again located in figure 7 according to the season in which they appeared in the fishery. Mode **C** entered the fishery at 212 mm., which corresponded roughly with the location of **A** and **B** in their second season, but this accounts only in part for the consistently higher location of the modes for **C**. The average progression of the three modes is defined in the lower graph of figure 7. The average increase from season to season was 6.7 mm.

3.5.1.3. Height of the Modes

Because the length frequencies are expressed in percentages of the total, the height of the mode of any dominant group is affected

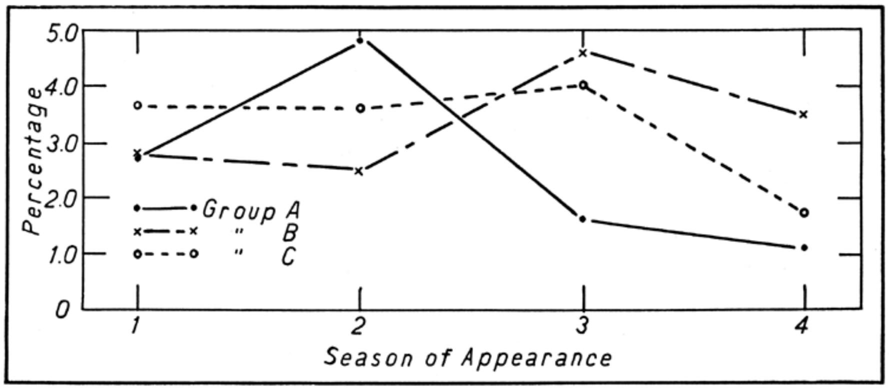

FIG. 8. Height of the mode of each dominant group according to the season of appearance in the Monterey fishery.

FIG. 8. Height of the mode of each dominant group according to the season of appearance in the Monterey fishery

by the presence or absence in the seasonal catch of other such groups. If two dominant groups occur in a seasonal frequency neither mode will be as high as if only one superabundant group were present. Similarly incoming dominant groups will decrease the amount of dominance of the group already present in the catch. Since all of the dominant groups were subjected to the influence of other abundant groups, the height of the mode constitutes only a very rough measure of the amount of dominance of each group. These heights, given in table 2, are represented in figure 8 in accordance with the season of appearance in the fishery. Mode **A** was higher in its second season than in its first, but diminished rapidly in the third and fourth years. **B** differed but little in the first two seasons, increased in the third and decreased in the fourth. **C** remained relatively constant in the first three seasons, but fell off greatly in the fourth. In the first season of appearance, **C** exceeded **A** and **B**; in the second **A** surpassed **B** and **C**; and in the third and fourth **B** was greater than **A** or **C**.

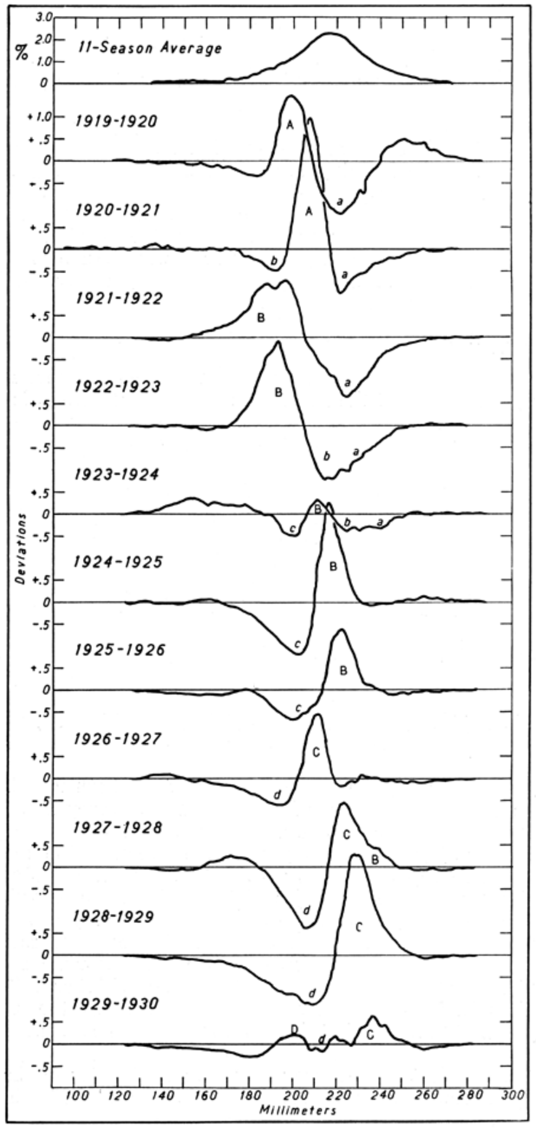

FIG. 9. Seasonal deviations from the eleven-season average frequency polygon of the Monterey data.

FIG. 9. Seasonal deviations from the eleven-season average frequency polygon of the Monterey data

The height of the mode in the season that a dominant group enters the Monterey fishery apparently gives little indication of the amount of dominance of that group in succeeding years. As a rule, however, little decrease in dominance should be expected in the two succeeding seasons, a falling off will probably occur in the fourth, and a size-group can not be expected to maintain its dominance after the fourth season.

3.5.1.4. Deficient Size-Groups

The dominance of the size-groups **A, B, C**, and **D** in the Monterey data is again demonstrated in figure 9, which depicts the deviations of each seasonal length frequency curve from the eleven-season average curve. In addition, figure 9 discloses the paucity of certain size-groups. The scarcity of sardines larger than group **A**, comprised in depression **a**, was evident during the first five seasons of the investigation. A deficiency of sardines between groups **A** and **B**, revealed by depression **b**, appeared in the fishery from 1920–1921 to 1923–1924, with the exception of the 1921–1922 season. In this year, group **A** largely lost its dominance, **B** had not yet entered in any great numbers, and the fishery relied on these size-classes previously defined by depression **b**. For this reason, **b** was not evident in the deviation curve for 1921–1922, but an increase of fish amounting to dominance occurred at sizes which presumably should have been represented by **b**. That this was not a permanently dominant condition was manifest by the recurrence of **b** in the following season.

Depression **c** followed group **B** and preceded **C**. This scarcity of fish smaller than group **B** influenced the fishery for three seasons, from 1923–1924 to 1925–1926. Group **C** was immediately succeeded by a paucity of fish comprised in depression **d**. The depth and breadth of **d** would seem to indicate that this scarcity of fish involved several year-classes and, with the possible exception of depression **a**, no other such lack of sardines occurred in the Monterey fishery during the period of investigation.

In the 1929–1930 season dominant group **C** was very much diminished, group **D** was only slightly evident, and the fishery depended largely on the size-classes previously represented by **d**. Depression **d** was therefore only slightly evident in this deviation curve, a condition somewhat paralleling the 1921–1922 season. The possible reappearance of depression **d** in 1930–1931 will be awaited with much interest.

3.5.2. San Pedro

3.5.2.1. Frequency of Appearance

The seasonal length frequency curves for the San Pedro sardine data, given in figure 10, disclose the same dominant size-groups as do the Monterey and also the combined frequencies. Group **A** was apparent from 1919–1920 to 1922–1923, when **B** entered the fishery. Group **B** stood out as a dominant group for five seasons and was evident in the catch until 1929–1930. Group **C** appearing in 1925–1926 was still manifest in the fishery in 1929–1930, when **D** first made its entrance. In 1928–1929, the dominance of **C** was appreciably reduced, and the fishery depended largely on the size-classes

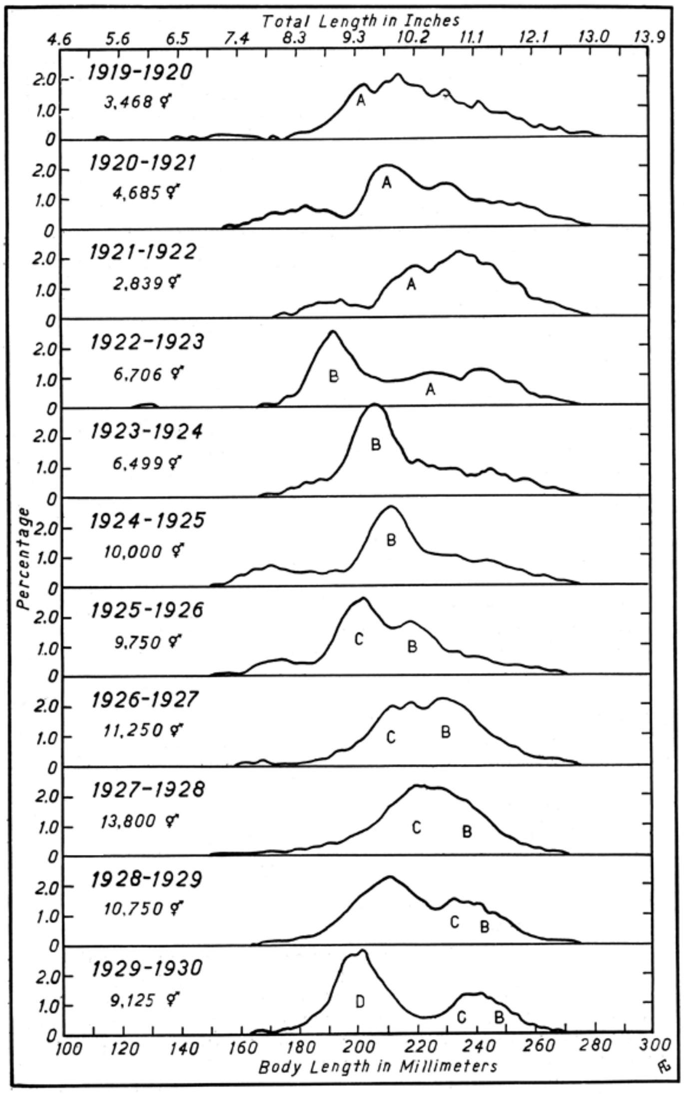

FIG. 10. Seasonal length frequency polygons of sardines measured at San Pedro, expressed in percentages of the season's total.

FIG. 10. Seasonal length frequency polygons of sardines measured at San Pedro, expressed in percentages of the season's total

just smaller than **C**, causing in this season a superabundance of these groups. That this did not indicate a new dominant group is demonstrated by the scarcity in 1929–1930 of sizes just smaller than **C**. A somewhat analogous condition existed at Monterey in 1929–1930, but the similarities and differences of the length frequencies for the two ports are more clearly illustrated in the following section, "Comparison of Dominant Groups in Each Locality."

The frequency curves for San Pedro sardines indicate that at this port each season's fishery was not so largely dependent on a single dominant group as was the fishery at Monterey. At San Pedro two such groups were discernable in four of the eleven seasons and in no season did a single group completely dominate the size distributions.

As at Monterey, a fluctuating time interval occurred between the entrance of any two abundant groups. Group **B** followed three seasons after **A; C** also succeeded **B** in three years; but **D** did not appear until four seasons after **C**. Up to the present time, therefore, a four-year period has been the maximum interval between the entrance of any two dominant groups into the San Pedro fishery.

3.5.2.2. Size Progression

The seasonal size progression, defined in table 3 and figure 11, of the dominant groups in the San Pedro fishery was relatively regular. The modes of each group were located, as in the previous curves, by smoothing the length frequency data twice by a moving average of three. Group **A** in three seasons progressed 22 mm.; **B**, 26 in three years and in four years 36 mm.; while **C** moved 30 and 34 mm., respectively. The accurate location of mode **C** in 1928–1929 and in 1929–1930 was difficult. The dominance of this group in these two seasons was much reduced and the mode poorly defined. The interpretation here given is considered the best that can be made from the data, but probably fails to indicate the true mode for this group.

TABLE 3

Position and Height of the Modes in the Length Frequency Curves of San Pedro Sardines

Season	Mode A		Mode B		Mode C		Mode D	
	Position, mm.	Height, per cent	Position, mm.	Height, per cent	Position, mm.	Height, per cent	Position, mm.	Height, per cent
1919–1920	203	1.80						
1920–1921	209	2.12						
1921–1922	220	1.68						
1922–1923	225	1.08	192	2.55				
1923–1924			206	3.10				
1924–1925			212	2.69				
1925–1926			218	1.78	202	2.56		
1926–1927			228	2.24	212	2.01		
1927–1928					220	2.37		
1928–1929					232	1.51		
1929–1930					236	1.33	201	2.77

TABLE 3

Position and Height of the Modes in the Length Frequency Curves of San Pedro Sardines

The modes are again located in figure 12 according to the season of entrance into the fishery. Modes **A, C** and **D** first appeared in practically identical locations, 203, 202 and 201 mm., but **B** entered

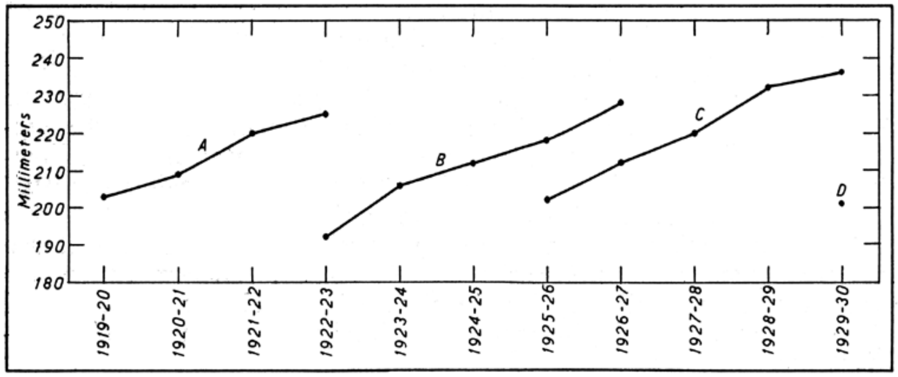

FIG. 11. Seasonal size progression of the modes of each dominant group in the San Pedro data.

FIG. 11. Seasonal size progression of the modes of each dominant group in the San Pedro data

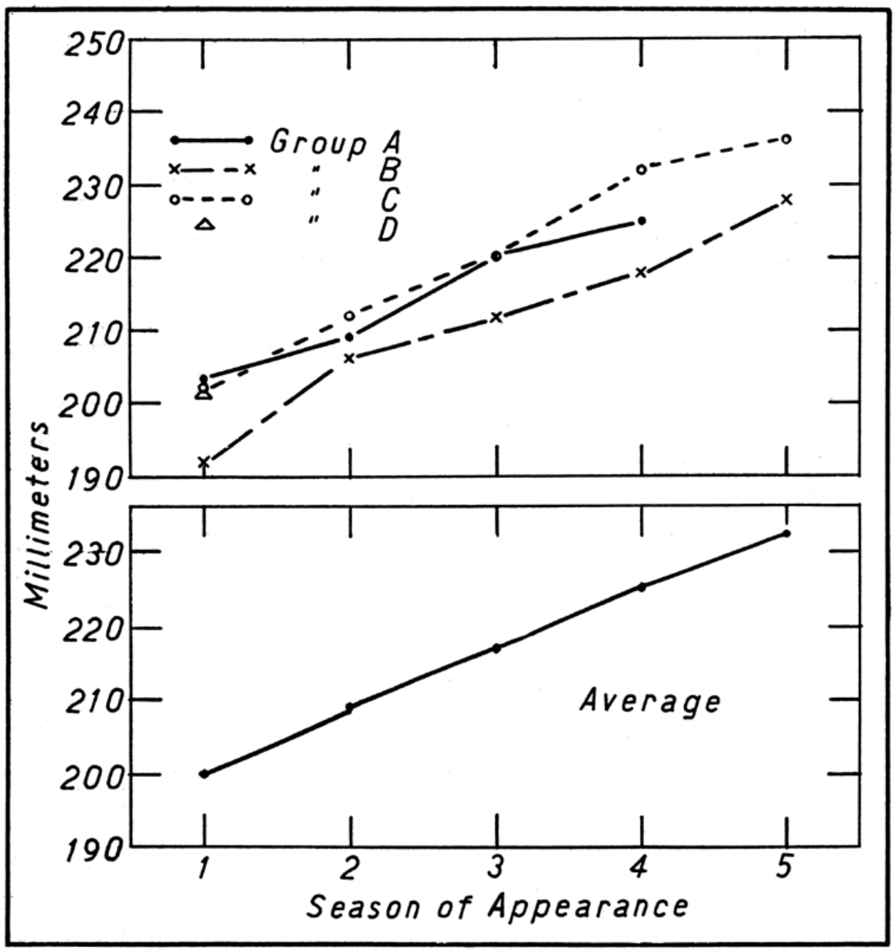

FIG. 12. Progression of modes of the dominant groups according to the season of appearance in the San Pedro fishery.

FIG. 12. Progression of modes of the dominant groups according to the season of appearance in the San Pedro fishery

at 192 mm., and the modes of **B** fell at points consistently lower throughout the following seasons. This discrepancy in the location of **B** may be involved in age differences. If the age-classes comprised in **B** are considered one year younger at the time of entrance than the age-classes of **A** and **C**, the second season of entrance for **B** would correspond to the first for **A** and **C**, and the locations of **B** would very closely coincide with **A** and **C** for this and the following seasons. On the other hand, group **B** may be composed of fish of the same age-classes in the season of entrance as **A** and **C**, which entered the fishery at a smaller size. The size progression of **B** during the three years after first appearance exceeded **A** by 4 mm. and fell short of **C** by 4 mm. Since the length frequencies can not be broken up into their component age-classes, we can only consider the size increase in relation to the time of entrance of each dominant group.

The average size progression of the three groups is expressed in the lower graph of figure 12. The seasonal average increase was 8.1 mm.

3.5.2.3. Height of the Modes

To measure roughly the amount of dominance of the groups, the heights of each mode in percentage of the total frequency are given by seasons in table 3, and according to time of entrance in figure 13. With the exception of the second season, the height of **A** at no time equalled **B** or **C**. Mode **B** exceeded all other groups except for the first season when it coincided with **C** and was higher than **A**. In the year of entrance **D** was higher than any of the other modes, but this excess was not sufficiently great to warrant the assumption that **D** will be more dominant in the succeeding years. The height of all of the modes dropped off in the fourth season; **A** could not be accurately defined in the fifth; **C** was slightly lower than in the fourth; and **B**, although somewhat higher, did not equal its height in the seasons previous to the fourth. No mode could be defined accurately after the fifth season.

The data indicate that for two seasons after a dominant group enters the San Pedro fishery little decrease in dominance occurs, in the fourth and fifth years the amount falls off, and no dominance is apparent after the fifth season.

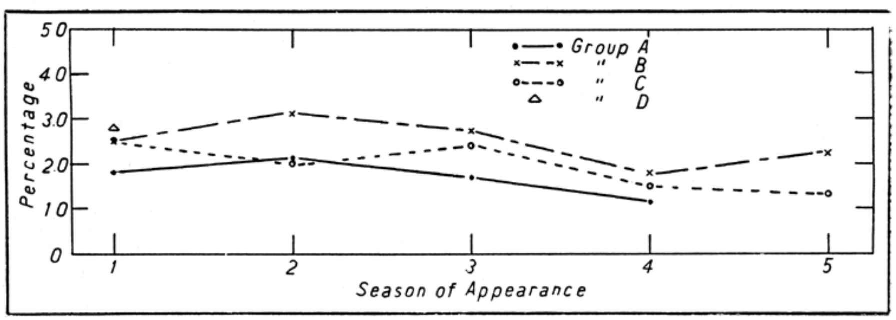

FIG. 13. Height of the modes of each dominant group according to the season of appearance in the San Pedro fishery.

FIG. 13. Height of the modes of each dominant group according to the season of appearance in the San Pedro fishery

3.5.2.4. Deficient Size-Groups

The deviation curves of figure 14, derived by subtracting the eleven-season average curve from each seasonal frequency curve, again demonstrate the dominant size-groups in the San Pedro fishery. As in the Monterey and the combined data, there are also evident size-classes characterized by a scarcity of fish. The first of these, indicated by depression **a**, immediately preceded dominant group **A**. The lack of this group of fish was much less pronounced than the similar scarcity in the Monterey fishery. Immediately following dominant group **A** appeared depression **b**, which markedly influenced the fishery for seven seasons. After 1923–1924 the dominance of group **A** was entirely lost and **a** and **b** became fused into one depression traceable throughout the remainder of the deviation curves. Depression **c** was evident for three years from 1923–1924 to 1925–1926, when the first effect of **d** was noted. These last sparsely represented size-groups gave **d** a depth and breadth almost equal to **b**. That **d** will persist in the fishery as many seasons as did **b** seems quite probable.

The deviation curves for 1921–1922 and 1928–1929 are worthy of special note. In 1921–1922, the industry depended chiefly on size-groups larger than **A** and the dominancy of **A** was very much suppressed, with the result that depression **a** did not appear in this deviation curve. For the same season at Monterey, the deviation curve presented a contrasting appearance. At Monterey also group **A** lost its dominance, but at this latter port the fishery depended on size-classes smaller than **A** rather than on larger groups as at San Pedro. This does not mean, however, that during the 1921–1922 season only large fish were present in the San Pedro fishing area and at Monterey only small sardines. Other factors are involved. Chief of these is the change in size of fish occurring in each fishing season. At both San Pedro and Monterey, the sardines average smaller in size in the fall than in the winter months. Scofield (1926, p. 196) gave the dates covered by the samples for Monterey in 1921–1922. The season closed early in February, with the result that the major portion of the sardines were sampled in the fall months. On the other hand, as shown by Higgins (1926, p. 134) the 1921–1922 San Pedro fishery was confined to January, February and March when large fish dominated the fishing grounds. This difference in the time of the fishing season at the two ports was possibly the chief cause of the variation in the deviation curves for 1921–1922. A preliminary comparison for this season of the winter fishery only, indicated much less size discrepancy in the two localities. The completion of such studies should give a better measure of the sizes of fish available to the fishermen, but the present study depicts the relative abundance of various sized sardines actually taken in the entire 1921–1922 season at Monterey and San Pedro.

In the San Pedro deviation curve for 1928–1929, a dominant group is suggested at sizes which in the previous and succeeding years were comprised in depression **d**. In the following season, 1929–1930, **d** reappears in the deviation curve. The curve for 1928–1929 at San Pedro is similar in some aspects to the 1929–1930 curve at Monterey.

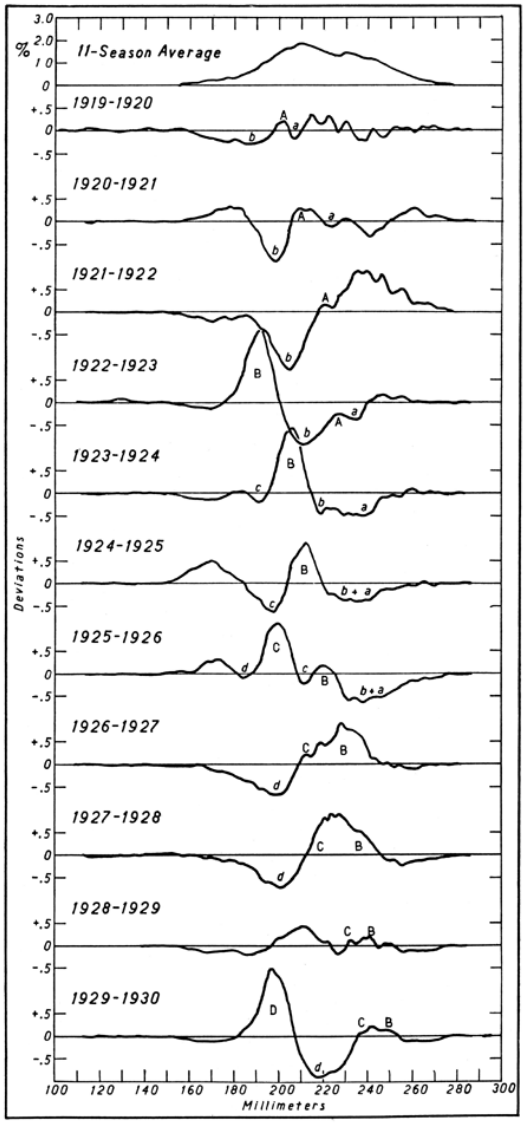

FIG. 14. Seasonal deviations from the eleven-season average frequency polygon of the San Pedro data.

FIG. 14. Seasonal deviations from the eleven-season average frequency polygon of the San Pedro data

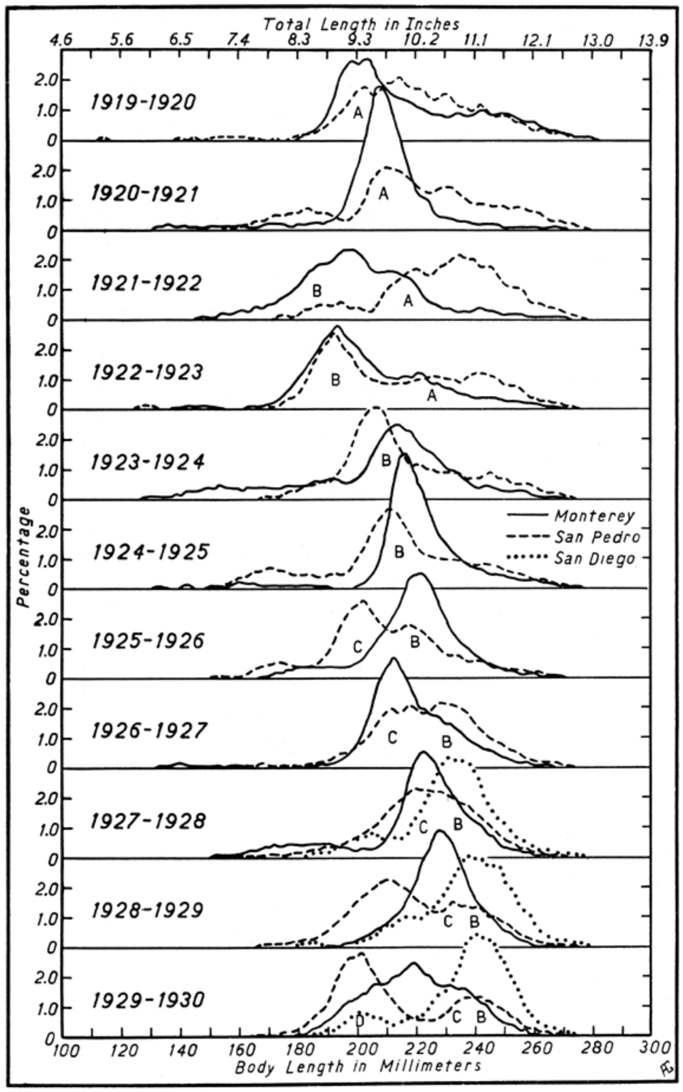

FIG 15. Comparison by seasons of the length frequency polygons of sardines measured at Monterey, San Pedro and San Diego.

FIG 15. Comparison by seasons of the length frequency polygons of sardines measured at Monterey, San Pedro and San Diego

3.6. COMPARISON OF DOMINANT GROUPS IN EACH LOCALITY

The superimposing in figure 15 of the seasonal length frequency curves from the Monterey, San Pedro and San Diego localities brings forth many similarities and some differences in the size composition of the catch landed at these three ports. Data have been collected at San Diego for only the last three seasons of the investigation, and because of the short fishing season in this region, the comparison here made is somewhat misleading. Since the frequency curves are expressed in percentage of the total and the fishery at San Diego for "pound-oval"[1] sardines occurs in the winter months only, the relative numbers of large fish appear much greater than at Monterey and San Pedro. The small sardines taken in the fall fishery at the two latter ports reduce the relative numbers of large fish in the entire seasonal curves. Actually, more large fish are caught at Monterey and San Pedro than at San Diego, but a true measure of the numbers of fish at each size unit must await a comparison of the winter fishery at the three localities. The frequency curves here presented merely compare the dominant groups in each fishery and show the relative distribution of sizes throughout the entire season. No "quarter-oil" and "half-pound" sizes are included in the San Diego data and the curves represent the "pound-oval" fishery at that port as at Monterey and San Pedro.

During 1919–1920 and 1920–1921, dominant group **A** was present in both the Monterey and San Pedro fisheries, but Monterey relied more completely on **A** than did San Pedro. In 1921–1922 the dominance of **A** decreased greatly at both ports, but as pointed out in the previous sections of this paper, entirely different sized fish supplanted **A** at Monterey than at San Pedro. This difference in the curves is presumably largely explainable by the fact that the 1921–1922 Monterey fishery was chiefly supplied by the smaller fall fish, while the San Pedro fishery for this season drew only from the large winter stock of fish.

In 1922–1923 group **B** entered both fisheries and comprised fish of the same sizes. In the next two seasons, **B** chiefly maintained the fishery at both ports but the locations of the modes of this group were higher at Monterey than at San Pedro. Group **B** still dominated the Monterey fishery in 1925–1926 and was evident in the San Pedro catch. At the latter port, however, a new group, **C**, had surpassed **B** in dominance. **C** did not appear at Monterey until one season later, 1926–1927, and in this season the locations of the modes of **C** were almost identical at each locality. **B** as a dominant

1 In trade nomenclature California sardines are termed "pound-ovals," "halves" and "quarter-oils." The first group comprises fish suitable for packing in an oval-shaped can of one-pound size; the second consists of smaller fish packed in half-pound, oval or square cans; and the third, of still smaller fish packed in one-fourth-pound square cans. The fish of these three categories have an approximate size range as follows:

	Body Length Millimeters	Total Length Inches
Pound-ovals	180–300	8.3–13.9
Halves	150–180	7.0–8.3
Quarter-oils	100–150	4.6–7.0

All three classes are packed at San Diego but only pound-ovals and a few halves at Monterey and San Pedro group had disappeared from the Monterey fishery in 1926–1927, but was still discernable at San Pedro. Group **C** persisted through the following three seasons at both ports, but by 1929–1930 was less manifest at Monterey than at San Pedro. In 1928–1929 sardines of sizes smaller than **C** dominated the catch at San Pedro, while at Monterey this condition occurred in 1929–1930. Group **D** which was so dominant at San Pedro was only suggested at Monterey in this last season.

At San Diego group **B** was the chief support of the fishery in 1927–1928 and 1928–1929, but by 1929–1930 **C** had somewhat replaced **B**. In contrast to the Monterey frequency curve for 1929–1930, group **D** was more evident at San Diego than at the former port. The mode of **D** at San Diego closely approximated in location the mode of this group at San Pedro.

The occurrence of the same dominant groups in the Monterey and San Pedro fisheries and probably also in the San Diego region can be explained in either of two ways: (1) The fish taken in the three fishing areas intermingle and the fisheries draw upon the same major sardine population; or (2) separate populations support the fishery at each port, but these populations are subjected to environmental influences so similar that the same dominant groups are produced at each locality. That parallel conditions exist in the sea off Monterey, San Pedro and San Diego appears doubtful and the first explanation seems more plausible, especially since previous studies have demonstrated at each port similar fluctuations in average size throughout a fishing season, and preliminary investigations (Hubbs, 1925) have indicated no racial differences in the sardines from the three localities. Similar environmental conditions, however, would also produce the same racial characters, and until the factors which cause dominant groups are known and definitely demonstrated as different in each locality, we can not consider the presence of the same dominant groups at Monterey, San Pedro and San Diego as conclusive evidence that the fisheries at the three ports are supplied by the same population.

The major reliance of the Monterey fishery on a single dominant group in each fishing season as contrasted with a dependence on more than one group in most of the seasons at San Pedro is explained by the fact that the fall fishery at Monterey extends over a longer time interval than at San Pedro. The fall fishery at each port is maintained by smaller fish and the winter by larger fish. (Andrews, 1928, and Clark, 1930.) At Monterey the fall fishery continues for three to four months and the winter for two and one-half to three months. As a result, more smaller, fall fish enter the Monterey catch than larger, winter fish and the character of the entire seasonal length frequency curve is determined mainly by the nature of the unimodal, fall frequency curve. At San Pedro, on the other hand, the fall and winter fisheries extend over approximately equal time intervals, and modes present in the frequency curves for each period are apparent in the entire seasonal length frequency. Consequently most of the seasonal frequency curves for San Pedro are bimodal and for Monterey unimodal.

3.7. NORMAL HISTORY OF A DOMINANT GROUP

Since the height of the mode of each group is a rough measure of the amount of dominance, this measure is depicted in figure 16 through the average height of the modes of the three dominant groups at Monterey and at San Pedro. These averages, derived from the data of tables 2 and 3 and figures 8 and 13, furnish a crude indication of what may be expected from future groups. At Monterey for the second and third seasons after a group has entered the fishery, the dominance presumably will slightly exceed the first season, but in the fourth year the abundance will be appreciably diminished. However, as indicated in figure 8, the heights of the modes from season to season have been very irregular and considerable departure from the average may take place. On the other hand, at San Pedro the modes progressed through the fishery with much

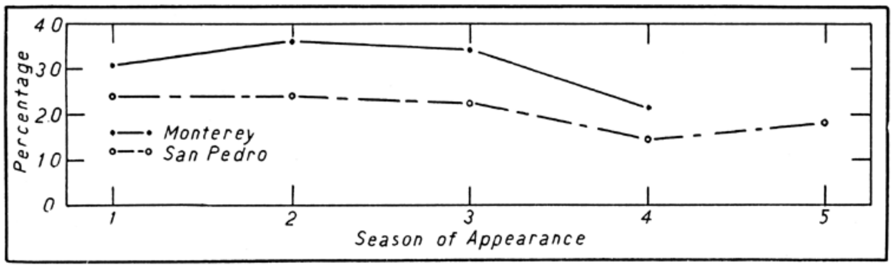

FIG. 16. Average height of the modes of the three dominant groups in the Monterey and the San Pedro fisheries, according to the season of appearance.

FIG. 16. Average height of the modes of the three dominant groups in the Monterey and the San Pedro fisheries, according to the season of appearance

less variation in dominance. No great decrease in height is normally to be expected until the fourth or fifth season, and as a rule, dominance should be evident for four or five years.

Due to the variation in the heights of the modes in the first season of entrance into the fishery, the changes in height in succeeding years have been made directly comparable by calling the height in the first season 100 per cent and expressing the amount of dominance in the following years in percentages of the first. The resultant curves are depicted for Monterey in figure 17 and for San Pedro in figure 18. As in the previous data, at Monterey many irregularities can be expected in the second and third seasons, while at San Pedro much smaller variations in dominance will normally take place. At both ports, however, no consistent decrease in dominance occurred before the third or fourth season. Also, each group persisted as a dominant class for four years at Monterey and for four or five at San Pedro. Many factors, such as the natural death rate, length of the fishing season, the entrance of new and more dominant groups, and possibly changes in fishing methods and localities, affect the amount and duration of the dominance of these superabundant groups. But since all these factors were operative in the eleven years of the investigation, presumably this analysis of the dominant groups portrays the normal history of these superabundant size-classes.

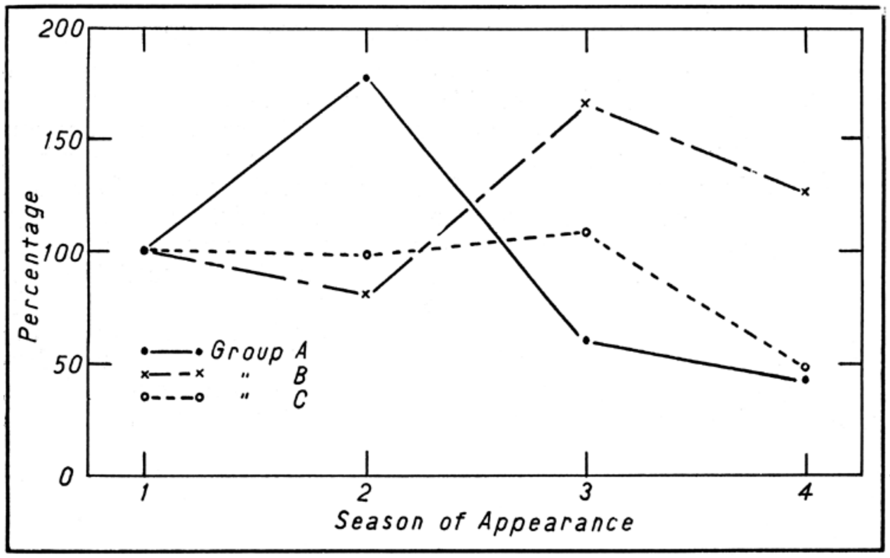

FIG. 17. Height of the modes of the dominant groups in each succeeding season in percentages of the height in the first season of entrance into the Monterey fishery.

FIG. 17. Height of the modes of the dominant groups in each succeeding season in percentages of the height in the first season of entrance into the Monterey fishery

3.8. RELATION OF THE DOMINANT GROUPS TO DEPLETION

The length frequency curves and the deviation curves in figures 1, 4, 5, 9, 10, and 14, demonstrate that the sardine fishery is dependent to a major extent on the renewal of the stock through the appearance in the fishing areas of new superabundant size-classes. The failure of these dominant groups might prove disastrous to the fishery whether their failure was from natural causes or not. In such an

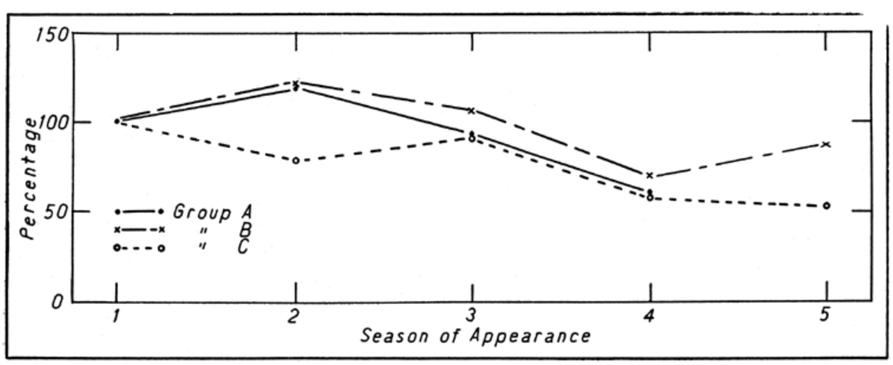

FIG. 18. Height of the modes of the dominant groups in each succeeding season in percentages of the height in the first season of entrance into the San Pedro fishery.

FIG. 18. Height of the modes of the dominant groups in each succeeding season in percentages of the height in the first season of entrance into the San Pedro fishery

event the fishery would rely on the last abundant group remaining in the fishing area, and since these fish would continually increase in size, the relative numbers of large fish might not appreciably decrease until the group had been exhausted. This persistence of large fish in the commercial catch would obscure the effect of depletion if measured only by the disappearance of large fish. For this reason we should watch closely any protracted time interval in which a new dominant group does not enter the fishery, and guard against the assumption that the presence of an apparent abundance of large fish is indicative of a healthy fishery. The final disappearance of the last abundant group unaccompanied by an entering dominant size-class might cause a gradual collapse of the fishery.

3.9. EFFECT OF DOMINANT GROUPS ON THE FISHERY

Studies of the daily average length of sardines by Andrews (1928) and Clark (1930) showed that, during the later seasons of the sardine investigation, the fish averaged larger than in the earlier years. This was true for Monterey from 1924–1925 to 1928–1929 and for San Pedro from 1926–1927 to 1928–1929. The seasonal length frequencies here presented in figures 5 and 10 show that this increase in size resulted from the progression through the fishery of the dominant groups **B** and **C** and the lack of new entering groups composed of smaller fish. At Monterey in 1924–1925, **B** had attained a sufficient size to raise the average of the entire catch and in the next two seasons this average was only slightly lowered by the entrance of **C**. The growth of **C** again increased the sizes in 1927–1928 and 1928–1929. At San Pedro, on the other hand, **C** entered at a smaller size than at Monterey and this counteracted the influence on the averages of the larger fish comprising **B**. Not until 1926–1927 did the combined effect of **B** and **C** result in unusually high averages. These were maintained until 1929–1930, when the entrance of **D** again reduced the average size of the fish in the commercial catch. Thus the changes which have occurred in the sizes of sardines taken from season to season have been dependent on the character of the dominant groups present in the fishery.

That these size variations affect the canning industry was shown by Higgins (1926, p. 151–158) in a demonstration of the close relationship between the size of the fish brought in by the fishermen and the numbers of fish packed in a pound-oval can. This dependence of the nature of the pack on the size composition of the commercial catch was further illustrated by Clark (1930, p. 14–16).

TABLE 4

Average Number of Fish Packed Each Fishing Season in a Pound-oval Can at Monterey and San Pedro

Season	Monterey	San Pedro
1921–1922	7.14	----------
1922–1923	7.02	6.84
1923–1924	6.46	6.97
1924–1925	6.47	6.19
1925–1926	6.30	6.58
1926–1927	6.06	5.75
1927–1928	5.75	5.38
1928–1929	5.67	6.09
1929–1930	6.23	6.38

TABLE 4

Average Number of Fish Packed Each Fishing Season in a Pound-oval Can at Monterey and San Pedro

Since the type of the pack depends on the sizes of fish caught and the size of fish is determined largely by the dominant groups, to indicate the direct influence of these dominant classes on the nature of the pack, as expressed by the average number of fish in a pound-oval can, figure 19 is presented. In this figure the size progression of the modes of each group, already shown in figures 6 and 11, is again depicted by the solid lines. On these modal progression lines, the seasonal averages of the number of fish per can have been superimposed. The data for the average number of fish was obtained from two canneries at Monterey and two at San Pedro. The trend of these averages is indicated by the broken line. To make the correlation between the average number of fish and the progression of the modes direct, the scale of averages on the right hand side of figure 19 is reversed.

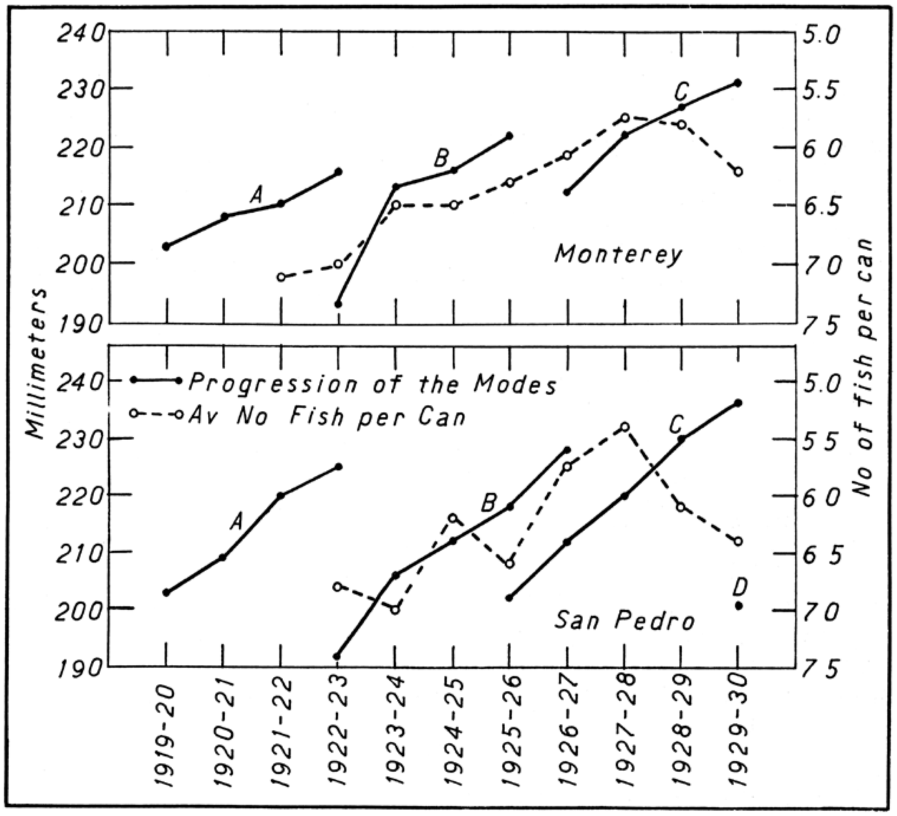

FIG. 19. Relationship between the average number of fish packed each season in a pound-oval can and the size progression of the dominant groups. As the modes progress the number of fish packed in a can decreases.

FIG. 19. Relationship between the average number of fish packed each season in a pound-oval can and the size progression of the dominant groups. As the modes progress the number of fish packed in a can decreases

At Monterey the average number of fish packed in a can was smaller in the later seasons than in the earlier. This decrease resulted from the influence of dominant groups **B** and **C.** In 1921–1922, although large fish of group **A** similarly tended to decrease the average, the major dependence of the catch in this season on fish smaller than **A** (see fig. 5) caused an increase in the numbers in each can. The next season the many small fish in group **B** in a like manner offset the effect of the large fish of **A** and the average number of fish per can showed little change from the former year. The progression of mode **B** from 1922–1923 to 1923–1924 was great and this rapid increase in the size of fish dominating the catch produced a corresponding decrease in the number of fish in a can. **B** advanced very little in the following year and the pack also evinced practically no change. In 1925–1926 fish of **B** were larger than in the previous year, and in consequence fewer were packed per can. While the entrance of group **C** in 1926–1927 would have been expected to bring about an increase in the average number of fish, this increase did not occur because of the large size of the fish comprised in **C** in its first year of entrance and because **B,** although no longer dominant, still influenced the fishery. In the three succeeding seasons, mode **C** consistently progressed, but after 1927–1928 the numbers of fish per can showed no decrease. That there was no decrease in average number of fish between 1927–1928 and 1928–1929 presumably is partly explainable by the fact that cans containing six to eight fish are more in demand, and to provide such a pack, the number of large fish placed in a can is increased by utilization of a smaller portion of each fish. The industry can thus, to a limited extent, make adjustments to offset the effect of the natural size fluctuations of the commercial catch. In 1929–1930, although mode **C** had attained the greatest maximum location of any mode during the period of the investigation, the dominance of group **C** materially diminished, and the dependence of the industry on smaller sized fish (see fig. 5) brought about an increase in the average number of fish packed per can.

That the influence of the dominant groups on the number of fish in the can was as strong at San Pedro as at Monterey is indicated by the lower graph of figure 19. Due to the effect of groups **B** and **C,** at this port also, the average number of fish tended to decrease from 1922–1923 to 1927–1928. But because the San Pedro fishery was never so completely dominated by one group and because, consequently, more than one superabundant class affected the pack in nearly every season, the seasonal averages fluctuated more in this locality than at Monterey. In 1922–1923 the effect of large fish of group **A** sufficiently offset the influence of the smaller fish of **B** to produce a smaller average number of fish per can than in the following year, 1923–1924, when **B** alone dominated the fishery. In the succeeding season, 1924–1925, the decrease in the number of fish per can was caused by the model progression of **B**. This decrease was followed by an increase in 1925–1926, which resulted from the incoming small fish of group **C.** The size increase of the fish in both **B** and **C** in 1926–1927 and 1927–1928 again produced a decrease in the average number of fish per can which reached a maximum in the latter season. By 1928–1929, **B** exerted little influence on the catch, the dominance of **C** was greatly diminished, and the fishery depended largely on fish smaller than **C.** This resulted in an increase in the average number of fish in the can, in spite of the fact that mode **C** showed a marked progression. The continued increase in 1929–1930 in the number of fish per can was caused by the incoming small fish of group **D** and the further decrease in the dominance of group **C.**

This close relationship between average number of fish packed in a pound-oval can and the amount of dominance and size progression of the superabundant groups indicate that these dominant size-classes not only largely maintain the commercial fishery, but they also determine the nature of the pack.

3.10. PREDICTIONS FOR THE FUTURE CATCH

An attempt to foretell the character of a future fishery is an exceedingly questionable procedure. Such forecasts can be based on a knowledge of past events only, and we have no assurance that these former occurrences will be repeated in the future. Furthermore, while the same natural phenomena may be evident, if fishing methods or the demands of the industry change, these natural variations will produce a different effect on the fishery and the predictions may not be fulfilled. The following suggestions concerning the future of the California sardine fishery are made, therefore, with the clear understanding that their fulfillment depends on a repetition of former biological fluctuations, and on a continuation of present fishing methods and industrial needs.

At Monterey, in the 1930–1931 season, dominant group **D** should play an important role. Since **C** as a dominant group will presumably be little evident, the small fish comprised in **D** will cause a decrease in the average length of the fish, and an increase in the number of fish packed in a pound-oval can. If no new dominant class enters the Monterey fishery during the immediately ensuing years, and such a group is not to be expected for at least two seasons, the sizes of sardines caught in the 1931–1932 and the 1932–1933 seasons will be determined chiefly by the size increase of group **D.** The amount of this increase is difficult to foretell since the size progression of former dominant groups was very irregular. In 1930–1931, however, the location of mode **D** probably will fall at approximately 210 mm. and by 1932–1933 between 220 and 230 mm. The dominance of **D** should be maintained through these years with no consistent decrease in the height of the mode, provided no new superabundant groups enters and overshadows **D**.

As at Monterey, the fishery at San Pedro in 1930–1931 and for the two following seasons should be dominated by group **D.** This group will show a size progression from 1929–1930 to 1930–1931, and the fish of this latter season will average larger than the former. This size increase of **D** will continue through 1931–1932 and 1932–1933, and if no new group of smaller fish appears, the average size of the sardines in the seasons' catch will increase correspondingly, and the numbers of fish packed per can will decrease. By 1932–1933 the mode of **D** should be located between 220 and 230 mm. Group **D** will probably still be manifest as a dominant class in 1933–1934.

Dominant group **C** appeared in the Monterey fishery one season later than at San Pedro. If group **D** enters at Monterey as expected in 1930–1931, again a dominant group will have become manifest in this fishery one year later than at San Pedro. From this we might conclude that the entrance of a dominant group into the Monterey locality could be foretold a year in advance by a study of the San Pedro fishery. Group **B,** however, appeared in both localities in the same season and the later discrepancies in the season of entrance of a dominant group may be merely fortuitous. We will have to await further evidence, therefore, before we can determine whether the entrance of a dominant group into the Monterey fishery normally will be preceded by a similar appearance at San Pedro one season earlier.

3.11. SUMMARY

A study of the fishery for the California sardine has been carried on for eleven years, 1919–1931. During this interval three dominant size-groups passed through the fishery and a fourth appeared in 1929–1930.

An interval of three or four seasons elapsed between the time of entrance of any two dominant groups.

The appearance of the same superabundant size-classes in the Monterey, San Pedro and San Diego fisheries indicates either that these fishing centers are maintained by fish from the same population, or that similar environmental factors produce simultaneous dominant groups in each locality.

The apparent major dependence of the fishery on the dominant groups suggests that should these groups fail to appear in the future, the industry may suffer materially.

The entrance into, progression through, and disappearance from the fishery of the dominant size-classes determined the sizes of fish caught each season, and the average number of fish packed in a pound-oval can. An incoming group of small fish decreased the average size and increased the number of fish per can, while an outgoing group of large fish exerted a reverse influence.

An understanding of the normal history of a dominant group, based on the behavior of the three groups observed in the past eleven seasons, furnishes a basis for prediction for the future catch.

If fishing methods and cannery demands do not change, the Monterey and San Pedro fisheries during the ensuing two or three years presumably will be dominated by the group which entered in 1929–1930. This will cause at Monterey a decrease in sizes in 1930–1931, and then a gradual increase during the two or three following seasons. At San Pedro, the sizes will be somewhat larger in 1930–1931 than they were in 1929–1930 and this increase will continue for the next two or three years.

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4. THE COMMERCIAL CATCH OF ADULT CALIFORNIA SARDINES (Sardina caerulea) AT SAN DIEGO

By

H. C. Godsil

Contribution No. 108 from the California State Fisheries Laboratory, August, 1930.

The commercial catch of California sardines has been systematically sampled for a number of years at the ports of Monterey and San Pedro. For purposes of comparison it was decided in 1927 to collect similar samples from the San Diego catch. Accordingly, throughout three seasons—those of 1928, 1929 and 1930–such samples were taken. The main characteristics of the fishery from year to year appear to be similar. It therefore seems advisable to compile the results of this work. In the following pages the sample data will be presented, and the observations pertaining to the fishery recorded. No analysis will be attempted.

The situation at San Diego differs in one important respect from that at Monterey or San Pedro. At San Diego two distinct size-classes enter into the sardine catch. One is composed of small, immature fish which are packed in the quarter-pound square or half-pound can. These fish are present locally throughout the year. The second class consists of the large, adult sardines which compose the entire catch at Monterey and San Pedro. They are present at San Diego during only about three months of the year. It is with the latter group exclusively that this paper deals, and to this group alone do the statements and conclusions apply. For the sake of convenience the word, "sardine," where not qualified, will be used throughout this paper to designate the large, adult fish under discussion.

In relation to the total catch of California sardines, the amount landed at San Diego is entirely negligible. The quantity taken in an entire season at San Diego constitutes only a fraction of the daily catch at either San Pedro or Monterey. Thus the season's catch at San Diego for 1930 amounted to 1584 tons, while the daily catch at either Monterey or San Pedro in the same year not infrequently exceeded 2000 tons. The reasons for this are as follows: The season at San Diego is considerably shorter than at either Monterey or San Pedro. Whereas at San Diego the large, adult sardines are present during only about three months of the year, they may be taken at the latter two ports in excess of six months. Secondly, the supply appears to be more regular and more abundant both at Monterey and San Pedro. Experience with the fishery has convinced the writer that such is actually the case. While a number of factors have been steadily contributing to the growth of the industry at Monterey and San Pedro, San Diego, due to its proximity to the rich Mexican and high seas fisheries, has become increasingly interested in and dependent upon the lucrative tuna trade. Tuna packing has increased at the expense of the sardine industry; until by 1930 only 2 of the 6 local fish canneries handled the large sardines.

Practically the entire catch of sardines at San Diego is taken by small, local boats. Their average estimated capacity is about 25 tons. of these boats, all used the lampara or round haul net. In 1930 one crew converted its net into a half-ring or semi-purse seine. In 1928 and again in 1930, one purse seiner of 65 tons capacity fished for a local plant. Because of the small size of the boats their cruising radius is limited, and the bulk of the local catch is taken within 15 miles of San Diego. The number of boats operating decreased from about 14 in 1928 to about 7 in 1930, due to the fact that only 2 plants operated in 1930 against 4 in 1928.

The sardine season at San Diego extends from January to April. The presence of the fish at this time appears to be definitely associated with a spawning migration. The gonads are large and rapidly approaching the spawning condition. The fish are fat and rich in oil. The run begins some time in January, and the yield increases erratically until the latter part of February when the largest catches are landed. From then until the middle of March fishing continues with varying success. The run is virtually over by the end of March, though irregular catches are made in April. Throughout the remainder of the year no large sardines are seen or taken in local waters. Small, straggling schools have occasionally been reported in the late summer.

The methods of sampling the sardine catch at San Diego were essentially similar to those employed at San Pedro or Monterey, however with this difference: Forty instead of fifty fish constituted a sample. Five samples, each of forty fish, were collected each half week, each sample coming from a different boat. Conditions at San Diego often rendered this impossible. Not infrequently fewer than five boats, occasionally only one, would bring in fish. At such times the writer secured the quota (200 fish) by taking equal samples from as many boats as were successful. The fish were measured for body and total length.[1] The sex was recorded and the condition of the gonads noted. The size frequencies (based on body lengths) were then compiled, and these were grouped by lunar months.[2] These frequencies were then twice smoothed by a moving average of three. The smoothed frequencies were converted into percentages of the total, and the percentages plotted. All graphs in this paper were thus treated.

The presentation of the San Diego data was complicated by the fact that small, immature fish occasionally entered into the cannery catch. These fish, as explained above, are derived from the population

[1] Body length is the length from tip of the snout to the posterior extremity of the silvery area, scales removed, on the caudal peduncle.

[2] The lunar instead of the calendar month has been used throughout the sardine investigation. The fishery is prosecuted at night in the dark of the moon. At the time of full moon all fishing ceases for a few days. The lunar interval is therefore the logical one to use.

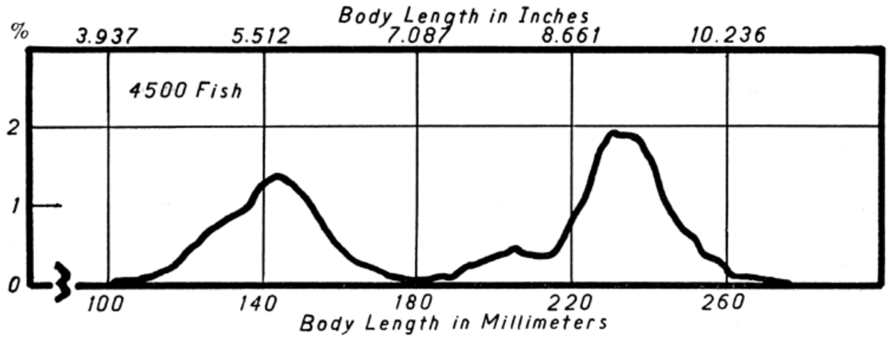

FIG. 20. Length frequency of all sardines taken at San Diego between January 12 and April 11, 1928.

FIG. 20. Length frequency of all sardines taken at San Diego between January 12 and April 11, 1928

of immature fish present locally throughout the year. Samples of adult and young fish were often taken at the same time,[3] but the data were kept separate. Not infrequently, however, boat catches were somewhat mixed and samples of the large sardines included a fair percentage of young fish. Since these young fish are with rare exceptions entirely absent from the catch at Monterey and San Pedro, it seemed advisable to omit them in this discussion. It was finally decided to eliminate from the frequencies all sardines less than 181 millimeters in body length. That this segregation is justified, should be apparent from the following considerations:

1. The population of spawning fish is quite distinct from that of the smaller ones. The latter is present throughout the year, while the former is, as it were, superimposed upon it for a period of about three months. Even at this time the two populations do not mingle. Each schools separately and in more or less different areas.[4]

2. The size of the smallest spawning fish taken in abundance during the winter months at all three ports is approximately 18 centimeters in body length. This figure marks the upper limit of the population of immature fish.

3. If the entire local catch of sardines, including all sizes, is plotted as a frequency distribution, this distribution will be divided into two groups separated by a very marked and fairly constant trough in the vicinity of 180 millimeters. Figure 20, showing such a curve for 1928, illustrates this point. The explanation of these facts involves a differential movement of fish of different age groups, but a discussion of this problem can not be adequately treated until studies now in progress have been completed.

4.1. SEASON OF 1928

With these general characteristics in mind, we may now proceed to the actual frequency distributions for the successive seasons. Graph A, figure 21, presents the catch for January, 1928. This month is divisible into three periods. During the first, from January 14 to 19, the catch consisted almost entirely of small, immature

[3] The young fish are the subject of a separate study.

[4] Godsil, H. C. A discussion of the localities in which the California sardine (Sardina caerulea) was taken in the San Diego region, 1928–1929. Calif. Division of Fish and Game, Fish Bull. no. 25, p. 40–44.

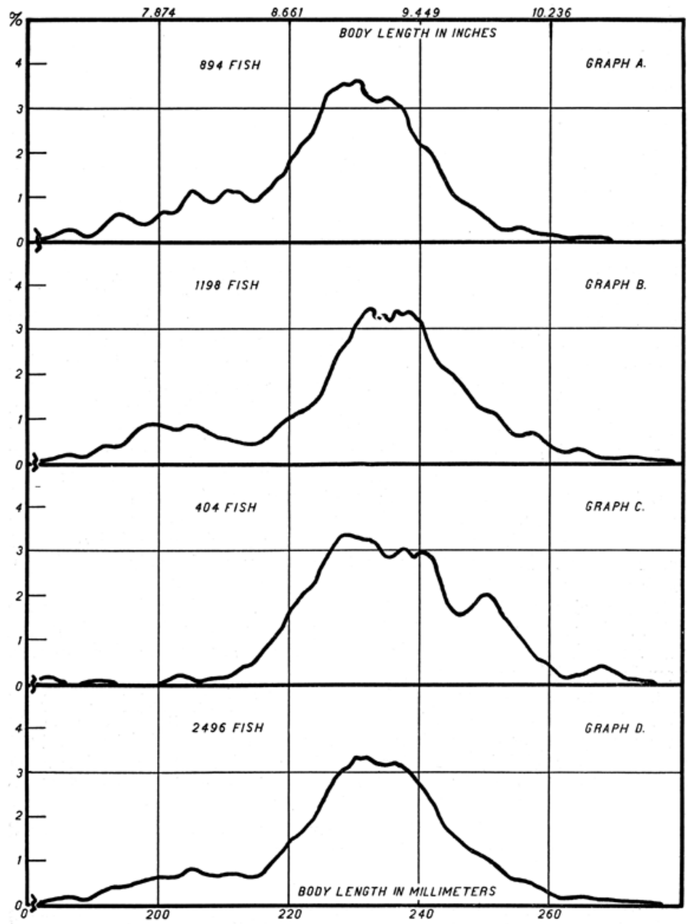

FIG. 21. Length frequencies of adult sardines taken at San Diego in 1928.
Graph A: Data for January 7 to February 4.
Graph B: Data for February 5 to March 6.
Graph C: Data for March 7 to April 4.
Graph D: Season, January 7 to April 4

FIG. 21. Length frequencies of adult sardines taken at San Diego in 1928

sardines (below 18 centimeters in body length), with a few straggling fish measuring up to 22 centimeters. It is these straggling fish that cause the first two or three modes in the curve. The second period is from January 20 to 24, during which the sardine run really began. The fish taken in this period ranged from 20 to 24 centimeters in body length, with the greatest numbers between 21 and 23 centimeters. On January 25, larger fish appeared, and these larger fish formed the entire catch throughout the remainder of the month. The skewness of the curve towards the lower limits is therefore due to the small, straggling adults included in the catch of immature fish, and to the small fish which initiated the run.

Graph B, figure 21, represents the catch for February (February 5 to March 6). Throughout this period the catch was very uniform, as portrayed by the curve above the 215-millimeter ordinate. The percentage of fish below this size is greatly exaggerated in the graph for the following reason: Almost all the fish within this group were derived from a single sample taken just prior to the full moon period. The catch at this time had dropped to almost nothing, and it was necessary to collect the whole semiweekly sample from this one boat. This gives undue emphasis to a relatively insignificant catch.

Graph C, figure 21, illustrates the catch for March (March 7 to April 4). Practically all the fish this month were caught between the approximate dates of March 12 and 16. Two other catches were made on March 23, and on that date the run was virtually over. The catch this month was negligible. The last catch, of 15 tons, was landed on April 11 by one boat. The fish were soft and unfit for canning, and in consequence the canneries closed down. Though small, straggling schools lingered beyond this date, the bulk of the sardines was gone by the end of March.

Graph D, figure 21, represents the season's catch. It embraces the three months discussed above. Here again the percentage of fish below the 215-millimeter ordinate is unduly weighted, though to a less extent than in graph B. Inspection of the graph shows that the catch of sardines at San Diego in the 1928 season consisted essentially of adult fish ranging from 215 to 260 millimeters in body length, plus a scattering of smaller fish which had not attained the adult size.

4.2. SEASON OF 1929

During this season only one cannery operated continuously. Two other canneries packed for brief intervals throughout the season. Hence, the number of boats engaged in the fishery was greatly curtailed, making it difficult to secure the 200 fish in the semiweekly sample from five boats. Moreover, the writer's time was largely employed in making an extensive collection of otoliths for age determinations. More often than not, the samples included fish from fewer than five boats.

Practically no sardines were taken in the month ending January 25, 1929. On January 14, a boat scouting for sardines returned with about two tons of fish; and on January 18, a second boat brought in about one ton. Samples were taken from these two catches, and the results plotted in graph A, figure 22. The range

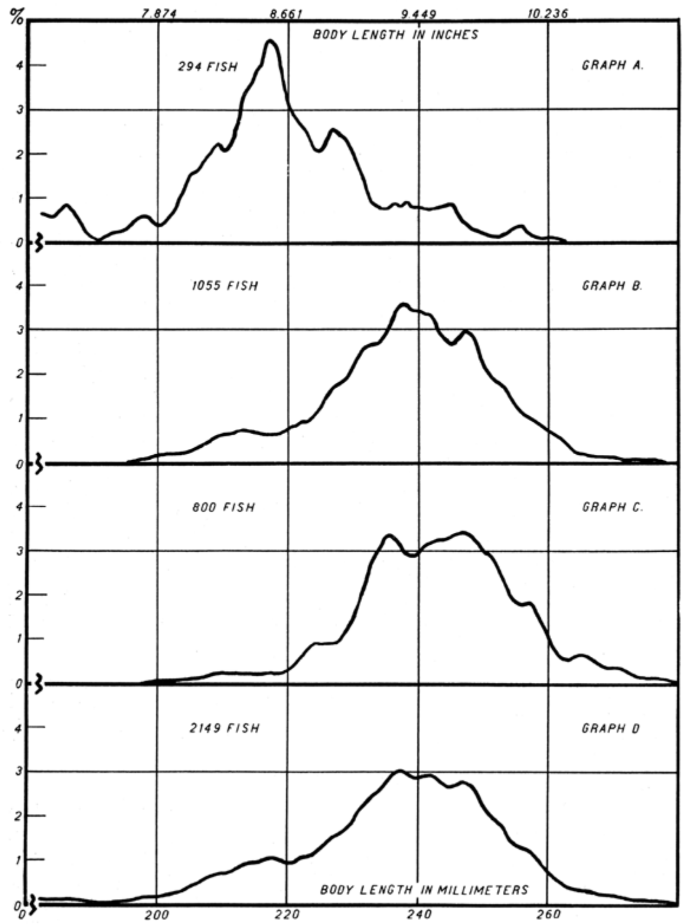

FIG. 22. Length frequencies of adult sardines taken at San Diego in 1929.
Graph A: Data for December 27, 1928, to January 25, 1929.
Graph B: Data for January 26 to February 23.
Graph C: Data for February 24 to March 25.
Graph D: Season, December 27, 1928, to March 25, 1929.

FIG. 22. Length frequencies of adult sardines taken at San Diego in 1929

in size is large, and the number of fish included in the two samples was inadequate to give a smooth distribution. However, it is obvious that the majority of fish were relatively small.

The bulk of the catch for the entire season was landed in the period January 26 to February 23 (graph B, fig. 22). The fish taken at this time were fairly uniform. They were mostly between 23 and 25 centimeters in body length. A general resemblance exists between this and the comparable period for 1928. Similar conditions continued into the next period (February 24 to March 25; see graph C, fig. 22) culminating on March 7, with the largest catch for any single night in the season. From this date on, there was a marked decline, the boats going farther and farther afield for their loads. The season was over by March 17, though, as in 1928, small, occasional catches were made subsequently. The graph D for the season is shown in figure 22.

4.3. SEASON OF 1930

The season was a little late in opening this year. Sardines were very scarce until the last few days of January. In the absence of the true adults, the fishermen made a few mixed catches of smaller fish. Many of these were immature, less than 18 centimeters in body length, and in consequence were eliminated from the frequencies. The balance of the fish in these samples cause the mode at 20 centimeters in graph A, figure 23. In the last part of January, schools of larger sardines arrived and a few loads were landed in the two following weeks. These fish were large, the majority of them being around 235 millimeters in body length. Thus the frequency distribution for this period shows two distinct modes. One represents the smaller, not fully mature, sardines taken in the absence of others, while the second is caused by the larger fish arriving in the latter part of the period, January 15 to February 13.

Graph B, figure 23, depicts the catch in the following lunar month, February 14 to March 14. This is a typical curve for the large, adult sardines. Practically no small fish were taken in this period. Fish were abundant and the bulk of the season's catch was landed at this time.

Similar conditions prevailed into the next lunar month (graph C, fig. 23). Fishing continued good until the latter part of March, all fish landed being large in size. On about March 22, one of the two plants operating closed down. The remaining cannery had only two boats in service. Conditions were not strictly comparable after that date. Fish appeared to be abundant until the last few days in March, when, as in previous years, they disappeared. The last catch was landed about March 28, and at that time the crews reported that they saw only one or two small schools throughout the entire night. After this the boats went out two or three times, but seeing no fish whatsoever concluded the run was over. The graph D for the season is shown in figure 23.

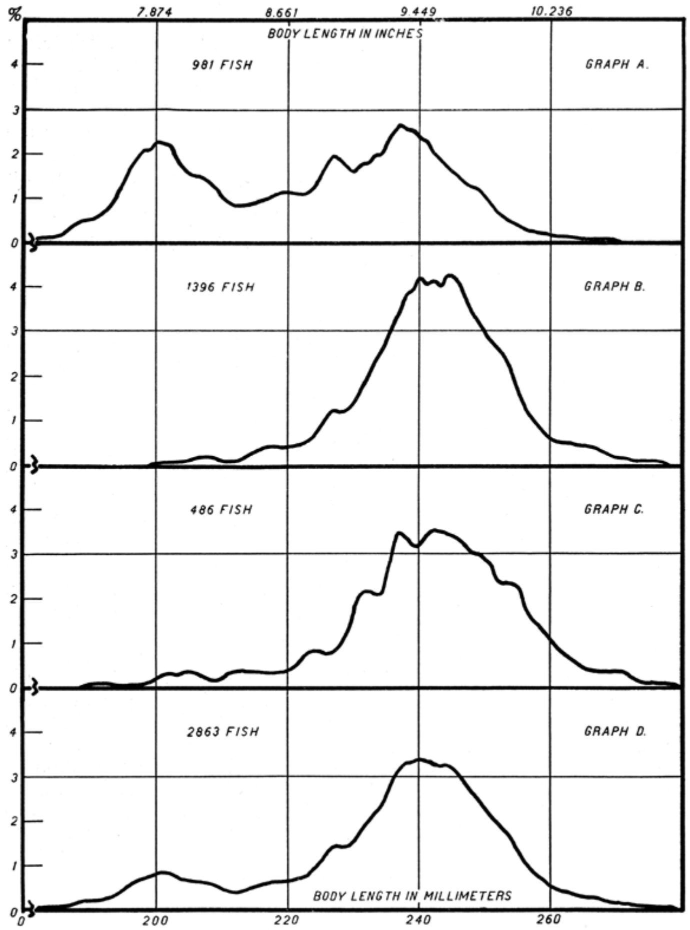

FIG. 23. Length frequencies of adult sardines taken at San Diego in 1930.
Graph A: Data for January 15 to February 13.
Graph B: Data for February 14 to March 14.
Graph C: Data for March 15 to April 13.
Graph D: Season, January 15 to April 13.

FIG. 23. Length frequencies of adult sardines taken at San Diego in 1930

To facilitate comparison the seasonal curves for the three years are shown together in figure 24. They are essentially similar. It may therefore be concluded that for these three seasons the catch at San Diego consisted predominantly of fish ranging approximately from 22 to 26 centimeters in body length. A lesser percentage of the season's total comprised smaller fish. These were usually taken early in the season. The larger fish arrived later. The height of the season came in the latter part of February.

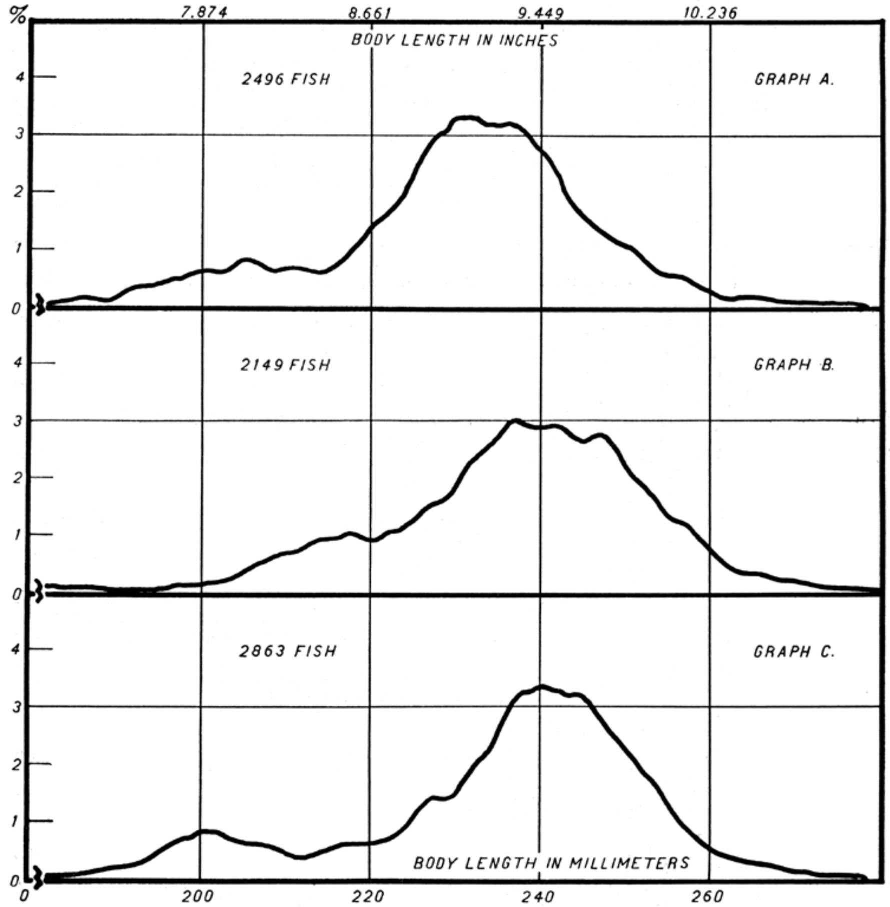

FIG. 24. Length frequencies of adult sardines taken at San Diego in 1928 (graph A), in 1929 (graph B), and in 1930 (graph C).

FIG. 24. Length frequencies of adult sardines taken at San Diego in 1928 (graph A), in 1929 (graph B), and in 1930 (graph C)

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