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Interseasonal and Intraseasonal Changes in Size of the California Sardine (Sardinops caerulea)

By
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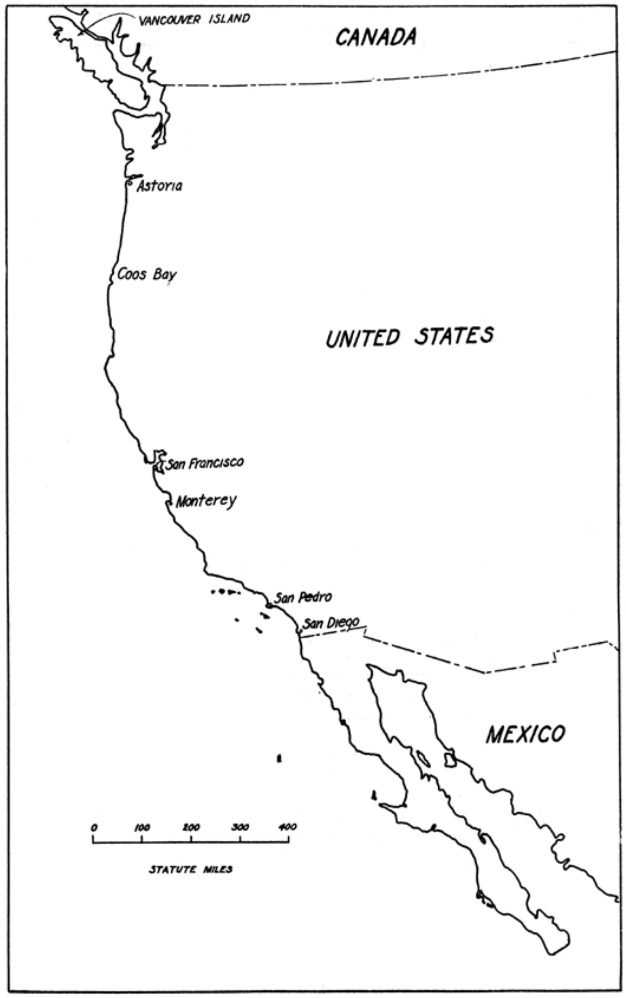

FIG. 1. Map showing the fishing ports for the California sardine. The fishing area off British Columbia lies outside Vancouver Island and landings are made at several small ports on the west side of the island.

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FOREWORD

The investigation of the California sardine, since its inception, has been a cooperative study to which every present and former member of the staff of the California State Fisheries Laboratory has contributed. No report on any phase of the work would be possible were it not for the combined labors and ideas that all of these have proffered to the study. Throughout the years of the investigation the number of these co-workers has been too many to permit an enumeration of individuals. The contributions of these fellow workers are none the less fully appreciated and acknowledged.

In this paper the name Sardinops has been used to designate the California sardine. Hubbs (Proc. California Acad. Sci., *18*, pp. 261–265, 1929) separated the Pacific sardines from the European and placed all Pacific sardines in the genus Sardinops. This change is now generally accepted and we are adopting the newer nomenclature.

September, 1935.

CONTENTS

1. INTRODUCTION

No true understanding of the California sardine fishery or of the sardine population can be reached until the size fluctuations which occur within each fishing season are clearly set forth. These rhythmic size changes, repeated with constant regularity season after season, must be analyzed and interpreted before any measure of other changes in the sardine fishery can be attempted. They result from successive movements of the various size-classes, composing the sardine population, into and out of each fishing area.

In addition to these size changes within each sardine fishing season, there also occur significant size fluctuations from season to season. These result from an entirely different cause, the relative success or failure of each season's spawn. A measure of the amount of variation in the success of each season's spawning is as important as is the understanding of the size variations within each season. The size changes within each season are of greater magnitude, however, than are the size changes from season to season. Consequently the measure of the success of each spawning season must be based on an analysis which eliminates the effect of size variations within each season. The simplest way to do this is to divide each sardine season into units, each of which represents a time interval characterized by certain sized sardines.

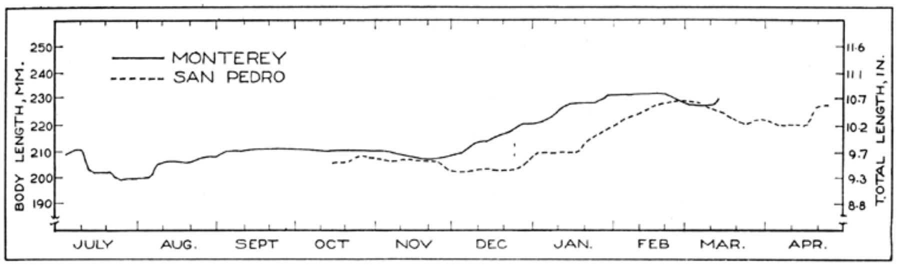

FIG. 2. Ten-season average length trends of the daily average lengths of Monterey and of San Pedro sardines, 1919–20 to 1928–29.

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With the exception of the bait fishery and a limited canning of young fish at San Diego, the California sardine industry depends on adolescent and adult fish. These are not present in California fishing areas throughout the summer months in sufficient numbers to maintain the industry. As a result the sardine fishing season is confined to the fall, winter and early spring. The nature of the size fluctuations occurring during this time interval is illustrated in Figures 2 and 3. Figure 2 shows the trend of the daily average lengths and Figure 3 the month by month length frequency distributions throughout an average season.

These two figures demonstrate that in the two major fishing areas, Monterey and San Pedro, the fall fishery relies on smaller fish than does the winter fishery. Because of this consistent size difference, all recent conclusions drawn from the sardine studies have been based on a fall and a winter fishery and the two fisheries have been analyzed as distinct units.

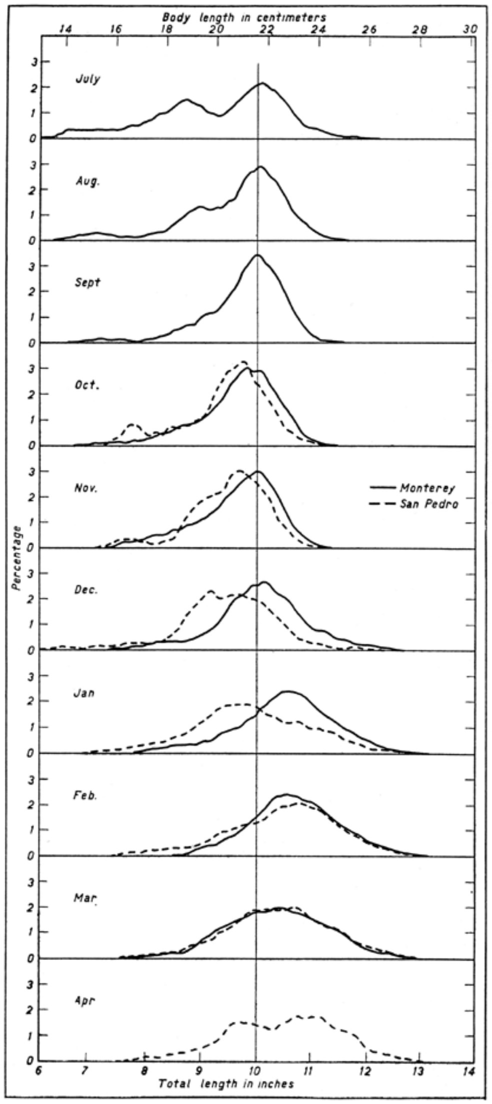

FIG. 3. Length frequency polygons showing the sizes of sardines taken each month of a sardine season at Monterey and at San Pedro. Each monthly frequency is an average of ten seasons' data, 1919–20 to 1928–29.

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The data, so treated in this paper, demonstrate that, with few exceptions, each season the fall fish at Monterey are somewhat larger than are the fall fish at San Pedro, and the San Francisco fall fish are correspondingly larger than the Monterey fish. (There has never been a fall fishery at San Diego.) Certain superabundant year-classes have been discernible in the fishery and these groups have been traced from season to season. They have been followed through the fall fishery for three or four successive seasons until they grew to sizes larger than those taken in the fall months. These findings are interpreted as indicating that any given year-class will be taken in the fall fishery for three or four seasons only.

On the other hand, the sardines from which the winter fishery draws evince quite different characteristics. They represent a much larger size range. Fish as small as those taken in the fall also are present in the winter, but in addition there occurs a high percentage of larger, older fish. In contrast to fall conditions, the winter fish at all fishing localities from San Francisco to San Diego are similar in size. The sizes have varied from season to season but for each season similar size-classes have been found in all the winter fisheries.

The same superabundant year-classes discernible in the fall fishery have also been traced through the winter fishery, although the evidence is not as clear cut. But, because the winter fish comprise older as well as younger fish, these exceptionally abundant year-classes can be followed for a greater number of seasons. Some of them have been apparent for ten years or longer and have exerted a dominating influence for six or seven years. Since during the winter months all adult size-classes appear in the sardine catch, this fishery furnishes the best basis for a study of significant changes in the population and makes possible some measure of man's inroad on the supply.

The length frequency polygons and deviation curves as herein presented indicate that the dominating factors influencing the changes in population abundance were, in the early years of the industry, the presence of these superabundant year-classes. These persisted in the fishery in spite of the moderately heavy toll taken by man. In the later years new superabundant groups have entered the fishery, but due to the greatly increased fishing intensity they can no longer be traced for the normal eight to ten seasons. These later groups have begun to lose their dominance in two or three years and after the third year have been below normal in abundance. This indicates that the present intense fishery is capable of reducing the number of fish of a year-class to a very low level within three or four years after the group appears in the fishery. Under normal conditions a year-class should retain sufficient numbers to make it important to the fishery for eight or ten years. This constitutes a sign of overfishing which in the near future may prove very serious.

2. SOURCE OF MATERIAL

The material used in this study consists of measurements of the lengths of sardines taken in the cannery catch at San Francisco, Monterey, San Pedro and San Diego. In addition, in the San Pedro region, supplemental measurements have been made from the catch delivered to the San Pedro wholesale fish markets.

3. METHODS

3.1. Length Measurements

Since the beginning of the sardine investigation, the cannery catch has been sampled regularly each fishing season. The methods and tests of accuracy are set forth in detail by Sette (1926). After a year's preliminary work, a system of semiweekly sampling was adopted. At Monterey, San Pedro and for the years when sardines were sampled at San Diego, fifty fish each from five different boat loads have been measured twice a week. This gives weekly measurements of 500 fish. At San Francisco, because of lack of personnel, semiweekly sampling has not been carried on, but when possible, 1000 fish have been measured in the middle of each lunar month. Measurements are read to the nearest millimeter and consist of the shortest distance between the tip of the snout and the end of the silvery area on the base of the caudal fin, exposed when the scales have been scraped away. This is termed the body or standard length and corresponds to the standard length used by fishery students in general.

3.2. Biological Year

Sardines spawn from February to July with the height of spawning occurring in April and May. The biological year for the sardine may be said to begin immediately after spawning and to continue through the succeeding twelve months. Because our calendar year is divided into spring, summer, fall and winter, the biological year for the sardine begins in the summer, continues through the fall and winter, and closes in the spring. The fall and winter months are the only ones of importance to the major phases of the sardine industry, canning and reduction. This is because only adolescent (fish approaching their first spawning) and adult fish are used for canning[1] and reduction purposes. These fish are not present in numbers adequate to support the industry except in the fall, winter and early spring. off San Francisco and Monterey the fall fish appear some time in August, the winter fish in November or December, and the majority of all sizes disappears between mid-February and early March. In the San Pedro region fall fish appear in late October or early November, winter fish in December or January, and all sizes begin to disappear in late March or April. On the basis of this behavior of the adult sardine population, the biological year has been divided into four units. The approximate correspondence of these four divisions to the calendar seasons is as follows:

	San Francisco-Monterey	*San Pedro-San Diego*
Summer	June–August 15	June–October
Fall	August 15–November 15	November–January 15
Winter	November 15–February	January 15–March
Spring	March–May	April–May

The dates of the appearance and disappearance of the sardines vary as much as a month from year to year, and consequently no fixed dates can be established for the initiation and the close of each division

[1] Small amounts of young sardines have been canned at San Diego in some seasons, and at Monterey and San Pedro in the early years of the industry.

within a season. The fall and winter divisions at Monterey and San Pedro have been delimited each season by the trend of daily average lengths. As shown in Figure 2, during the fall months the daily average lengths remain fairly constant during a certain time interval. When the averages begin to increase, the fall fishery is considered terminated. The beginning of the winter division is established by the date at which the gradual increase in daily average lengths ceases and the averages again remain relatively constant but at a higher level. The winter fishery terminates when the daily averages again begin to decrease. At San Francisco, where semiweekly sampling has not been carried on, the shape of the frequency curves has been used to delimit the fall and winter fishery. The dates of the fall and winter fisheries at each locality during the period of investigation are given in Table 1.

TABLE 1

Dates for each season of the beginning and termination of the fall and of the winter fishery for the four California fishing ports. The interval between the fall and winter fisheries covers that time during which the larger fish are gradually appearing on the fishing grounds.

Season	San Francisco		Monterey	
	Fall	Winter	Fall	Winter
1919–20			Nov. 6–Dec. 7	Jan. 22–Mar. 3
1920–21			Nov. 8–Dec. 25	Jan. 12–Jan. 31
1921–22			Aug. 19–Nov. 15	Jan. 7–Feb. 8
1922–23			Aug. 8–Nov. 4	Jan. 16–Feb. 18
1923–24			Aug. 28–Nov. 23	Dec. 24–Feb. 20
1924–25			Aug. 15–Nov. 12	Dec. 11–Feb. 26
1925–26			Aug. 5–Oct. 31	Jan. 18–Mar. 8
1926–27			July 24–Oct. 20	Jan. 18–Mar. 3
1927–28			Aug. 13–Nov. 8	Jan. 8–Mar. 6
1928–29			Aug. 2–Oct. 28	Dec. 27–Mar. 25
1929–30		Jan. 15–Feb. 13	Aug. 7–Oct. 18	Jan. 15–Feb. 13
1930–31	Aug. 20–Oct. 18	Jan. 1–Feb. 3	Aug. 10–Nov. 6	Jan. 26–Feb. 16
1931–32	Aug. 29–Oct. 26	Dec. 25–Jan. 23	Aug. 29–Nov. 25	Jan. 14–Feb. 15
1932–33	Sept. 15–Oct. 14	----------	Aug. 23–Oct. 20	Jan. 3–Feb. 16
1933–34	Sept. 5–Dec. 2	----------	Aug. 11–Nov. 21	Jan. 6–Feb. 15
1934–35	Aug. 25–Sept. 23	Nov. 27–Jan. 19	Aug. 9–Nov. 13	Dec. 27–Feb. 14

Season	San Pedro		San Diego	
	Fall	Winter	Fall	Winter
1919–20		Feb. 16–April 3		
1920–21		Jan. 25–Feb. 22		
1921–22		Jan. 20–Mar. 14		
1922–23		Feb. 2–Mar. 3		
1923–24		Feb. 8–Mar. 12		
1924–25	Oct. 29–Dec. 19	Feb. 13–Mar. 10		
1925–26	Oct. 14–Dec. 29	Feb. 2–Mar. 12		
1926–27	Sept. 22–Dec. 18	Feb. 7–Mar. 24		
1927–28	Sept. 23–Dec. 8	Jan. 31–Mar. 29		Jan. 23–April 4
1928–29	Oct. 5–Dec. 10	Mar. 1–April 4		Jan. 29–Mar. 15
1929–30	Nov. 1–Jan. 14	Feb. 14–Mar. 31		Feb. 14–Mar. 24
1930–31	Nov. 11–Jan. 15	Feb. 7–Mar. 31		
1931–32	Oct. 27–Jan. 23	Feb. 11–Mar. 22		
1932–33	Nov. 1–Jan. 19	Mar. 2–Mar. 30		
1933–34	Nov. 9–Dec. 7	Feb. 2–Mar. 19		
1934–35	Nov. 1–Dec. 14	Feb. 11–Mar. 14		

TABLE 1

Dates for each season of the beginning and termination of the fall and of the winter fishery for the four California fishing ports. The interval between the fall and winter fisheries covers that time during which the larger fish are gradually appearing on the fishing grounds

Material is lacking for an accurate determination of the dates of the spring and summer fisheries, but some data are available for Monterey and San Pedro and these indicate the sizes of fish present in these two fishing regions during the spring and summer months. The Monterey data were collected from the cannery catch when, in the early history of the industry, some fishing was carried on during the summer. At San Pedro, the spring fishery is represented by data based on samples taken from the cannery catch when fishing extended into the spring and is supplemented by measurements made in the San Pedro wholesale fish markets. The data for the San Pedro summer fishery are taken from the fish markets entirely. The method of sampling at the markets consists of measuring fifty fish from each boat load and sampling as many boat loads as possible each week. Because adult sardines are scarce at San Pedro during the summer, the number of samples taken in this way was necessarily greatly limited. Simultaneous measurements carried on during the fall and winter at the fish markets and from the cannery catch showed that the fishing boats taking adult sardines for the fish markets draw from the same population as do the boats delivering to the canneries. The measurements made during the summer, therefore, may be considered indicative of the sizes of adolescent and adult sardines present in the San Pedro region at that time. Young fish, also taken in the fresh fish market catch, have been omitted from the length frequency distributions.

3.3. Compilations of the Length Frequency Distributions

For each division within the biological year, the length frequency distributions of all samples taken during that time interval were combined into a single length frequency. This frequency was smoothed twice by a moving average of three and the resulting smoothed frequency expressed in percentages of the total.

To obtain a frequency representing an average or normal condition for a period of years, these percentage frequencies were combined and the sums at each length unit divided by the number of years involved. In addition, for the Monterey and San Pedro fall and winter fisheries, ten-season (1924–25 to 1933–34) average length frequencies were calculated and subtracted from individual season frequencies. This gave deviation frequencies which are positive, where the individual season exceeds the average, and negative where it is less than the average.

4. SIZE CHANGES THROUGHOUT AN AVERAGE YEAR

The changes which occur throughout the biological year in the sizes of sardines are most clearly demonstrated by Figure 4. These length frequency polygons indicate average conditions to be found at Monterey and at San Pedro. Individual seasons differ more or less, but these average frequencies give a general picture of the sizes of fish occurring in the fishing regions during each division of the biological year. The number of seasons of data on which each average frequency is based are:

	Monterey	*San Pedro*
Summer	6 seasons	2 seasons
Fall	10	10
Winter	13	14
Spring	__	6

Because so few sardines are taken at Monterey during the spring months, it has not been possible to obtain a length frequency of the Monterey fish for this portion of the year.

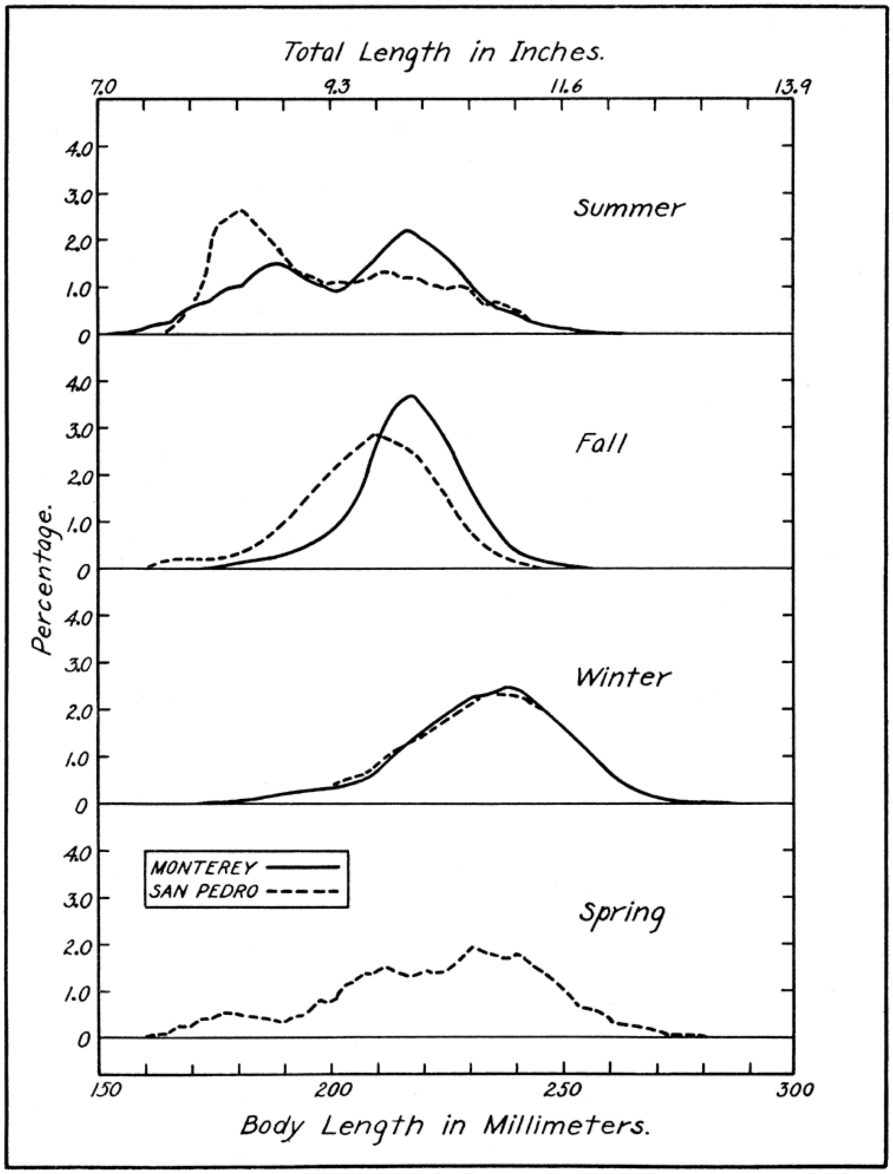

FIG. 4. Average length frequency polygons showing the sizes of sardines occurring at Monterey and at San Pedro during each of the four divisions of the biological year. The frequencies for the summer represent all available data, six seasons at Monterey and two at San Pedro. Ten comparable seasons were averaged for the fall fisheries at both ports. For the winter fisheries thirteen seasons' data were used for the Monterey frequency and fourteen for San Pedro. The San Pedro spring frequency is an average of six seasons' data

For each time interval of the entire year the maximum size ranges of the frequencies do not vary greatly. Some fish representing all adolescent and adult sizes of sardines can be found in both fishing localities at any time of the year. On the other hand, significant changes do occur in the sizes representing the bulk of the fish. During the summer at both Monterey and San Pedro the frequency curves are bimodal. At San Pedro the first mode comprises the majority of the fish, whereas at Monterey the second mode is the more prominent. This probably indicates that more small fish are present during the summer months at San Pedro than Monterey but, as the San Pedro frequency represents an average of only two seasons, this conclusion must remain tentative until more studies of the San Pedro summer fishery have been made. The first mode is apparently caused by the size distributions of a single year-class. Its constant appearance in the summer frequencies of individual seasons and the rate of progression of superabundant groups through the fall fishery lead to this conclusion. As indicated by studies on sizes at maturity (Clark, 1934) this year-class is composed of adolescent sardines, the majority of which will spawn the following spring. These fish will appear in the cannery catch for the first time in the immediately succeeding fall months. The shape of the summer frequencies further suggests that the second mode in these curves comprises the next older year-class, but the progression of superabundant groups through the fall fishery and variations in the individual summer frequencies indicate that this mode is composed of at least two, and probably more, year-classes.

In contrast to the average summer frequency distributions, the fall frequencies are unimodal. This single mode, composed in general of larger fish at Monterey than at San Pedro, corresponds in location to the second mode in the summer frequencies. This increase in the numbers of larger fish and an apparent lack of smaller fish results from the movement into each fishing area of a mass of sardines larger than many of those present during the summer months. This movement is attested by a notable increase in sardine abundance in the fall at each locality. The younger, adolescent fish remain but they no longer appear in the average frequencies as a distinct size-group due to the much greater abundance of the larger fish. In certain seasons, however, this younger, adolescent group has been clearly evident in the fall fishery also, as can be seen in Figure 5 which shows the individual frequency distribution for each season.

During the winter months the largest sizes of sardines are present in both fishing areas. The daily average lengths and the month by month frequency curves show that this winter size increase also results from the movement into the fishing area of yet larger sardines. The fall fish still remain but the largest fish are more abundant. At both Monterey and San Pedro the frequency distributions of winter sardines are practically identical.

The spring months may be considered a transition period during which the larger fish are gradually leaving the fishing grounds. The disappearance of these larger fish occurs earlier and apparently more rapidly at Monterey than at San Pedro. The industry has been carried on to a limited extent in the San Pedro region during this time, but the rather sudden marked scarcity of sardines in the Monterey area terminates the fishing for the canneries and reduction plants in that locality early each spring. This has been true throughout the history of the industry and formed the basis in 1929 for a legal closure on February 15 of the Monterey season. Scofield (1934) has shown that the center of spawning occurs off the southern California coast. This is the probable cause of the presence each spring of adult sardines for a longer period in the San Pedro than in the Monterey fishing region.

The spring months complete the biological year for the sardine. During this twelve-month interval a new adolescent year-class enters the fishery, the younger adults reappear in the fall and remain until spring or early summer, the older adults reappear in the winter and also remain until spring, and by the close of the spring months the majority of all adult sizes have again moved out of the Monterey and San Pedro fishing areas. Measurements of sardines from other localities indicate that similar changes occur each year at San Francisco and San Diego but the data are not complete enough to set forth clearly the details of these changes.

5. SIZE CHANGES FROM SEASON TO SEASON

5.1. Fall Fishery

The sizes of sardines taken in the fall fishery at each locality are shown in Figure 5. The sardine investigation was inaugurated in 1919, and thus data are available for the Monterey fishery for sixteen seasons. Little fall fishing occurred at San Pedro previous to 1924, and consequently the data cover eleven seasons for this port. At San Francisco the first data were collected in 1930, and five seasons' frequency distributions are included in this study.

During the eleven seasons of comparable data, with the exception of 1931–32 and 1932–33, more large sardines were taken at Monterey than at San Pedro. For the last five seasons, when collections were also made at San Francisco, the sardines from the San Francisco region averaged larger than either Monterey or San Pedro.

The second significant characteristic of the fall frequency distributions is the progressive advance and retreat from season to season of the position of the dominating mode. This variation from season to season in the location of the mode, which is brought about by a change in the sizes of fish available to the fishermen, can be interpreted in two ways. First, each season's fall frequency may be composed for the most part of a single year-class and the variations from season to season may result from differences in the growth rate of various year-classes. Second, the fall frequencies may be composed of more than one year-class. The position of the dominating mode, in this case, will be determined by the sizes of the fish comprising a superabundant age-group. The advance from season to season in the position of this mode will result from the yearly growth of the fish. When the fish grow to sizes greater than those appearing in the fall fishery, the advance will cease and the mode will disappear at the right of the frequency distributions. The entrance into the fishery of a new superabundant year-class will cause a new mode to appear on the left of the frequency and coupled with the disappearance of the former mode will cause a retreat in the position of the dominating mode.

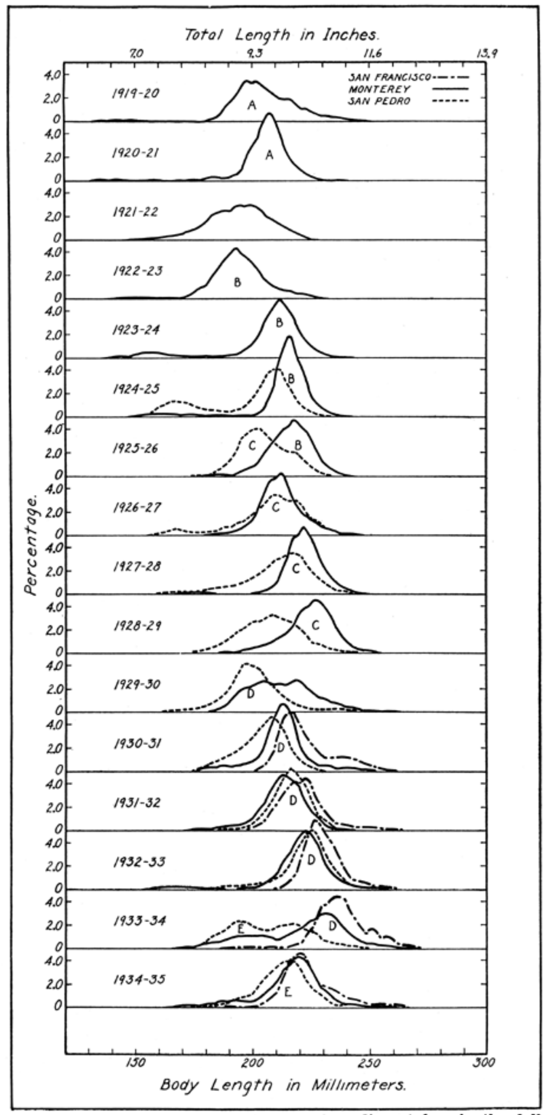

Fig. 5. Length frequency polygons of sardines taken in the fall fishery at San Francisco, Monterey and San Pedro.

FIG. 5. Length frequency polygons of sardines taken in the fall fishery at San Francisco, Monterey and San Pedro

The second explanation has been accepted in this study as the most reasonable. The comparatively consistent advance in the modes for a period of two to four years, as shown in Figure 5, has been repeated too many times to permit dismissal on the grounds of a fortuitous occurrence. The maximum variation in the position of the modes in the San Francisco frequencies is from 216 to 237 mm., for Monterey from 193 to 231 mm., and for San Pedro from 197 to 225 mm. This difference of two, three, or more centimeters appears too great to be explained as a simple variation in the growth rate of individual year-classes. The same dominating modes which occur in the frequencies of the fall fish are also evident in the winter frequency distributions and can be followed (especially in the deviation curves) through the entire size range of the adult sardine population. The rate of their progression through the winter fishery casts further doubt on the interpretation that the differences in the position of the modes in the fall frequencies result from variations in the growth rate of individual year-classes. Because no satisfactory method of interpreting either the scales or otoliths of sardines has been developed as yet, the problem can not be solved by the usual methods of age determination. The only method available at present, therefore, is to analyze carefully the length frequency distributions and to interpret them in the most logical manner possible. The occurrence in the fishery of superabundant year-classes and their growth from season to season are considered at present the true explanation of the season by season variation in the sizes of sardines taken by the fishermen in the fall and winter fisheries.

In accordance with a former publication (Clark, 1931) these superabundant year-classes are designated by letters. The appearance of group A (Fig. 5) coincided with the inauguration of the sardine studies in 1919, and in the succeeding years B, C, D, and E have entered the fishery at irregular intervals. The Monterey frequency for 1921–22 is puzzling. Group A should have been present in the fall fishery but there is no evidence of it in the frequency distributions although it is clearly apparent in the winter frequency for the same season. For some unexplained reason, during the fall months of the 1921—22 season, the fishermen took few fish from the A group and relied chiefly on smaller sized sardines. It has not been possible to connect the rather indefinite mode of this frequency with any superabundant group.

In the 1922–23 season, group B entered the fishery and is evident in the frequency distributions until 19257–26. In this season group C appeared at San Pedro but was not apparent at Monterey until the next season. In 1928–29, C still dominated the Monterey fall fishery but the San Pedro frequency curves give no evidence of the presence of a superabundant year-class in the fall of this season. The fishery appears to have relied on year-classes of average abundance. Group D entered the San Pedro fishery in 1929–30 and was also present but to a less extent at Monterey. In the succeeding three seasons this group dominated the fall fishery at all ports. In 1933–34, group E appeared at both San Pedro and Monterey although D was still dominant at Monterey and San Francisco. The shape of the frequency distributions

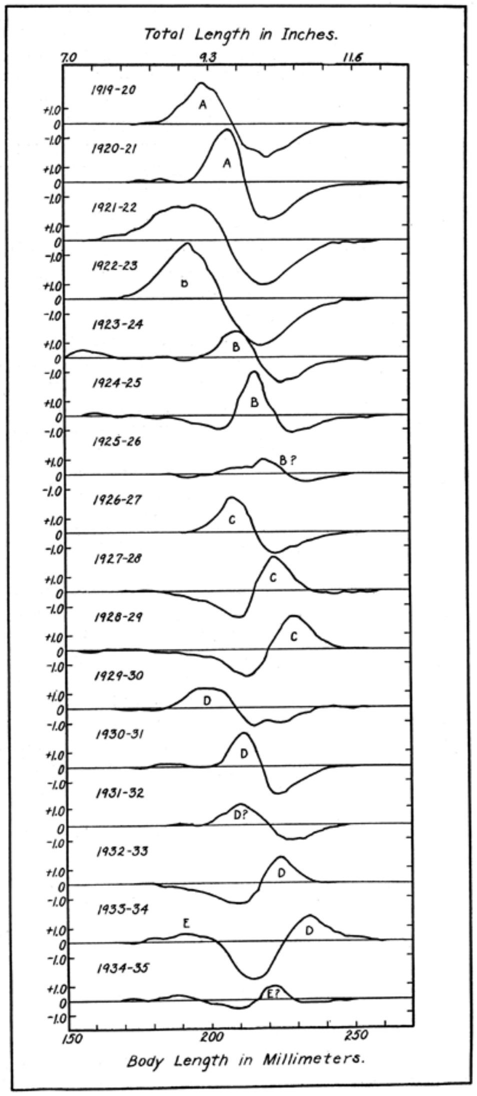

FIG. 6. Length frequency deviations from a ten-season average (1924–25 to 1933–34) of the Monterey fall fish.

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for both the 1933–34 and 1934–35 seasons indicates that group E is not an exceptionally superabundant year-class. Probably in the 1934–35 season year-classes older than group E contributed as many fish to the fishery as did E. This conclusion is based on the exceptional advance in the position of the mode in the frequencies for 1934–35 as compared to the position of mode E in the previous season, and to the indication at San Pedro in 1933–34 that the abundance of group E was about equal to but not greater than the abundance of the older age groups also present in the fall fishery.

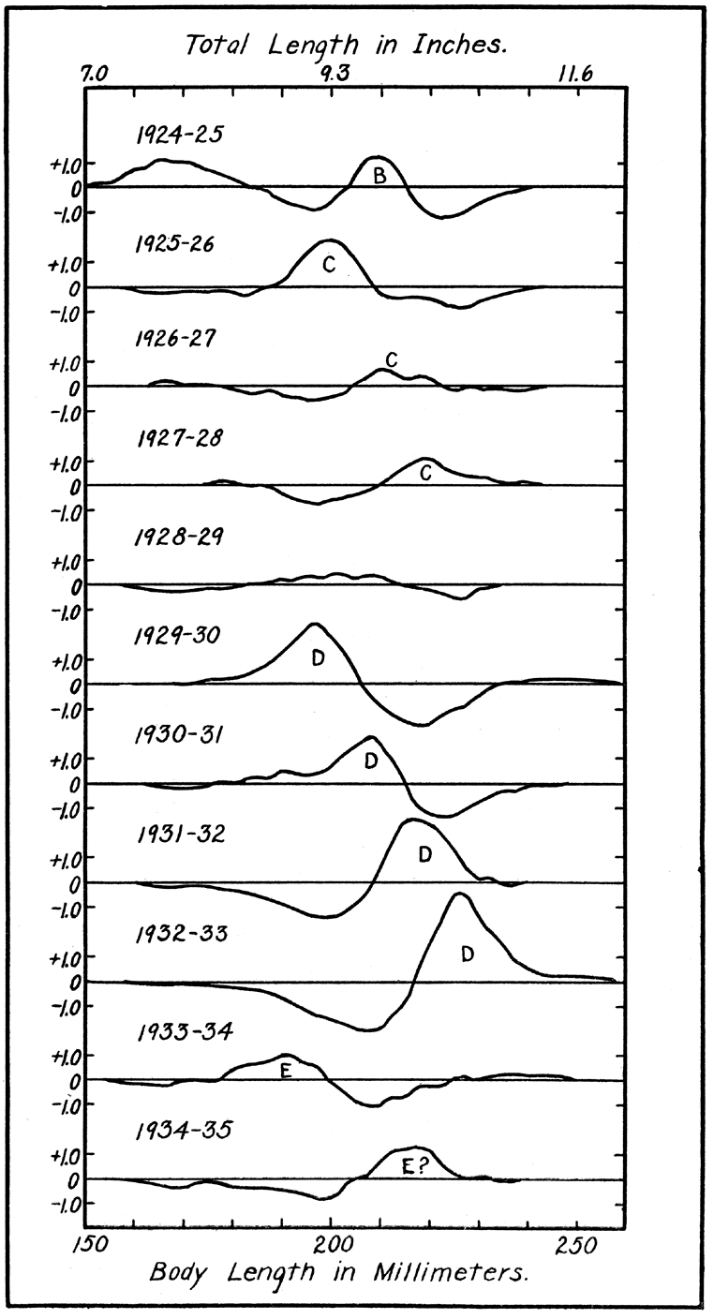

FIG. 7. Length frequency deviations from a ten-season average (1924–25 to 1933–34) of the San Pedro fall fish

To define more clearly the presence in and the progression through the fall fisheries of the superabundant groups, the deviations of each season from a ten-season average frequency are given for Monterey in Figure 6 and for San Pedro in Figure 7. In general the season by season advance in the positions of the superabundant groups has been regular. The most striking exception is in the deviation curve for the 1931–32 Monterey season. (Fig. 6.) The position of group D failed to show any progression beyond its position in the previous season. Both the Monterey and San Pedro frequencies for 1930–31 indicate that a second superabundant group may have entered the fishery in this season and group D may be composed of two age-classes instead of one. The Monterey fishery appears to have drawn more heavily on the younger of the two age-classes than did the San Pedro fishery since group D progressed at a normal rate through the San Pedro frequencies. Group E at both localities is irregular in its behavior. This, as mentioned above, probably results from the fact that the year-class, which E represents in part, was not much above normal in abundance and that older year-classes are also involved in the so-called group E.

TABLE 2

The location in millimeters, according to season in the fall fishery, of each mode of the superabundant groups, as these modes appear in the deviation curves

Season in the fishery	Group A	Group B	Group C		Group D		Group E		Average*
	Monterey	Monterey	Monterey	San Pedro	Monterey	San Pedro	Monterey	San Pedro	
1	197	193	--------	200	200	197	192	192	196
2	206	210	207	209	212	208	220?	218?	209
3	--------	216	222	219	210?	216	--------	--------	218
4	--------	218?	230	--------	223	226	--------	--------	226
5	--------	--------	--------	--------	234	--------	--------	--------	--------

* Groups marked with a "?" are omitted from the average.

TABLE 2

The location in millimeters, according to season in the fall fishery, of each mode of the superabundant groups, as these modes appear in the deviation curves

Table 2 gives the location in millimeters of each mode during the progression of a superabundant group through the fall fishery. These values were derived by inspection from the deviation frequencies. No two superabundant groups progressed through the fall fishery at the same rate, but aside from the irregularities already discussed the differences are not great. Because no one group advances at a consistently slower or more rapid rate, the discrepancies presumably result from the extremely rough method of measuring the rate of progression. Unless a more accurate means of age determination can be devised, however, these length frequency distributions give the best general measure of the rate of growth of adolescent and adult sardines. The average position of the modes as given in the above table (groups marked with a ? are omitted from the average) indicates that an age-class enters the fishery at a modal length of somewhat less than 200 mm. The second year in the fishery the modal length is about 210 mm., the third year not quite 220 mm., and the fourth year approximately

225 mm. After the fourth year fish of each year-class are not taken in any great numbers in the fall fishery. They have reached larger sizes and the larger, older sardines do not appear in the California fishing areas until the winter months.

The consistent occurrence of more large fish at Monterey than at San Pedro and at San Francisco than Monterey suggests that the older fall fish are distributed farther to the northward during the fall months than are the younger fall fish. This is indicated further by the fact that each new entering superabundant year-class is more clearly evident in the first season in the fishery at San Pedro than at Monterey. At each locality the fall fish appear, therefore, to comprise in general four age-classes, and a given year-class usually remains in the fall fishery for four seasons. Each age-group will, however, play a more important role in the southern California fishery during the first, second and third year of appearance in the fishery and in central California during the second, third and fourth year.

5.2. Winter Fishery

The length frequency distributions for the winter sardines are shown for each locality in Figure 8A and 8B. Data are available for sixteen seasons at San Pedro and for fifteen at Monterey. Because of unfavorable economic conditions, the industry did not operate at Monterey in the winter of 1920–21. It has not been possible to sample the catch at San Francisco every season since the canning and reduction of sardines began in this locality, but data are at hand for four different seasons. Fishing for adult sardines at San Diego has occurred irregularly throughout the history of the California sardine industry. The catch was sampled during three winters.

In contrast to the fall frequencies, no significant differences in the frequency distributions occur from port to port during the winter months. More large fish are present in the winter than in the fall but the same size distributions prevail in the winter fishery at all ports. Certain irregularities are evident but these vary in no consistent manner. During certain seasons more large fish are taken at one locality and in other years at another port. The variations appear to be merely fortuitous. The average winter length frequency curves of Figures 3 and 4 also demonstrate this similarity in the sizes of winter sardines throughout California.

Because of this similarity, the length frequencies for Monterey and San Pedro have been combined and are shown in Figure 9. This combination simplifies the analysis of the changes in the sizes of the winter sardines. The superabundant age-groups present in the fall frequency distributions can also be traced through the winter frequencies but not clearly. Many more year-classes occur in the winter fishery, and as a result no single superabundant group can so completely dominate the fishery. The deviations of each season's frequencies from the ten-year average as given in Figure 10, however, again demonstrate the presence of the superabundant groups and their progression through the fishery.

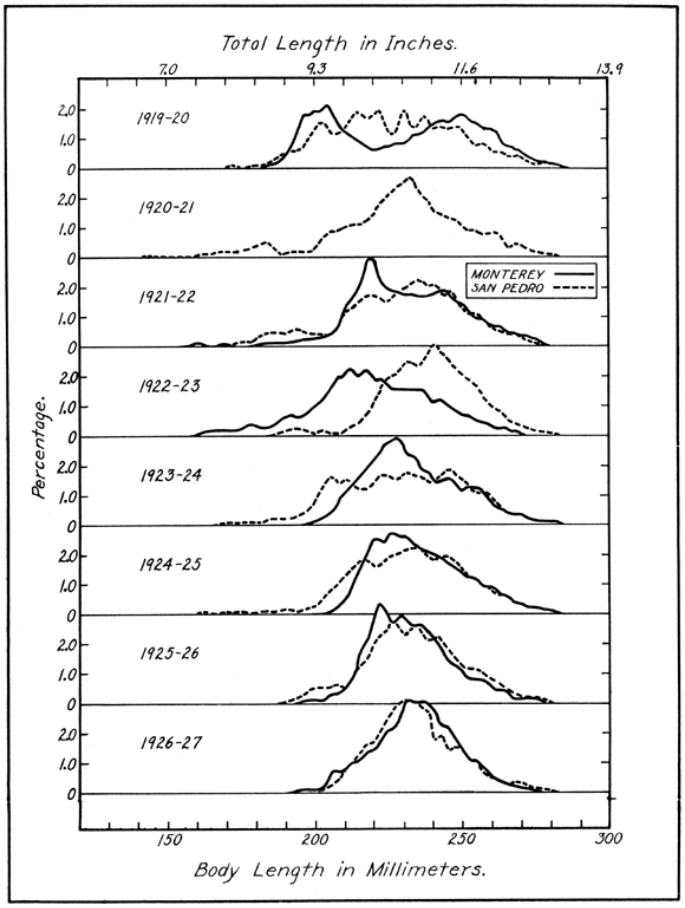

FIG. 8 A. Length frequency polygons of sardines taken in the winter fishery at Monterey and San Pedro for the seasons from 1919–20 to 1926–27.

FIG. 8 A. Length frequency polygons of sardines taken in the winter fishery at Monterey and San Pedro for the seasons from 1919–20 to 1926–27

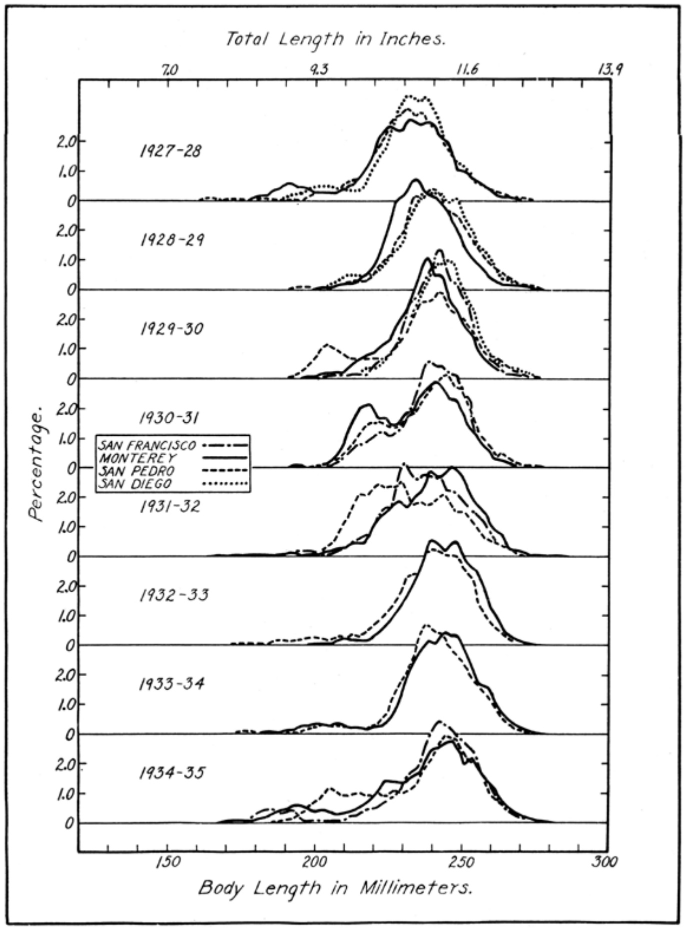

FIG. 8 B. Length frequency polygons of sardines taken in the winter fishery at San Francisco, Monterey, San Pedro and San Diego for the seasons from 1927–28 to 1934–35.

FIG. 8 B. Length frequency polygons of sardines taken in the winter fishery at San Francisco, Monterey, San Pedro and San Diego for the seasons from 1927–28 to 1934–35

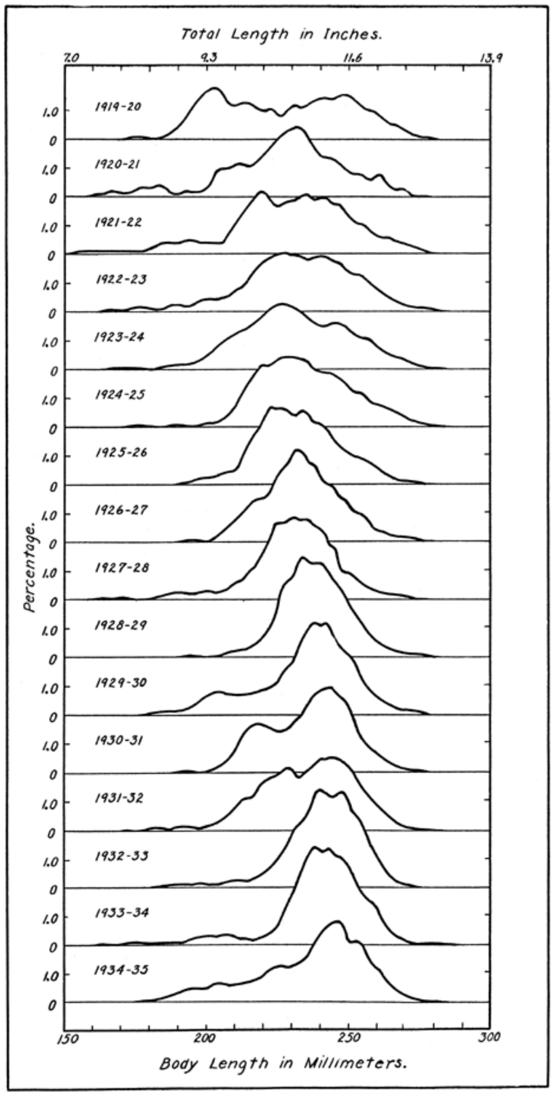

FIG. 9. Length frequency polygons of the combined Monterey and San Pedro winter sardines.

FIG. 9. Length frequency polygons of the combined Monterey and San Pedro winter sardines

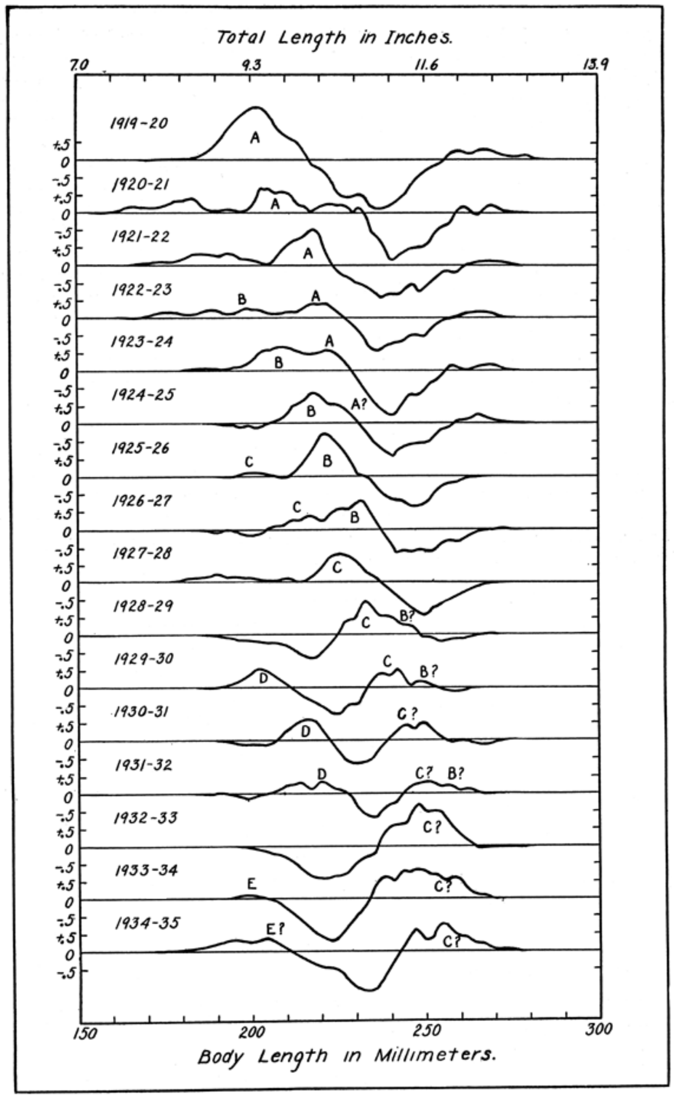

FIG. 10. Length frequency deviations from a ten-season average (1924–25 to 1933–34) of the combined Monterey and San Pedro winter fish.

FIG. 10. Length frequency deviations from a ten-season average (1924–25 to 1933–34) of the combined Monterey and San Pedro winter fish

Group A can be followed through the deviation curves for five seasons before it becomes fused with group B. The plus deviations on the left of the curves for 1920–21 and 1921–22 suggest new superabundant groups which entered the fishery during each of these seasons. These groups, however, do not appear as distinct units in subsequent years unless they be considered as forerunners of group B. To regard them as a part of group B would postulate too slow a growth rate for adolescent fish and a more reasonable assumption is that group B first appeared in the 1922–23 season. Groups B and C can be traced through the deviation curves for ten or more seasons although the groups are closely fused after the 1926–27 season. Group D appeared in the winter deviation curves for three seasons and in succeeding years was no longer evident as a superabundant group. The bimodality of D in the 1931–32 deviation curve also suggests, as did the fall frequencies, that D is composed of two year-classes. Group E is only indefinitely apparent in the winter curves.

No clear cut figures can be presented as a measure of the rate of progression of these superabundant age-groups through the fishery. The plus deviations, representing each group, frequently do not show definite modes and when two groups become fused their point of separation is largely a matter of personal opinion. This separation has been made, nevertheless, in accordance with the best judgment of the writer, and the median of each group of plus deviations calculated on the basis of these arbitrary definitions. Table 3 gives the points at which separations were made and Table 4 the median for each superabundant group on the basis of these separations.

TABLE 3

Season	Point in millimeters for the separation of groups	
	A and B	B and C
1922–23	208	
1923–24	218	
1926–27		221
1928–29		238
1929–30		246
1930–31		247
1931–32		254

TABLE 3

TABLE 4

Location in millimeters of the median of the plus deviations representing groups A, B, C, and D according to season in the winter length frequencies.

Season in the fishery	Group				
	A	B	C	D	Average
1	201	196	200	202	200
2	207	209	215	215	212
3	215	219	226	217	219
4	218	221	232		224
5	222	229	239		230
6			244?		
7		241?	249?		?245
8		249?	249?		?249
9					
10		258?	256?		?257

TABLE 4
Location in millimeters of the median of the plus deviations representing groups A, B, C, and D according to season in the winter length frequencies

As is true for the fall fishery, only general conclusions can be drawn from the data in Table 4. The average rate of progression of groups A, B, C and D through the first four seasons in the fishery corresponds very closely with the average rate through the fall fishery. In the first season the mode or median falls at about 200 mm., in the second at approximately 210 mm., in the third at slightly less than 220 mm., in the fourth at about 225 mm., and in the fifth at approximately 230 mm. Only groups B and C can be followed beyond the fifth season and an accurate location of the medians in these later years is questionable. The average yearly growth increment for the next five years appears to approximate 5 mm.

These winter length frequency distributions indicate that any year-class of sardines will be taken in California for ten or more years after it has reached adolescence or adulthood, and a small percentage of the individuals of an age-group may remain in the fishery for perhaps fifteen years. Each year-class plays an important role in the fishery, however, for about eight years only.

6. SIZE CHANGES IN RELATION TO SARDINE MOVEMENTS AND OVERFISHING

6.1. Sardine Movements

Other studies of the California sardine, especially the discovery of the major spawning area in southern California waters (Scofield, 1934), and the seasonal nature of the sardine fishery indicate that the sardine population undertakes certain movements into and out of the fishing areas each season. The changes in sizes of sardines within each fishing season, as shown by the length frequency distributions, furnish further information about these movements.

The fall frequencies indicate that most of the largest and oldest fish are not present in California waters throughout the fall months, and of the sizes which are taken in the fall fishery, the larger and older fish occur farther north than do the younger and smaller sizes. In the winter months the largest and oldest fish first appear at San Francisco (Phillips, 1935), next at Monterey, and last at San Pedro and San Diego. This suggests that these largest sardines are distributed still farther to the northward throughout the summer and early fall. The British Columbia summer fishery, supported by extremely large sardines, and the absence of these fish in the northern waters in the winter months (Hart, 1933) indicate that the oldest fish are distributed as far northward as British Columbia each summer but move southward throughout the fall and winter to spawn off southern California each spring.

The adolescent and adult sardine movements, as indicated by the size changes occurring within the fishery each season, result as follows: (1) the first appearance of an adolescent year-class in the southern California fall fishery and to some extent in the Monterey fall fishery; (2) a southern spawning in the succeeding spring months; (3) a northward movement the following summer after spawning; (4) a return the next fall; (5) a more extended northward movement each succeeding summer, until eventually the oldest fish reach the northern-most range of the species; (6) a correspondingly delayed return southward each season, until the return occurs in the winter rather than in the fall; and (7) finally the congregation each winter of the major portion of the population in southern California waters previous to the spring spawning, followed every season by the summer northward dispersal.

6.2. Overfishing

Theoretically, when overfishing occurs it can be detected in the length frequency distributions by the gradual decrease in the numbers of the largest fish. This will be true if there are no major fluctuations in the abundance of individual year-classes and if the fishery draws equally upon all sizes of a fish population. For the sardine population there are major fluctuations in the success of certain spawning seasons with resultant variations in the abundance of individual year-classes. As a consequence, when a new superabundant age-group enters the fishery, more than the normal numbers of fish of these younger sizes are taken by the fishermen, and the larger fish, although as numerous as formerly, appear to be decreasing in numbers. As a superabundant year-class grows older and the fish reach the larger sizes there is a temporary increase in the numbers of large fish. Because of this influence of the superabundant year-classes, a short-time variation in the abundance of the largest fish can not be interpreted either as a sign of overfishing or as an indication of a healthy fishery. A long series of years is necessary to establish an increase or decrease in the trend of abundance of the largest fish, and overfishing may have advanced to a serious state before it will be clearly evident in the frequency distributions if the decreasing abundance of largest fish is the only criterion.

In addition to the variations in the abundance of individual year-classes, the sardine fishery does not draw equally from all age- and size-classes. Only the younger adult fish are taken during the fall months, but nevertheless practically half and in some of the later seasons more than half of the season's tonnage has been caught during the fall months. The fall fishery, drawing from three or four age-groups only, places a greater strain on each individual year-class than does the winter fishery which takes fish from eight to ten year-classes. This strain is still greater because the fall fish as a whole are smaller than are the winter fish, and a ton of sardines represents about 25 per cent more individuals in the fall than in the winter months.

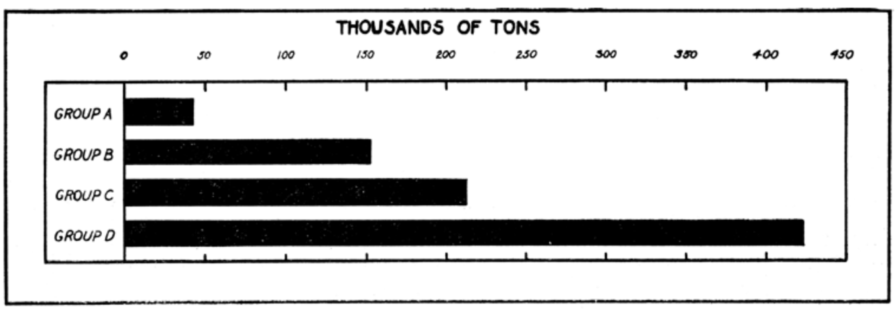

FIG. 11. Estimated tonnages contributed to the fall fishery by each of the superabundant groups during the two to five seasons that each group was fished in the fall months.

FIG. 11. Estimated tonnages contributed to the fall fishery by each of the superabundant groups during the two to five seasons that each group was fished in the fall months

The effect of this strain, which the industry places on the fall fish, is evident in the deviation curves of the winter frequency distributions. (Fig. 10.) When group D entered the fishery it appeared to represent one or two-year classes equal to if not exceeding in numbers the age-classes involved in each of groups B and C. By the third season in the fishery the amount of dominance of group D had decreased, and in the three succeeding years the age-groups of D were less than normal in abundance. In a similar manner the superabundance of group E appears to have been practically wiped out in its second season in the fishery.

Figure 11 illustrates the greater strain placed on each succeeding year-class due to the increased intensity of the fall fishery. This bar chart shows a rough estimate[2] of the tonnages that were taken in the fall months from each of the four superabundant groups, A, B, C and D, during the two to five seasons that each dominated the catch. The tremendous increase in the tonnages taken from group D explains why in the later seasons a superabundant group has lost its dominance long before it has run its normal course through the fishery. Since every year-class as it passes through the fall fishery is subjected to this intense strain, the immediate effect of overfishing on the sardine population is to produce a scarcity of younger and smaller sized sardines. Within a few seasons, however, the older fish, which passed through the fall fishery without being subjected to such intense fishing, will have run their life course and a scarcity of all sizes will occur. Unless the magnitude of the fall fishery is abated the time is not far distant when each new year-class will be practically destroyed before it has grown to sizes which support the winter fishery. Such conditions may eventually result in inadequate numbers of spawning fish and serious depletion of the sardine population.

[2] This estimate was based on the assumption that the total California tonnage of sardines taken in the fall of 1919–20 and 1920–21 was supplied by group A; all the tonnage of the fall of 1922–23, 1923–24, 1924–25 and two-thirds of 1925–26 were supplied by group B; one-third of the tonnage of the fall of 1925–26, all of 1926–27, and 1927–28, and all of the Monterey fall tonnage for 1928–29 were supplied by group C; and one-half of the Monterey and all the San Pedro fall tonnage of 1929–30, all the California fall tonnage of 1930–31 and 1931–32, three-fourths of 1932–33, and two-thirds of 1933–34 were supplied by group D. This method of estimating the tonnages taken from each superabundant group undoubtedly attributes to each group certain poundages actually composed of older and younger year-classes. These dominating groups are fished during the winter months also, and because this estimate does not include the tonnages caught in the winter fishery, it is probably not in excess of the total tonnage taken from each group each season. In addition, this overestimate, if such it be, is similarly applicable to the estimates for all the superabundant groups and, therefore, does not invalidate the comparisons between groups.

7. SUMMARY

The biological year for the sardine population begins with the summer months, continues through the fall and winter and closes in the spring.

During the summer months, with the exception of young, immature sardines not considered in this report, only the adolescent and smaller adult fish are present in the fishing areas, more of the larger fish appear in the fall months, and the largest sizes are present in the winter. In the spring, the majority of the adult fish leave the fishing areas and only the adolescents and a small percentage of the adults remain.

The success of each year's spawning varies, and as a result the sardine population is subject to variations in abundance due to the presence or absence of superabundant year-classes. Five such groups have occurred in the fishery during the sixteen years covered by the investigation.

The size changes which occur each season further substantiate the theory that a northward movement of the sardine population occurs each summer followed by a returning southward movement each fall and winter.

The seasonal change in size causes a more intense fishery for the younger adult sardines than for the older adults. This has produced a scarcity of the smaller sizes which, it is predicted, will soon create a scarcity of larger sizes also, and if not checked, will result in serious depletion of the sardine population.

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