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Measures of Abundance of the Sardine, Sardinops caerulea, in California Waters

By
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ACKNOWLEDGMENT

The California sardine study, as carried on by the State Fisheries Laboratory, of the California Division of Fish and Game, is a cooperative investigation. Consequently no report on the results would be possible were it not for the loyal aid and generous labor given to the study by the entire staff of the laboratory. The present analysis of the size changes and decreasing life span of year-classes is possible because of the faithful measuring year after year of thousands of sardines from the cannery catch. To the estimate of the return per unit of effort, the staff of the statistical department of the laboratory contributed countless hours of exacting and meticulous work. In addition, the aid given to the sardine study goes beyond the laboratory of the Bureau of Marine Fisheries to the Bureau of Patrol. This latter bureau not only collects from the dealers the records of individual boat catches but also records the definite locality of capture of each sardine catch. For many other phases of the investigation the staff and equipment of the Bureau of Patrol have been generously placed at the disposal of the laboratory staff.

CONTENTS

1. INTRODUCTION

The proper administration of any fishery must be based on a knowledge of the abundance of the species on which that fishery relies and the variations in that abundance must be measured from year to year. Seldom can the absolute abundance of a population be measured, and for a marine species practically never. The fisheries researcher has, therefore, only one recourse; he must rely on relative measures of abundance. He can not say that a given species consisted of so many individuals in year A and a certain number in year B. He can only measure the abundance of year B in terms of year A and say that the population of year B was a certain percentage more or less than year A.

For measuring this ratio, fisheries workers have set up certain yardsticks and as a rule use that yardstick which is most applicable to the fishery under study. The most commonly used of these measures of changing relative abundance of a population are the return to the fisherman per unit of effort expended, the variations in the length of time a given year-class can be detected in the fishery, the variations in the proportions of largest fish in relation to all sizes, and the development of new fishing grounds when older, first exploited grounds fail to meet the demand for fish. In more recent years, the results of marking experiments indicate that such studies may constitute a trust-worthy measure of changing population abundance.

Frequently, no single measure of changing abundance will tell the entire tale and the use of several measures more accurately reveals the true condition of a fish population. For the sardine in California waters certain measures have been applicable for a longer time interval than have others. The last to be indicative has been the return per unit of effort. From its inception the industry expanded rapidly and no constant unit of fishing effort was expended. Each season a larger unit was applied and no unit was comparable with the former. Only in the past five or six seasons has the industry become sufficiently stabilized to make comparable from year to year the return per unit of effort. This paper presents such a return for the Monterey and San Pedro sardine fisheries from 1932–33 to 1937–38.

The unit used is based on the lunar month catches of selected boats expressed in percentages of each boat's catch for the corresponding lunar month of the previous season. The geometric mean of these percentages measures the variations in the return to the fishermen by means of the effort expended. In each locality the fishing season is made up of two more or less distinct divisions, the fall and the winter fisheries. The distinction is based on the sizes of fish caught, the fall fishery depending on smaller fish and the winter fishery on larger sizes (Clark, 1936.1). These fisheries have been treated separately in this study and the trends of the return per unit of effort are shown in figures 2 and 3. In these figures the returns for 1932–33 are considered as 100 per cent and the succeeding seasons are expressed in percentages of 1932–33. In general the trends of all four comparisons are very similar and suggest no consistent change until 1934–35. In the three succeeding seasons, each year's fishing yielded less return than did the previous and in 1937–38 the fishermen were catching, with the same expenditure of effort, less than half as much as they had six seasons before.

A decline of more than 50 per cent in the return per unit of effort indicates a rather serious decrease in the abundance of the sardine population but an additional yardstick measuring changes over a longer time interval is desirable. This is to be found in the length of time that a given year-class now remains in the fishery as compared to former years. It has not been possible to trace the history of every year-class, but certain superabundant groups are outstanding due to exceptional survival of the spawn in some seasons. The history of several of these groups has been traced. A previous publication (Clark, 1936.1) pointed out that formerly superabundant groups could be followed through the fishery for as much as six to ten years, but by 1932–33 this was no longer true. Such a group, which entered the fishery in 1929–30, remained in the winter fishery for three seasons only. Since that time (See Figs. 4, 5, 6, 7) no superabundant group has maintained a definite dominance past its second year in the fishery. This would indicate that the serious decline in abundance of the sardine population began about 1930 and has continued for the succeeding eight years. At present the population has reached such a low level and is subjected to such an intense fishery that the life span of a year-class after reaching adulthood may be not more than four or five years. This is in contrast to a former adult life span of ten years or more.

As the length of life of each year-class decreases, fewer fish remain to grow to larger sizes and the average length of the fish in the fishery should show a corresponding decline. For the past decade the California sardine fishery has taken approximately half its tonnage during the fall months when only the younger, smaller adults are present in the fishery. This places an excessive strain on the smaller sizes and allows fewer and fewer fish to grow to larger sizes. As a result, since 1932–33 there has been an almost constant decrease in the average size of the fish in the fishery. (See Figs. 12 and 13.)

of the measures of relative abundance as yet applied to the sardine, there remains to be discussed the expansion of the fishing grounds. During the earlier years of the California sardine fishery, the fishing grounds were constantly extended. This was possible because larger boats with a greater cruising radius were built each year. For the past ten years, although more and larger boats were still being built, the fishing grounds off the California coast have experienced little expansion. Nearly all areas where sardines are to be found from San Francisco south to San Diego were tapped by 1930. The only change in the later seasons has been heavier fishing in the more distant areas as more and more boats capable of making such extensive trips have entered the fishery and as the nearer grounds have failed to meet the demand for fish.

As we have come to understand more clearly the life-history of the sardine, we realize that an expansion of the fishing grounds does not exploit new sardine populations. Various studies of the biology of the sardine have indicated that the sardine is a migratory species and the results of a tagging program now under way. (Janssen, 1938) bear this out. Since the sardines are moving freely from one fishing ground to another, a given locality after being fished out may shortly be repopulated by a new group of fish. Conversely fishing in one locality takes its toll from the entire population rather than affecting only the population in the one locality. At present, the sardine fishermen are searching for fish along the California coast from Point Arena south to the Mexican boundary, except in the region around Point Buchon which is still too remote from markets to be profitably fished. A dramatic picture of the extension of the fishing grounds is shown in figures 14 and 15.

An extensive tagging program now being carried on promises to furnish, in the future, an additional measure of the sardine population abundance. The number of tags recovered per ton of fish handled should indicate the percentage of the population caught yearly by the fishermen. The study covers too few seasons as yet to permit a report on the results.

2. RETURN PER UNIT OF EFFORT

2.1. Characteristics of the Fall and Winter Fisheries

Previous publications[2] have made clear the fact that our California sardine fishing season must be divided into two parts. These we term the fall and winter fisheries. The division is based entirely upon the sizes of fish found on the fishing grounds during these two time intervals. The canning and reduction industry of California does not use small immature sardines but only the adolescent and adult fish.[3] These are present in California waters in sufficient numbers to support a major industry during the fall, winter and spring months only. As has been demonstrated,[4] the sardine is a migratory fish moving northward during the spring and summer and south in the fall and winter. Each year as the fish grow older the northward movement is extended and the largest and oldest fish reach the waters off the Washington and British Columbia coasts. As a result the southward return is delayed and these largest fish are not found on the central

[2] Andrews (1928), Clark (1930, 1936.1), Higgins (1926), Phillips (1937), W. L. Scofield (1926).

[3] In earlier years and sporadically in more recent seasons a small pack of immature sardines has been made at San Diego. This constitutes an unimportant exception to the above statement.

[4] Clark (1934, 1935, 1936.1, 1936.2), Hart (1933, 1934), Hubbs (1925), Janssen (1938), Phillips (1937), E. C. Scofield (1934).

and southern California fishing grounds until the winter months. The younger adults, not migrating as far to the north, return in the fall and are exploited by California fishermen for several months before the largest and oldest fish can be found. In central California, present studies indicate that the younger fish have largely left the fishing grounds by the time the oldest fish arrive. In southern California, the younger fish apparently remain on the fishing grounds and are joined by the oldest fish. In central California, which comprises the grounds exploited by the fishermen operating out of the ports of San Francisco and Monterey, the period August to November delimits in a general way the time in which the younger adults are present in the fishery, and December to February the interval when the oldest adults are found on the fishing grounds. In southern California, from Point Conception to San Diego, the smaller adult sardines are present in November and December and they are joined by the largest fish in January. Thus, the fall fishery in central California lasts from August to November and the winter fishery from December to February. In southern California, the fall fishery continues through November and December and the winter fishery from January to March. In this study of the return per unit of effort, the fisheries have been divided according to these time intervals.

2.2. Effect of Limits and Increase in Boat Size

From the beginning of the sardine industry the canning plants have needed a constant supply of fish. Because a fisherman's luck is always precarious, if a cannery has only a few boats fishing there will be days when very few fish are delivered. To prevent this mishap, the canners contract for many boats but if all these boats were to make capacity catches the cannery could not handle the deliveries. Such gluts have been avoided by placing each boat on a limited catch. When fish were scarce the limits were high or inoperative, when fish were abundant the limits were correspondingly lower. Also as the total capacity of the plants has increased, the size of the limits has become larger and larger. In the early days of the industry the boats operated on 10- and 12-ton limits (W. L. Scofield, 1929). These were increased season by season until they became as great as 50 and 60 tons, and finally no limits were applied at all. This last point was reached with the large capacity of our present plants and the increasing scarcity of sardines.

At the same time that the sardine canning and reduction plants were increasing in capacity, the sardine boats were also increasing in size and using larger and more efficient gear. The first sardine boats fished with lampara nets and had total capacities of not more than twenty or thirty tons. They had a limited cruising radius and could not operate far from port. After the reintroduction of the purse seine about 1925, newer and larger nets and boats were built each year. By 1938 some of the boats had capacities of over 200 tons and could cruise hundreds of miles.

This constant increase in the size of the limits applied to each boat and the continued increase in the size of gear and boats have made any analysis of the return per unit of effort in the sardine fishery very unreliable, if such a return is to be interpreted as a measure of the abundance of the population or even of the availability of the fish to the fishermen. As long as limits were in effect, with one exception, all units of effort merely measured the increase in the size of the limits or the increase in the size of the boats. The one exception was the "length of scouting time."

2.3. Length of Scouting Time

On the theory that varying abundance of the sardine population would be reflected in the length of time it took the fishermen to locate schools of fish, the length of scouting time was calculated for the Monterey and San Pedro sardine fisheries (Clark, 1933). Scouting time was calculated as the number of hours elapsing between moonset or one hour after sunset and the time when the fisherman made his first set for fish. Sardines are located by the luminescence caused by the movement of the school through the water and this luminescence can only be seen at night when the moon is not shining. The fishermen do not "set" or "pay out" a net until a school of fish has been found. The use of the length of scouting time as a measure of abundance of sardines had the one virtue that it eliminated to a large degree the effect of limits. Limits had some influence, however, because on nights when limits were high the fishermen may have passed by small schools hoping to find larger schools before the night was over. Nonetheless for several seasons, length of scouting time did give a rough measure of the availability of sardines to the fishermen. Unfortunately, as fish became scarcer it was no longer a useful criterion. Scouting time could be used only when a boat actually made a catch. Boats which scouted all night without making a set are not recorded in our statistics and could not be included in the calculations. There are only so many hours of darkness each night and this automatically places a maximum limit on the average scouting time. Increasing scarcity of fish is not reflected, therefore, in increased scouting time. It merely results in more boats failing to make catches and the average scouting time for the boats which do make catches remains the same.

2.4. Lunar Month Catch

2.4.1. Decrease in the Effect of Limits

In the later seasons more and more frequently no limits have been placed on the sardine boats, and it is now possible to use as a unit of effort the lunar month catch of the fishing boats. The present measure, here discussed, covers the seasons 1932–33 to 1937–38 for the ports of Monterey and San Pedro. The fishery out of San Francisco is of recent development and not sufficiently stabilized to make comparisons possible if deliveries to shore plants alone are considered. The United States Bureau of Fisheries is making an analysis of the San Francisco fishery, using boats fishing for both shore plants and floating reduction ships.

Previous to 1932–33 limits played so important a role that the calculations are not to be relied upon. Even in these later seasons, limits have been applied at times. The percentage of the time when limits were enforced is shown in table 1 and also the average size of

TABLE 1

PERCENTAGE OF THE TIME WHEN SARDINE BOATS WERE RESTRICTED BY LIMITS AND THE AVERAGE SIZE OF THE LIMITS

Season	Monterey				San Pedro			
	Fall fishery		Winter fishery		Fall fishery		Winter fishery	
	Days with limits, per cent	Average size limits, tons	Days with limits, per cent	Average size limits, tons	Days with limits, per cent	Average size limits, tons	Days with limits, per cent	Average size limits, tons
1932–33	9.4	65.0	0	0	70.9	45.4	34.7	49.1
1933–34	8.3	58.3	0	0	44.6	43.0	65.0	44.9
1934-35	29.2	50.1	20.0	50.8	43.1	51.8	38.6	47.2
1935–36	83.4	43.2	46.2	50.3	62.9	48.7	50.5	61.6
1936–37	15.7	38.3	0	0	0	0	0	0
1937–38	0	0	0	0	0	0	0	0

TABLE 1

PERCENTAGE OF THE TIME WHEN SARDINE BOATS WERE RESTRICTED BY LIMITS AND THE AVERAGE SIZE OF THE LIMITS

the limits. Not until 1937–38 was there a complete absence of limits, but in 1936–37 there were no limits except for a short time interval in the fall fishery at Monterey. For the previous four seasons, limits were in effect during part of each season. The influence of these limits was measured in the following manner:

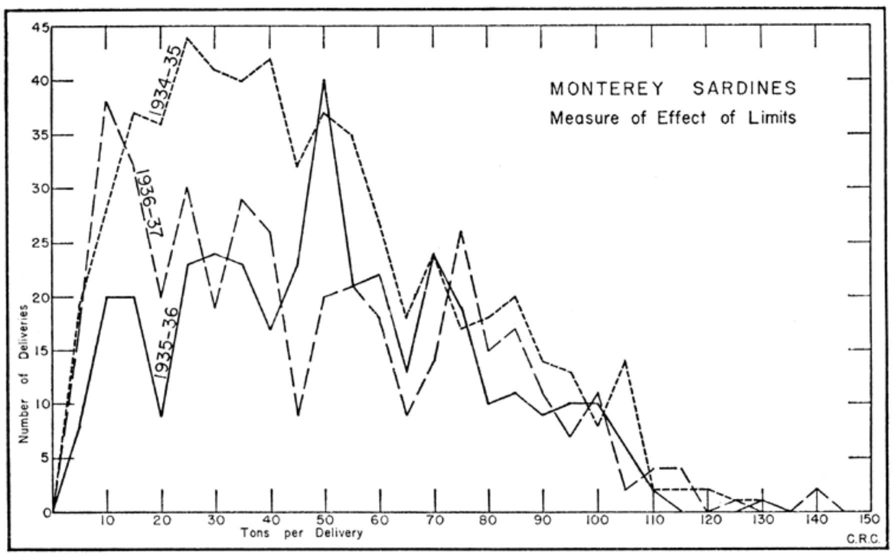

FIG. 1. Frequencies of the tons per delivery of sardine boats fishing at Monterey during the lunar months corresponding to January and February of 1934-35, 1935-36, and 1936-37. Limits were enforced 60 per cent of the time in 1935-36. There were no limits in 1934-35 and 1936-37.

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At Monterey during the lunar months corresponding to January and February of 1935–36, limits were enforced 60 per cent of the time. For the same time interval of 1934–35 and 1936–37 no limits were applied. Frequencies of the number of tons per delivery of all boats fishing during these two lunar months for each of the three seasons are shown in figure 1. The distributions of the sizes of the catches for these three seasons are very similar in spite of the limits enforced in 1935–36. A chi-square test applied to the comparison of the 1935–36 frequency with the 1934–35 gave a value for P of .1040. This would indicate that differences as great as those between these two frequencies might occur by chance once in ten times. Few would attach any significance to differences which might happen by chance as frequently as one in ten. In addition, the differences which do exist occur because more small catches were made in 1934–35 when no limits were applied than in 1935–36 when limits were in effect. For the comparison between 1935–36 and 1936–37, the chi-square test gave a value for P of .9996, indicating the differences between these two frequencies would occur by chance ten times in ten. Evidently the limits of 1935–36 had no effect on the size of the catches.

It is apparent, therefore, that limits which have been placed on the boats in the last six seasons have been of such a magnitude as not to seriously curtail the size of the fishermen's catch. The tons caught can be used, therefore, as a unit of effort provided the effect of increasing boat size can be compensated.

2.4.2. Selection of Boats

The simplest way to compensate for the increase in size of boats would be to select those boats which had fished continuously over the six seasons involved in this study. But because of the constant change in the sardine fishing fleet, it was not possible to find enough boats fishing continuously in any locality to give a reliable average of return per unit of effort. In no case had as many as ten boats fished constantly throughout either the fall or winter fishery for six consecutive seasons at either Monterey or San Pedro. Obviously the catches of different boats can not be compared, especially when each season more larger boats are entering the fishery.

To obviate this difficulty comparisons were made between the catch of any one boat for two seasons only. A series of boats was selected which fished in season 1 and season 2. The catch of each of these boats in season 2 was expressed in percentage of its catch in season 1. For seasons 2 and 3 a new group of boats was selected and the catch for each boat in season 3 expressed in percentage of its catch in season 2. This method was continued for the six seasons of the study.

Boats were chosen which had fished continuously throughout the fall or winter at each port. For Monterey, boats fishing continuously from August to November were selected for the analysis of the fall fishery, and from December to January for the winter fishery. At San Pedro, boats fishing in November and December comprised the fall fishery and January to March the winter fishery.

TABLE 2

DATES OF THE LUNAR MONTHS USED FOR THE COMPARISON OF THE CATCH OF EACH BOAT WITH ITS CATCH IN THE CORRESPONDING LUNAR MONTH OF THE PREVIOUS SEASON

	1932–33	1933–34	1934–35	1935–36	1936–37	1937–38
August	Aug. 16–Sept. 14	Aug. 6–Sept. 4	July 27–Aug. 24	Aug. 15–Sept. 12	Aug. 3–Sept. 1	July 24–Aug. 22
September	Sept. 15–Oct. 14	Sept. 5–Oct. 3	Aug. 25–Sept. 23	Sept. 13–Oct. 12	Sept. 2–30	Aug. 23–Sept. 20
October	Oct. 15–Nov. 12	Oct. 4–Nov. 2	Sept. 24–Oct. 22	Oct. 13–Nov. 10	Oct. 1–30	Sept. 21–Oct. 19
November	Nov. 13–Dec. 12	Nov. 3–Dec. 2	Oct. 23–Nov. 21	Nov. 11–Dec. 9	Oct. 31–Nov. 28	Oct. 20–Nov. 18
December	Dec. 13–Jan. 11	Dec. 3–Dec. 30	Nov. 22–Dec. 20	Dec. 10–Jan. 8	Nov. 29–Dec. 27	Nov. 19–Dec. 17
January	Jan. 12–Feb. 10	Dec. 31–Jan. 30	Dec. 21–Jan. 19	Jan. 9–Feb. 7	Dec. 28–Jan. 26	Dec. 18–Jan. 16
February	Feb. 11–Mar. 12	Jan. 31–Mar. 1	Jan. 20–Feb. 18	Feb. 8–Mar. 8	Jan. 27–Feb. 25	Jan. 17–Feb. 14
March	Mar. 13–April 10	Mar. 2–31	Feb. 19–Mar. 20	Mar. 9–April 6	Feb. 26–Mar. 26	Feb. 15–Mar. 16

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DATES OF THE LUNAR MONTHS USED FOR THE COMPARISON OF THE CATCH OF EACH BOAT WITH ITS CATCH IN THE CORRESPONDING LUNAR MONTH OF THE PREVIOUS SEASON

The unit of effort selected was the total catch of each boat for a lunar month. The dates of the lunar months used are given in table 2. Because sardine schools are located by the luminescence which the fish movements produce in the water, fishing must be carried on in darkness. This results in a cessation of fishing for about five days during each full moon and the lunar month, from full moon to full moon, forms a natural time unit in the sardine fishery. The catch per delivery is not a satisfactory unit because it does not take into account the failures to make catches, and sardine fishermen do not set their nets until a fair sized school of fish is located. Our statistical system gives us no record of nights when fishermen were out searching for schools but brought in no catch. These zero catches become of increasing importance as fishing grows more and more difficult. An extended time unit solves this problem because the total catch delivered over the interval will be larger or smaller in accordance with the number of catches made as well as the size of each catch.

This selection of boats and expression of each boat's catch in percentage of its catch for the corresponding lunar month of the previous season gives a series of percentages for each season. These percentages must be averaged to show a general picture of the availability of the fish to the fishermen and thus a measure of the changes in population abundance.

2.4.3. The Geometric Mean and the "Chain" System

Any frequency curve based on the catches of fishing boats will be skewed toward the right. This is because there are always a few exceptionally large catches. For such data the geometric mean is the best average and in addition this mean lends itself more readily to the "chain" system. Consequently, the geometric mean was selected to average the percentages resulting from comparing each boat's catch with its catch for the previous season. Mechanically the use of the geometric mean much simplified the calculations, for once the logarithms of the lunar month catch of each boat had been found, the remaining calculations could all be carried on by addition and subtraction.

Because the catches of the same group of boats could not be compared for more than two seasons, a season's geometric average compared the catch of season 2 with season 1 and season 3 with season 2 but did not compare season 3 with season 1. This comparison was made by linking each of the six seasons' geometric mean percentages by the "chain" system (Fisher, 1927). This method established 1932–33 as the base, or 100 per cent. Each succeeding season was compared to this base year "by way of" the intermediate bases, 1933–34, 1934–35, etc.

The fall fishery at Monterey includes the lunar months corresponding most closely with the calendar months of August, September, October and November. For any two seasons' comparison, each boat's lunar month catch for August was expressed in percentage of its catch for the corresponding lunar month of the previous season, similarly September with September, etc. This gave percentages for four lunar months for the group of boats selected. As far as possible only boat catches were used when the boat fished continuously over the four-month period, but occasionally data would be lacking for a few boats in certain lunar months. To determine the average for the fall fishery, the percentages for the four lunar months were combined. The data for each month were given weight in determining this fall average in proportion to the number of boats which entered into the calculations for each month. In a similar manner the geometric means for the Monterey winter and the San Pedro fall and winter fisheries were calculated. The number of boats involved is shown by months in tables 3 and 4.

During each season storms interfere with fishing for short time intervals. At San Pedro and Monterey, the time lost because of bad weather is not great, however. A careful check was made for the six seasons covered by this study and the interruption to fishing because of storms was not a serious factor. Some time was lost each season but the amount varied little from season to season. Because of this no allowance was made for the effect of storms.

Occasionally at San Pedro and more frequently at Monterey, fishing has been interrupted because of strikes. To compensate for this, each boat's lunar month catch was multiplied by a factor to weight the catch to a full lunar month. For example, if a strike lasted five days the catch would be multiplied by 29/24. Because fishing is interrupted for five or six days at the time of the full moon the factor used might have been 29–6/23–5 or 23/18. The number of days lost to fishing because of full moon "lay-ups" has varied, however, from season to season and occasionally fishing has been continued through the full moon interval. For these reasons it seemed best to consider 29 days as the lunar month unit. No adjustment was made for strikes occurring during any part of a six-day interval at the time of full moon.

Due to legal restrictions, sardine fishing begins at Monterey on August 1 and closes on the following February 15. At San Pedro the season extends from November 1 to March 31. In a few instances a lunar month began a few days before the season opened or extended beyond the closing date. Because of this, some fishing time was lost. When this occurred the catches were weighted in the same manner as for strikes. Because the Monterey season closed in the middle of February the lunar month corresponding to February was not used in the Monterey calculations. Its use would have necessitated weighting to a point where the results would not have been trustworthy. To compensate for the effects of strikes and short lunar periods, during the six seasons studied, boat catches were weighted for five different lunar months of the Monterey fall fishery, one lunar month of the Monterey winter fishery, one in the San Pedro fall and one in the San Pedro winter fisheries. Because of a strike at San Pedro, no fishing occurred during November of 1936. This left only December to represent the fall fishery of the 1936–37 season. The difficulty was circumvented by comparing December catches of 1936–37 with November and again with December of 1935–36. In the same manner November and also December of 1937–38 were compared with December of 1936–37.

TABLE 3

MONTEREY. GEOMETRIC MEAN OF THE PERCENTAGES RESULTING FROM COMPARING THE LUNAR MONTH CATCH OF EACH BOAT WITH ITS CATCH FOR THE CORRESPONDING LUNAR MONTH OF THE PREVIOUS SEASON. The Percentages Are Not Linked to 1932-33 as a Base Year

	1933–34		1934–35		1935–36		1936–37		1937–38	
	Geo. mean	Number boats	Geo. mean	Number boats	Geo. mean	Number boats	Geo. mean	Number boats	Geo. mean	Number boats
August	89.4	13	174.5	19	56.2	22	51.7	29	20.3	10
September	50.2	21	269.8	32	73.7	38	110.2	32	12.1	37
October	118.2	20	173.2	33	55.3	39	65.1	32	84.7	42
November	155.7	17	134.9	31	60.2	39	124.5	32	40.7	43
Fall fishery	93.1	71	183.3	115	61.5	138	83.3	125	34.7	132
December	65.3	29	132.0	40	56.4	45	115.7	43	35.0	35
January	148.4	29	70.4	41	146.7	45	65.2	42	55.9	37
Winter fishery	98.5	58	96.0	81	91.4	90	87.1	85	44.5	72

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MONTEREY. GEOMETRIC MEAN OF THE PERCENTAGES RESULTING FROM COMPARING THE LUNAR MONTH CATCH OF EACH BOAT WITH ITS CATCH FOR THE CORRESPONDING LUNAR MONTH OF THE PREVIOUS SEASON. The Percentages Are Not Linked to 1932–33 as a Base Year

TABLE 4

SAN PEDRO. GEOMETRIC MEAN OF THE PERCENTAGES RESULTING FROM COMPARING THE LUNAR MONTH CATCH OF EACH BOAT WITH ITS CATCH FOR THE CORRESPONDING LUNAR MONTH OF THE PREVIOUS SEASON. The Percentages Are Not Linked to 1932-33 as a Base Year

	1933–34		1934–35		1935–36		1936–37		1937–38	
	Geo. mean	Number boats	Geo. mean	Number boats	Geo. mean	Number boats	Geo. mean	Number boats	Geo. mean	Number boats
November	84.5	30	158.0	42	68.2	30	46.5	38	87.8	68
December	141.5	30	86.2	46	35.8	34	96.1	53	131.7	77
Fall fishery	109.3	60	115.1	88	48.4	64	71.0	91	108.9	145
January	110.4	29	135.7	36	88.9	58	29.6	73	154.7	54
February	144.8	30	90.8	38	67.3	60	69.2	74	41.5	61
March	179.0	26	140.8	39	57.0	60	135.8	73	44.5	60
Winter fishery	140.8	85	120.0	113	69.7	178	65.3	220	63.8	175

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SAN PEDRO. GEOMETRIC MEAN OF THE PERCENTAGES RESULTING FROM COMPARING THE LUNAR MONTH CATCH OF EACH BOAT WITH ITS CATCH FOR THE CORRESPONDING LUNAR MONTH OF THE PREVIOUS SEASON. The Percentages Are Not Linked to 1932–33 as a Base Year

The data for the lunar month catch of each boat were obtained from the regular statistical system developed by the California Division of Fish and Game (Conner, 1935). This system provides that each dealer upon buying fish from a fishing boat must fill out a receipt in triplicate and the third copy is turned over to the Division of Fish and Game. This receipt shows, in addition to other detailed information, the date, name of boat, kind of fish and number of pounds sold. The vast amount of information accumulated from these receipts is tabulated and made usable by the statistical department of the State Fisheries Laboratory, which uses mechanical equipment for compiling the reports. Much of the preliminary information on which this study is based was obtained from the regular reports of the statistical department. In addition, the detailed records of lunar month catch for each boat were prepared by this department. The amount of time and labor thus saved was tremendous.

2.4.4. Six-Season Trends of the Geometric Mean Percentages

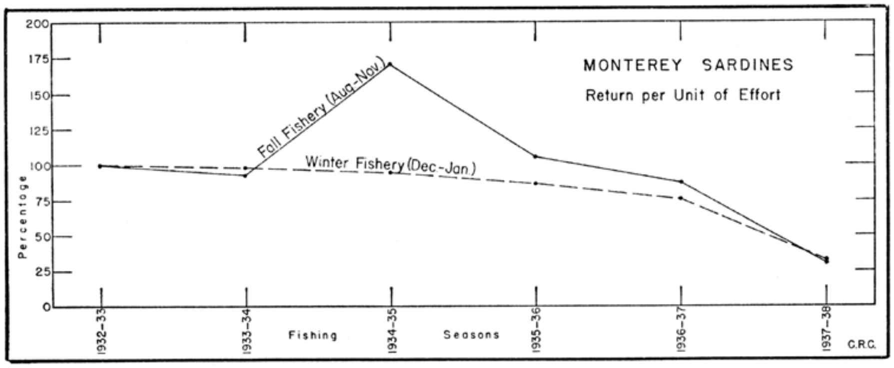

FIG. 2. Seasonal variations in return to the Monterey fishermen per unit of effort expended. For an explanation of the unit used, see text.

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The relative average return to the fishermen for the effort expended is shown in figures 2 and 3 and tables 3 and 4. The general trend of the catches for the four comparisons is similar. With the exception of the winter fishery at Monterey, maximum fishing conditions were attained in 1934–35. For all four trends there has been a steady decline in the yield since 1934–35. For the Monterey winter fishery the decline has been consistent since 1932–33. For the San Pedro fall fishery, fishing success in 1937–38 was equal to that of 1936–37.

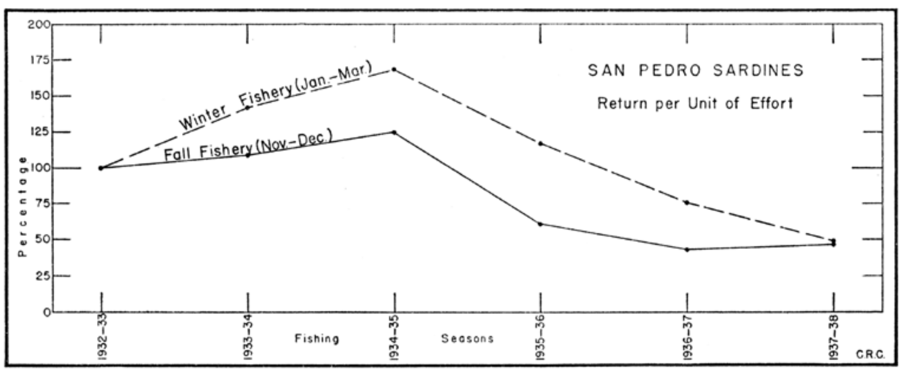

FIG. 3. Seasonal variations in return to the San Pedro fishermen per unit of effort expended. For an explanation of the unit used, see text.

FIG. 3. Seasonal variations in return to the San Pedro fishermen per unit of effort expended. For an explanation of the unit used, see text

The statistical significance of the variations in the percentage values was estimated by calculating the standard deviation and standard error of the log of the geometric mean of the percentages for each season's comparison. Because each of these mean percentages was later linked by the "chain" system to give the trends of figures 2 and 3, it is not possible to apply this statistical measure to the seasonal changes linked to the base season, 1932–33. It does measure, however, the significance of the change from season to season.

The formulae used in these calculations were:

$$S = \sqrt{\frac{\Sigma(x_1 - \bar{x}_1)^2 + \Sigma(x_2 - \bar{x}_2)^2 \dots \Sigma(x_n - \bar{x}_n)^2}{n_1 + n_2 \dots\dots n_n}}$$

$$SE_M = \frac{S}{\sqrt{n_1 + n_2 \dots n_n}}$$

FORMULA

Where S is the standard deviation, SE_M the standard error of the mean for the season, [X}sb1}/sb] the log of the mean for lunar month 1, (X}sb1}/sb—[X}sb1}/sb]) the deviation of the logs of individual catches from the log of the mean of lunar month 1, n_1 the number of boats in lunar month 1. The results of these calculations are given in table 5.

TABLE 5

THE STANDARD DEVIATION AND STANDARD ERROR OF THE GEOMETRIC MEAN PERCENTAGE RESULT ING FROM THE COMPARISON OF THE LUNAR MONTH CATCH OF A BOAT WITH ITS CATCH FOR THE COMPARABLE LUNAR MONTH OF THE PRECEDING SEASON.

	Monterey fall fishery				Monterey winter fishery			
	Log. Geo. mean	S	SE_M	$2SE_M$	Log. Geo. mean	S	SE_M	$2SE_M$
1933–34	$\bar{1}$.96913	.28702	.03406	.06812	$\bar{1}$.99330	.20567	.02701	.05402
1934–35	.26333	.24599	.02294	.04588	$\bar{1}$.98234	.21863	.02429	.04858
1935–36	$\bar{1}$.78860	.25898	.02205	.04410	$\bar{1}$.96076	.33660	.03548	.07096
1936–37	$\bar{1}$.92083	.28651	.02563	.05126	$\bar{1}$.94023	.31607	.03428	.06856
1937–38	$\bar{1}$.54058	.29650	.02581	.05162	$\bar{1}$.64831	.28337	.03340	.06680

	San Pedro fall fishery				San Pedro winter fishery			
	Log. Geo. mean	S	SE_M	$2SE_M$	Log. Geo. mean	S	SE_M	$2SE_M$
1933–34	.03876	.27350	.03531	.07062	.14871	.31867	.03456	.06912
1934–35	.06097	.26277	.02801	.05602	.07943	.29704	.02794	.05588
1935–36	$\bar{1}$.68485	.40679	.05085	.10170	$\bar{1}$.84305	.26184	.01963	.03926
1936–37	$\bar{1}$.85097	.39722	.04164	.08328	$\bar{1}$.81486	.30047	.02026	.04052
1937–38	.03700	.35180	.02921	.05842	$\bar{1}$.80485	.39850	.03012	.06024

TABLE 5

THE STANDARD DEVIATION AND STANDARD ERROR OF THE GEOMETRIC MEAN PERCENTAGE RESULT ING FROM THE COMPARISON OF THE LUNAR MONTH CATCH OF A BOAT WITH ITS CATCH FOR THE COMPARABLE LUNAR MONTH OF THE PRECEDING SEASON.

If twice the standard error be considered the level of significance, for the Monterey fall fishery the decrease from 1932–33 to 1933–34 is not significant, the increase from 1933–34 to 1934–35 is, and the continued decreases following 1934–35 are all significant, For the Monterey winter fishery the trend is consistently downward, from 1932–33, but none of the season by season decreases are significant except for the comparison of 1937–38 with 1936–37. For the San Pedro fall fishery, the increase from 1932–33 to 1933–34 is not statistically significant, that from 1933–34 to 1934–35 barely so. The decrease from 1934–35 to

1935–36 is significant, as is the decrease from 1935–36 to 1936–37. The slight increase from 1936–37 to 1937–38 is not significant. For the San Pedro winter fishery the increase from 1932–33 to 1933–34 is significant, that from 1933–34 to 1934–35 scarcely, and the continued decreases following 1934–35 are all significant.

In general if the return per unit of effort be considered a measure of population abundance, the trends of figures 2 and 3 and the calculations given in table 5 indicate relatively stable conditions from 1932–33 to 1934–35 but a consistent decline thereafter.

In any analysis of the return per unit of effort, it is difficult to determine how the unit chosen is influenced by variations in the total amount of effort expended. For a limited area with an intense fishery, theoretically, the return per unit of effort might fluctuate directly as the total effort varies. But in practical fisheries work the relationship is very complex, both because the population is subject to many biological variations and because the toll taken by the fishermen affects the population abundance in various ways, depending on whether the entire population is fished or only certain portions. One fundamental principle seems evident, however: if a fishery is drawing upon an entire population and if an increase in the total fishing effort results in a decrease in return per unit of effort, such a fishery can not long continue without dangerously reducing the basic supply.

Biological studies of the sardine have demonstrated that the California fishery for the canneries and reduction plants draws upon the entire adult population. During the fall months the younger adults are fished and in the winter months both the younger and older adults. In addition the sardine fisheries of British Columbia, Washington and Oregon (where the fish are called pilchards) take their toll from the older adult sardines during the summer months.

TABLE 6

TONS TAKEN IN THE CALIFORNIA SARDINE FISHERY BY SHORE PLANTS DURING THE FALL AND WINTER MONTHS, AND THE RELATIVE INCREASE OF EACH FISHERY EXPRESSED IN PERCENTAGE OF THE RESPECTIVE AVERAGE CATCHES FOR THE 5 SEASONS, 1919-20 TO 1923-24.

Season	Fall fishery		Winter fishery	
	Tons	Per cent of 5-season average	Tons	Per cent of 5-season average
1919–20	22,285	107	31,677	104
1920–21	20,751	100	11,607	38
1921–22	10,711	51	23,224	76
1922–23	20,659	99	39,973	131
1923–24	29,663	143	46,153	151
1924–25	65,149	314	101,400	332
1925–26	53,078	255	72,462	237
1926–27	58,887	283	75,862	249
1927–28	66,867	321	95,683	313
1928–29	105,656	508	123,922	406
1929–30	164,270	790	159,163	521
1930–31	98,478	473	74,764	245
1931–32	72,882	350	59,388	195
1932–33	89,868	432	101,292	332
1933–34	139,951	673	174,970	573
1934–35	256,838	1,234	225,943	740
1935–36	193,700	931	206,433	676
1936–37	238,157	1,145	246,394	807
1937–38	208,059	1,000	139,549	457

TABLE 6

TONS TAKEN IN THE CALIFORNIA SARDINE FISHERY BY SHORE PLANTS DURING THE FALL AND WINTER MONTHS, AND THE RELATIVE INCREASE OF EACH FISHERY EXPRESSED IN PERCENTAGE OF THE RESPECTIVE AVERAGE CATCHES FOR THE 5 SEASONS, 1919–20 TO 1923–24.

For readers interested in more details of the return per unit of effort, the trends of the percentages linked by the "chain" system for the individual lunar months are shown in the appendix, figures 16 and 17, and the supporting data are given in tables 3 and 4. Because fewer boats are involved, these trends are more irregular than are the season trends, but here also no consistent change is indicated until 1934–35 and an almost continued decrease thereafter.

3. DURATION OF SUPERABUNDANT GROUPS

Early in the history of the investigation, it became evident that our sardine population is characterized by marked differences in the number of young fish produced by each season's spawn. In some seasons spawning success is poor, in others average, and in still others much above average. A year-class resulting from a more than average spawning survival represents a superabundant group which can be detected in the adult population by length frequency polygons and by the deviations of each season's frequency from an average of several seasons.

Former publications[5] have shown such length frequency polygons and discussed the appearance and disappearance of four super-abundant groups. These length frequency studies have been based on representative samples of the cannery catch collected and measured consistently since 1919. The polygons for the Monterey and San Pedro fisheries are again presented and brought up to date in figures 18 and 19 of the appendix. As in the analysis of the return per unit of effort, the season is divided into a fall and a winter fishery and length frequencies are shown for each time unit. Because of the multimodal and otherwise complex character of these frequencies, the modes representing the superabundant groups are not readily apparent in these polygons. The data are much clarified by the simple device of subtracting from each season's frequency an average frequency. Ten-season averages involving the seasons from 1924–25 to 1933–34 were used, and the resulting deviation curves are shown in figures 4, 5, 6 and 7.

Only younger and smaller sardines are taken in the fall fisheries and hence a superabundant group will seldom be evident in the fall frequencies for more than four seasons. During the winter months, on the other hand, the older and larger adults, as well as the younger, are present on the fishing grounds. As a result in the winter the fishermen's catches tend to represent more completely the size distribution of all adolescent and adult sardines in the population, and the corresponding deviation curves permit the analysis of each superabundant group for a longer term of seasons.

In all deviation curves, however, groups A, B, C and D are clearly evident. In the fall deviations[6] (see Figs. 4 and 5) each of these four groups progressed through the fishery with regularity except at Monterey in 1931–32 when group D failed to show any size increase over the previous season. In the winter fishery, groups

[5] Clark (1931, 1936.1), Higgins (1926), W. L. Scofield (1926), Thompson (1926).

[6] No fishing occurred at San Pedro during the fall months previous to 1924–25, hence A does not appear in the San Pedro fall frequencies.

A, B and C follow a regular course. Group A is evident for four or five seasons until the entrance of B caused its dominance to be submerged. Group B maintains its dominance even after the entrance of C, and as the year-classes involved in these two groups reached older ages the two groups merge. They can be traced through the fishery for approximately ten seasons.

In contrast to the behavior of former superabundant groups, D presents a very irregular progression. In the Monterey winter fishery, it is only clearly evident in 1930–31 and suggested in 1931–32; at San Pedro it dominates the fishery for three seasons and then completely disappears. During both the fall and winter after 1931–32 no definite superabundant group entered the fishery nor has any group progressed with any regularity. Groups E and F are suggested but they appear and disappear in too irregular a manner to be designated as superabundant groups if submitted to the same measurement criteria as the former groups.

This raises the question : What is happening to the sardine population? Have we had a long time interval when spawning survival has been poor and no superabundant groups produced, or is fishing now so intense that the superabundance of any group is wiped out in one or two seasons? The first of these questions can not be answered positively without a complete measure of the number of eggs, larvae and young fish produced over a period of years. Since the sardine spawns over an extensive area of the ocean, such a measure is beyond the facilities available to the investigation at present. The fact remains, however, that during the first eleven years of the investigation new superabundant groups entered the fishery at intervals of three or four years; in the succeeding eight years no new dominant group has been clearly apparent. This tends to cast doubt on the suggestion that no superabundant groups have been produced by nature. At the same time we have a definite measure of the increasing magnitude of the fishery and we know that the strain on the population has been tremendously increased. To understand the effect of this strain, we must remember that the fishery does not take an equal toll from the entire population throughout the entire season. In the fall months only the adolescent and younger adults are fished, whereas in the winter all adult sizes are taken. During the summer months large adults are fished off British Columbia, Washington and Oregon. But because the California catch far exceeds the tonnages taken to the north, the smaller sizes are submitted to a more intense fishery than are the larger sizes. The ratio of this intensity will vary as vary the tonnages taken in the fall and winter fisheries. The more intense the fall fishery the more rapidly will the dominance of a superabundant group be wiped out.

In table 6 are given the tons delivered to California shore plants during the fall and the winter of each season since 1919–20. For the first ten seasons, with few exceptions, the total tonnage taken in the winter exceeded that taken in the fall. In the later seasons the fall tonnage has equaled if not exceeded that of the winter months. This more rapid increase in the intensity of the fall fishery is further illustrated in the percentage increase shown in table 6 and in figure 8. For these percentages the average catch of the first five

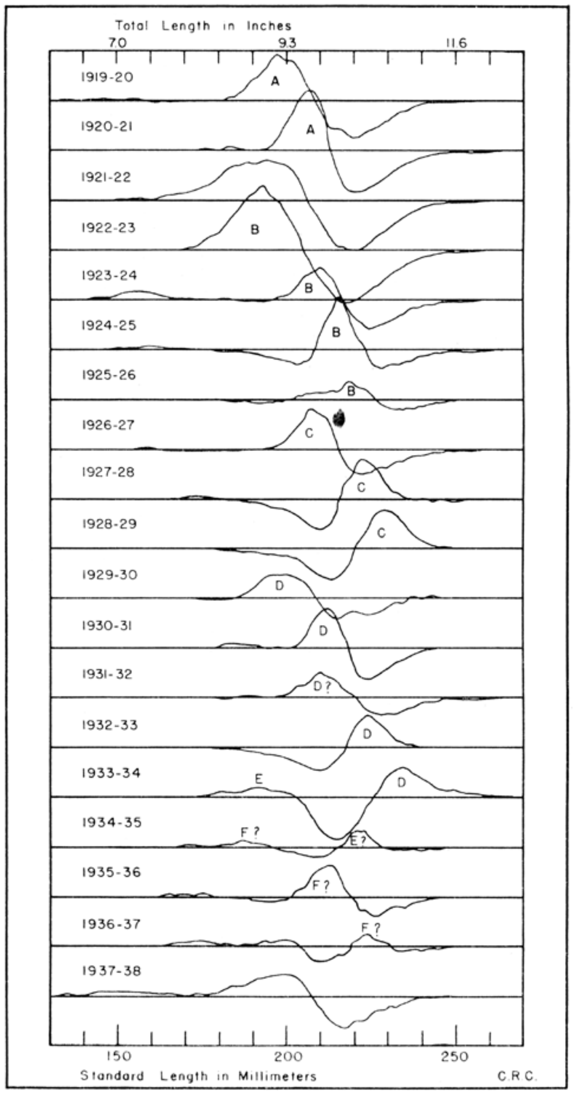

FIG. 4. Length frequency deviations from a ten-season average (1924-25 to 1933-34) of the Monterey fall fish.

FIG. 4. Length frequency deviations from a ten-season average (1924–25 to 1933–34) of the Monterey fall fish

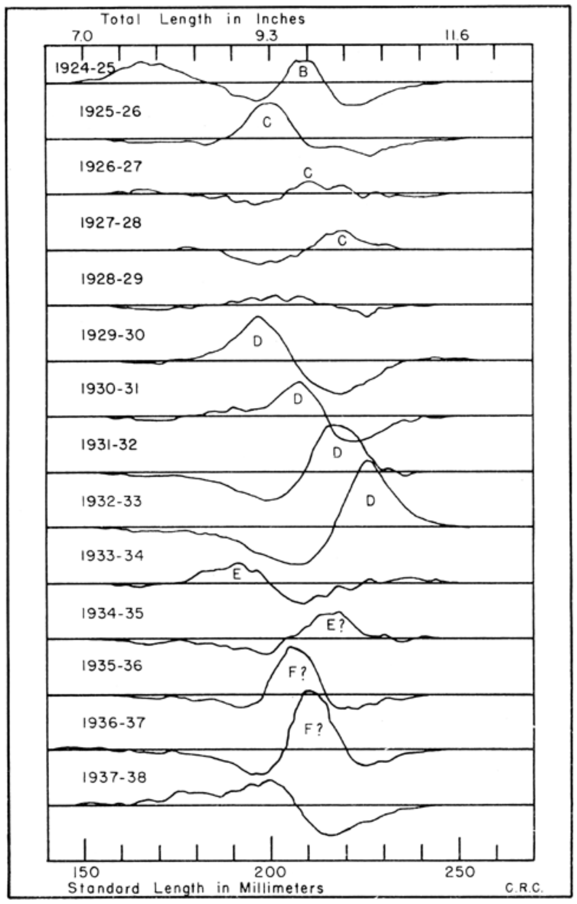

FIG. 5. Length frequency deviations from a ten-season average (1924-25 to 1933-34) of the San Pedro fall fish.

FIG. 5. Length frequency deviations from a ten-season average (1924–25 to 1933–34) of the San Pedro fall fish

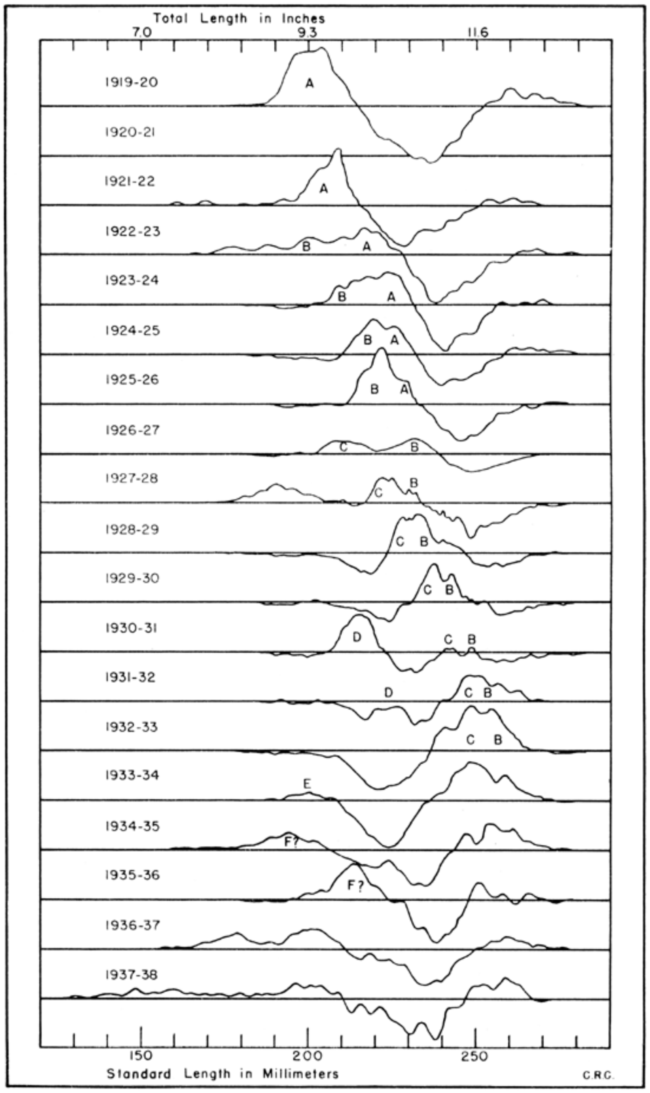

FIG. 6. Length frequency deviations from a ten-season average (1924-25 to 1933-34) of the Monterey winter fish. Due to unfavorable economic conditions no sardines were taken in the winter of 1920-21.

FIG. 6. Length frequency deviations from a ten-season average (1924–25 to 1933–34) of the Monterey winter fish. Due to unfavorable economic conditions no sardines were taken in the winter of 1920–21

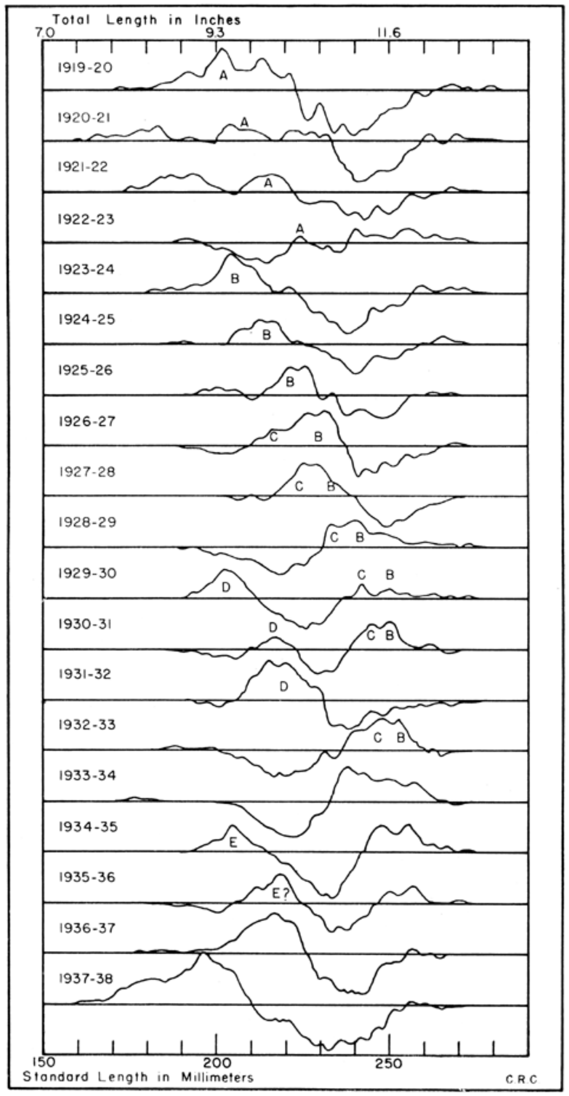

FIG. 7. Length frequency deviations from a ten-season average (1924-25 to 1933-34) of the San Pedro winter fish.

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

fall seasons is considered 100 per cent and each fall season's catch is expressed in percentage of this average. The winter fishery is similarly expressed in percentage of the average for the first five winter seasons. It is evident that the intensity of the fall fishery has increased much more rapidly than that of the winter. This more rapid increase has been brought about by a corresponding advance in the total fishing effort expended during the fall months.

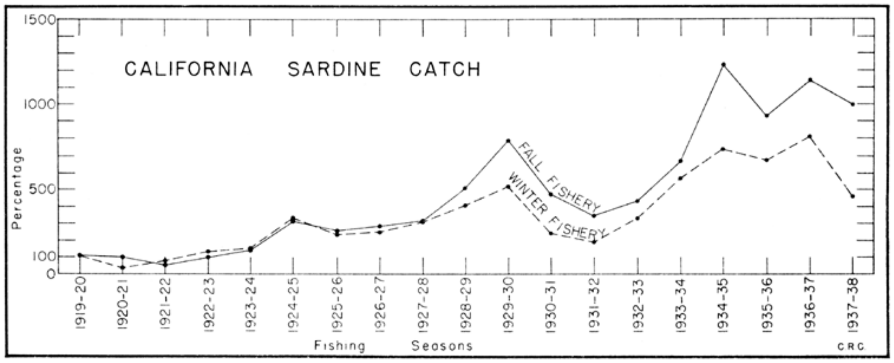

FIG. 8. Relative increase in the California sardine catch for the fall months and for the winter months. Each season's catch expressed in percentage of the average catch for five seasons, 1919-20 to 1923-24.

FIG. 8. Relative increase in the California sardine catch for the fall months and for the winter months. Each season's catch expressed in percentage of the average catch for five seasons, 1919–20 to 1923–24

Figure 8 indicates that the rapid expansion of the fall fishery began about 1928–29, just previous to the time that group D entered the fishery. This rapid expansion can be more simply demonstrated by considering the average tonnage taken during the five seasons, 1919–20 to 1923–24, the average tonnage, ten years later for the five seasons, 1929–30 to 1933–34, and for the four succeeding seasons, 1934–35 to 1937–38. The comparisons are as follows:

	Fall Fishery Average Tons	Fall Fishery Unit Increase	Winter Fishery Average Tons	Winter Fishery Unit Increase
1919–24	20,814	1.0	30,527	1.0
1929–34	113,090	5.4	103,706	3.4
1934–38	224,189	10.8	204,580	6.7

For the first five-year interval the winter fishery took about 1.5 times as great a tonnage as did the fall fishery. But the winter fishery draws from larger sardines than does the fall. As a result there are about 1.5 times as many fall fish in a ton as there are winter fish and consequently in the early history of the industry the fall and winter fisheries took about equal numbers from the sardine population. Following this initial equal intensity, ten years later the fall fishery was taking 5.4 times as many fish and 14 years later 10.8 times. At the same time the winter fishery increased 3.4 and 6.7 times. Obviously these variations in fishing intensity will affect the size distribution of sardines in the population in very complex ways.

To better understand the analysis of the sardine length frequency polygons and to measure as simply as possible the effect of varying fishing intensities on these frequencies, a hypothetical sardine population was created and submitted to different degrees of fishing intensity.

In figure 9 is shown the length frequency polygon of such an adult population consisting of 12 year-classes; each year-class in year I was composed of 10,000 individuals and experienced an annual natural mortality rate of 15 per cent. The growth rate has been adjusted to represent roughly the writer's conception of the growth rate of adult sardines. Figure 9 thus represents an unfished population with all year-classes of equal initial numbers. There are no superabundant or less than average year-classes involved.

The next step was the introduction of one superabundant year-class consisting of 1.5 times as many individuals as an average year-class comprises. The five curves on the left side of figure 10 show the length frequency polygons of the unfished population for five successive seasons as this superabundant group Z passes through the population and when each new entering year-class is composed of average numbers. The center and right hand curves of figure 10 show the same population submitted to different fishing intensities. A low fishing intensity will have little effect on the normal progression of a superabundant group, but as the fishing intensity increases the duration of dominance of a group decreases. The fishing intensities illustrated in figure 10 were selected as being perhaps a rough approximation of the actual intensity during the five-season interval, 1929–34, and the four-season interval, 1934–38. In this hypothetical population the assumption is made that the year-classes I–IV were fished during the fall months and the classes V–XII were fished during the winter months. Actually classes I–IV are fished to some extent in the winter also, but to simplify the illustration this has not been considered. The effect of this winter fishery for younger fish would be to augment the decline of dominance of a superabundant group as shown in these curves.

If the assumption is made that in the five-season interval, 1919–24, both the fall and winter fisheries had taken 3 per cent of the population each season, 10 seasons later, since the fall fishery increased 5.4 times,

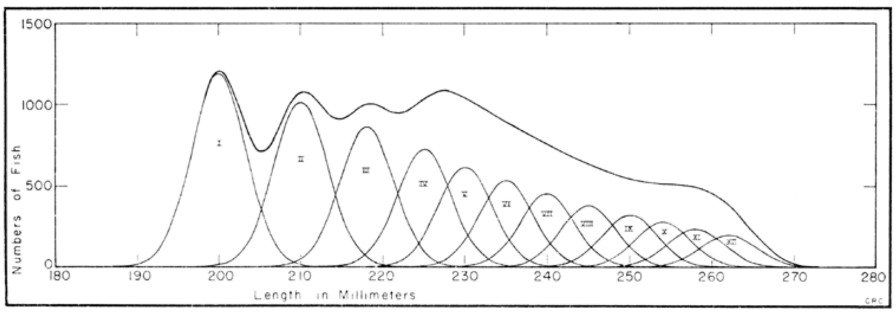

FIG. 9. Length frequency polygon of a hypothetical unexploited sardine population composed of 12 year-classes with a 15 per cent natural mortality rate.

FIG. 9. Length frequency polygon of a hypothetical unexploited sardine population composed of 12 year-classes with a 15 per cent natural mortality rate

the fishing intensity would be 16.2 per cent. The winter fishery increased 3.4 times and the fishing intensity would be 10.2 per cent. The center length frequency polygons of figure 10 illustrate the change over five seasons when year classes I–IV are submitted to a 16.2 per cent fishing intensity and classes V–XII to 10.2 per cent intensity. To this fishing mortality has been added each season the assumed 15 per cent

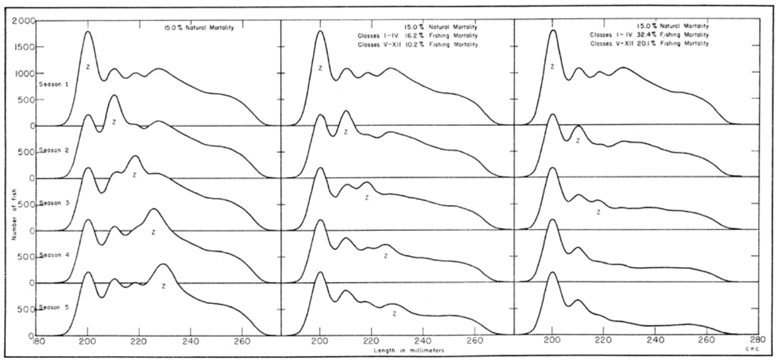

FIG. 10. Length frequency polygons of a hypothetical sardine population consisting of 12 year-classes. The year-class Z comprises 1.5 times as many individuals as do the other year-classes. The group of frequencies at the left shows the changes in this population resulting from a 15 per cent natural mortality rate but with no fishing mortality. The center frequencies show the population with a 15 per cent natural mortality and year-classes I-IV submitted to a fishing mortality of 16.2 per cent and classes V-XII to 10.2 per cent fishing mortality. The frequencies on the right show the population when, in addition to natural mortality, year-classes I-IV experience fishing mortality of 32.4 per cent and classes V-XII, 20.1 per cent.

FIG. 10. Length frequency polygons of a hypothetical sardine population consisting of 12 year-classes. The year-class Z comprises 1.5 times as many individuals as do the other year-classes. The group of frequencies at the left shows the changes in this population resulting from a 15 per cent natural mortality rate but with no fishing mortality. The center frequencies show the population with a 15 per cent natural mortality and year-classes I–IV submitted to a fishing mortality of 16.2 per cent and classes V–XII to 10.2 per cent fishing mortality. The frequencies on the right show the population when, in addition to natural mortality, year-classes I–IV experience fishing mortality of 32.4 per cent and classes V–XII, 20.1 per cent

natural mortality. With such a fishery, group Z loses its dominance rapidly and by the fifth season is scarcely discernible. The curves on the right in figure 10 result from submitting classes I–IV to 32.4 per cent fishing intensity, and classes V–XII to 20.1 per cent intensity. These percentages represent the initial intensity of 3 per cent multiplied by 10.8 and 6.7, the respective increases over 14 seasons to the last four-season interval, 1934–38. Under such intense fishing the dominance of group Z is practically lost by the third season.

Figure 10 illustrates the effect on a population of known numbers as fishing mortality increases. For our sardine population unfortunately we do not know the initial size of the population or the change in numbers from season to season. We can only measure samples from the fishermen's catch and calculate from these measurements the proportion of fish at each size interval. Then as these proportions change from season to season, we have to estimate what is happening to the population. When the curves of figure 10 are expressed in percentages of their totals, they correspond to the length frequency distributions we obtain from measuring a sample of the sardine population. The percentage curve for the normal population of figure 9 subtracted from each of these percentage curves gives the deviation curves of figure 11. As with the deviation curves of figures 4, 5, 6 and 7, the curves of figure 11 show more clearly the presence and absence of superabundant groups than do the length frequency polygons. In the unfished population represented by the curves on the left of figure 11, the dominance of group Z is markedly evident during the five seasons. In the center group of curves, group Z loses its dominance at the end of the third season but can be traced in season 4 as a hump in the minus deviations; a condition very similar to that of group D in the 1931–32 Monterey winter frequency, figure 6. In the right hand series of curves, group Z loses its dominance at the end of the second season and is not evident thereafter. This corresponds roughly to what has happened to groups E and F as shown by figures 4, 5, 6 and 7. In addition, figure 11 indicates that, as a fish population becomes decimated, each new entering group although only of average numbers will appear as a superabundant group simply because of the paucity of fish in older year-classes. Such a dominance will not be maintained into the second season, however, unless the next entering year-class is below average numbers. As the heavy fishing mortality continues season after season, more and more of the older fish disappear, fewer and fewer fish grow to larger sizes and plus deviations are found only on the left hand side of the frequency, a condition suggested in the 1936–37 and 1937–38 curves of figures 6 and 7.

The illustrations in figures 9, 10 and 11 show in a very simplified, diagrammatic manner what happens to a fish population when submitted to known fishing intensity. Obviously the interrelations between fishing mortality and the population are much more complex than here shown. In nature, no two year-classes are of equal numerical strength and the fishing mortality does not remain constant from year to year. The above diagrammatic analyses can not be used to determine an absolute measure of fishing intensity or population numbers. They do show, however, that changing fishing mortality will materially alter

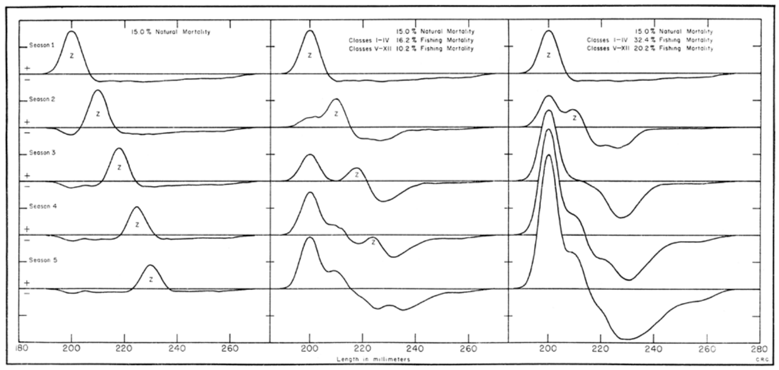

FIG. 11. Length frequency deviations of the frequency polygons of figure 10 from the normal frequency polygon of figure 9. Each of the frequencies was expressed in percentages of its total before the deviations were calculated.

FIG. 11. Length frequency deviations of the frequency polygons of figure 10 from the normal frequency polygon of figure 9. Each of the frequencies was expressed in percentages of its total before the deviations were calculated

the character of length frequency polygons and vary the history of superabundant groups as revealed by these frequencies.

Returning to actual conditions and referring again to the deviation curves of figures 4, 5, 6 and 7, it is evident that with a sardine fishery of the magnitude of that from 1919–20 to about 1927–28, superabundant groups could be followed for approximately 10 seasons, and that the adult life span of a year-class comprised about the same time interval. A small proportion of sardines lived to older ages but these fish did not play an important role in the fishery. Since 1928–29 the life span of a year-class has rapidly diminished and it is doubtful if it now lasts for more than four or five years and perhaps less. If such an interpretation is correct it means that the total sardine population is gravely reduced in numbers. This decrease in the abundance of the sardine population is further shown in the changes in average size of the fish in the fall and winter fisheries.

4. SIZE CHANGES

For multimodal frequency curves a simple arithmetic average is not entirely satisfactory as a measure of central tendency. It does furnish, however, an easily comprehended picture of general size changes within a fishery. The arithmetic averages of the fall and winter length frequency polygons have been calculated, therefore, for the Monterey and San Pedro data for the six seasons covered by the analysis of return per unit of effort. The trends of the average lengths

TABLE 7

AVERAGE LENGTH (SEXES COMBINED) OF THE SARDINES TAKEN IN THE FALL AND WINTER FISHERIES AT MONTEREY AND SAN PEDRO

Season	Average standard length in millimeters			
	Monterey		San Pedro	
	Fall	Winter	Fall	Winter
1932–33	220.45	245.07	222.08	238.55
1933–34	221.21	241.38	206.61	239.46
1934–35	216.30	236.74	213.05	236.09
1935–36	213.99	233.71	208.57	235.76
1936–37	213.84	231.27	210.66	229.48
1937–38	204.84	230.85	198.21	220.37

TABLE 7

AVERAGE LENGTH (SEXES COMBINED) OF THE SARDINES TAKEN IN THE FALL AND WINTER FISHERIES AT MONTEREY AND SAN PEDRO

are shown in table 7 and figures 12 and 13. For all four groups of frequencies the average length has fallen off with fair consistency for the past six seasons. The length frequency polygons demonstrate that the entrance of new superabundant groups could not have brought about this decrease in average length. Furthermore, when a superabundant group enters the fishery, the average length decreases and then increases during the following seasons as the superabundant group grows to larger sizes. The present continued decrease in the average must result, therefore, from the fact that our sardine industry is now removing the larger and older fish faster than they are replaced by the growth of younger sizes. This scarcity of larger sizes in its turn forces the fishermen to catch more and more smaller fish and thus makes a bad matter worse. If carried on at the present rate of size decrease, the final outcome will probably be that the largest winter fish will practically disappear from the fishery. This disappearance was suggested in the 1937–38 fishing season, when the largest winter fish were to be found for a brief time only, and during that time fish were located with difficulty.

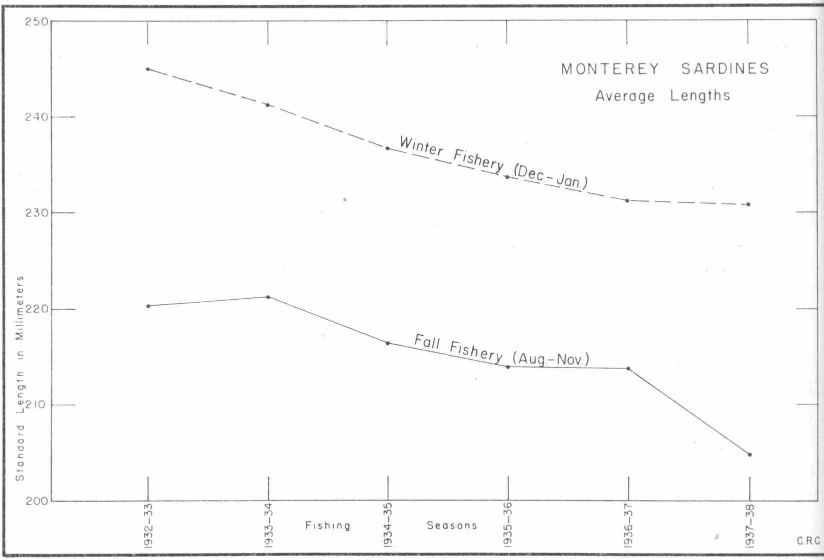

FIG. 12. Average length (sexes combined) of sardines taken in the Monterey fall and winter fisheries.

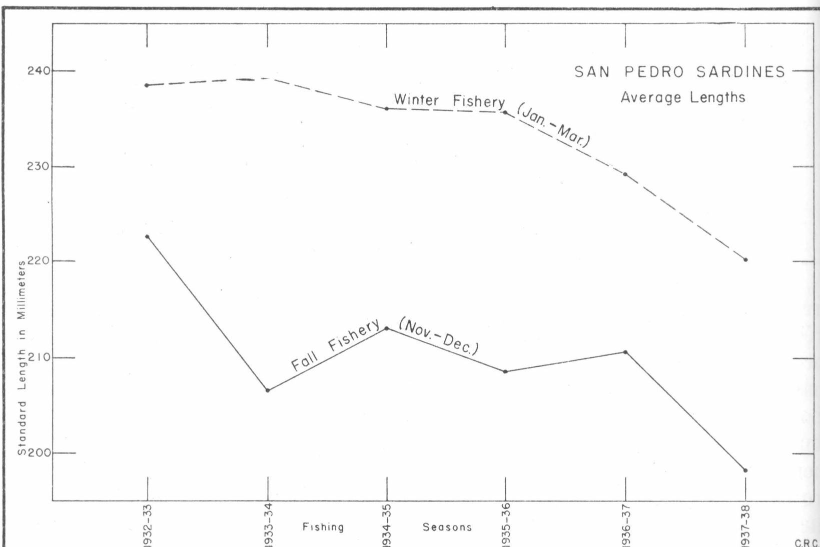

FIG. 13. Average length (sexes combined) of sardines taken in the San Pedro fall and winter fisheries.

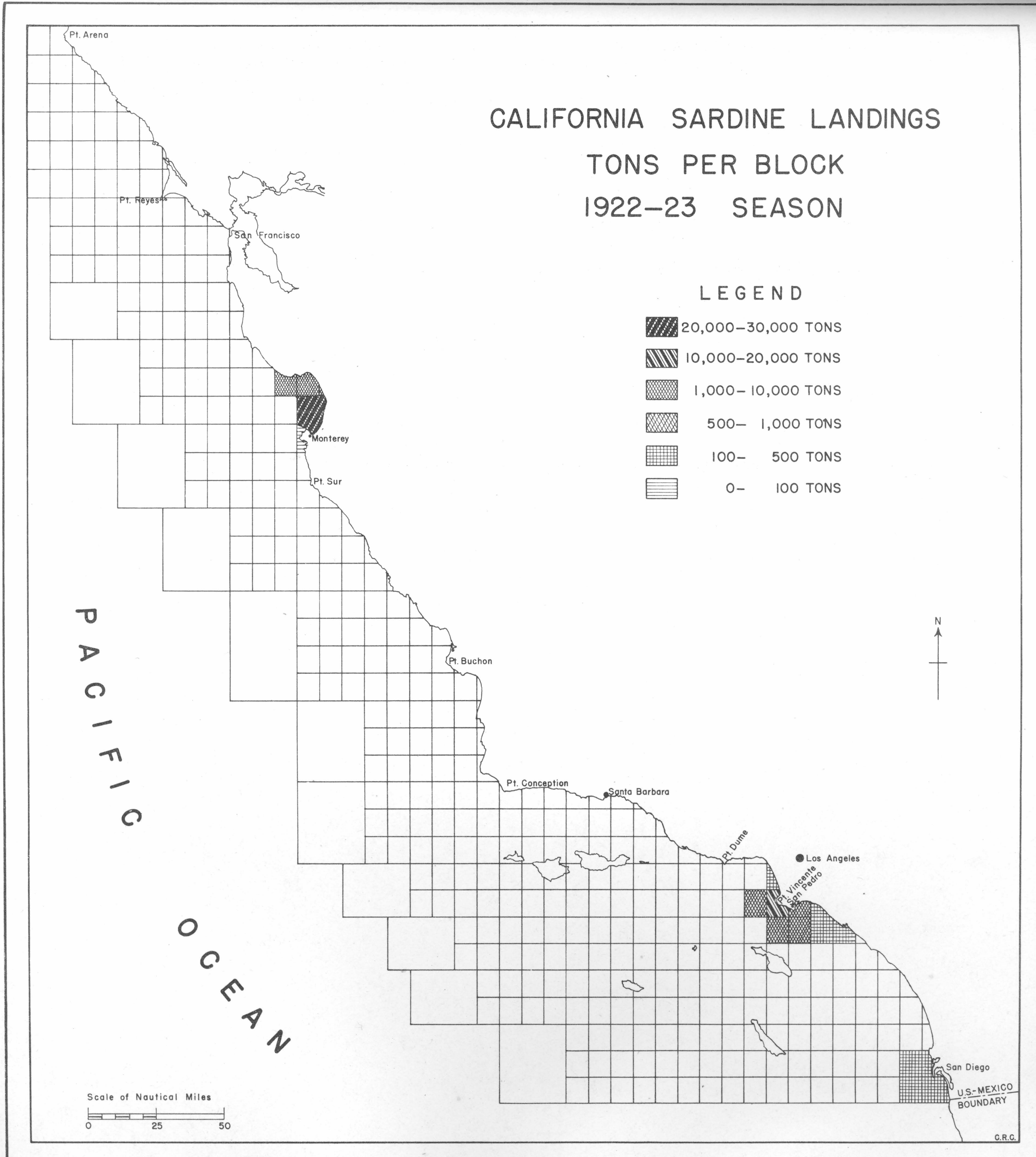
CALIFORNIA SARDINE LANDINGS
TONS PER BLOCK
1922–23 SEASON
LEGEND
20,000–30,000 TONS
10,000–20,000 TONS
1,000– 10,000 TONS
500– 1,000 TONS
100– 500 TONS
0– 100 TONS
Pt. Arena
Pt. Reyes
San Francisco
Monterey
Pt. Sur
Pt. Buchon
Pt. Conception
Santa Barbara
Pt. Dume
Los Angeles
Pt. Vincente
San Pedro
San Diego
U.S.-MEXICO BOUNDARY
PACIFIC OCEAN
N
Scale of Nautical Miles
0
25
50
C.R.C.

FIG. 14

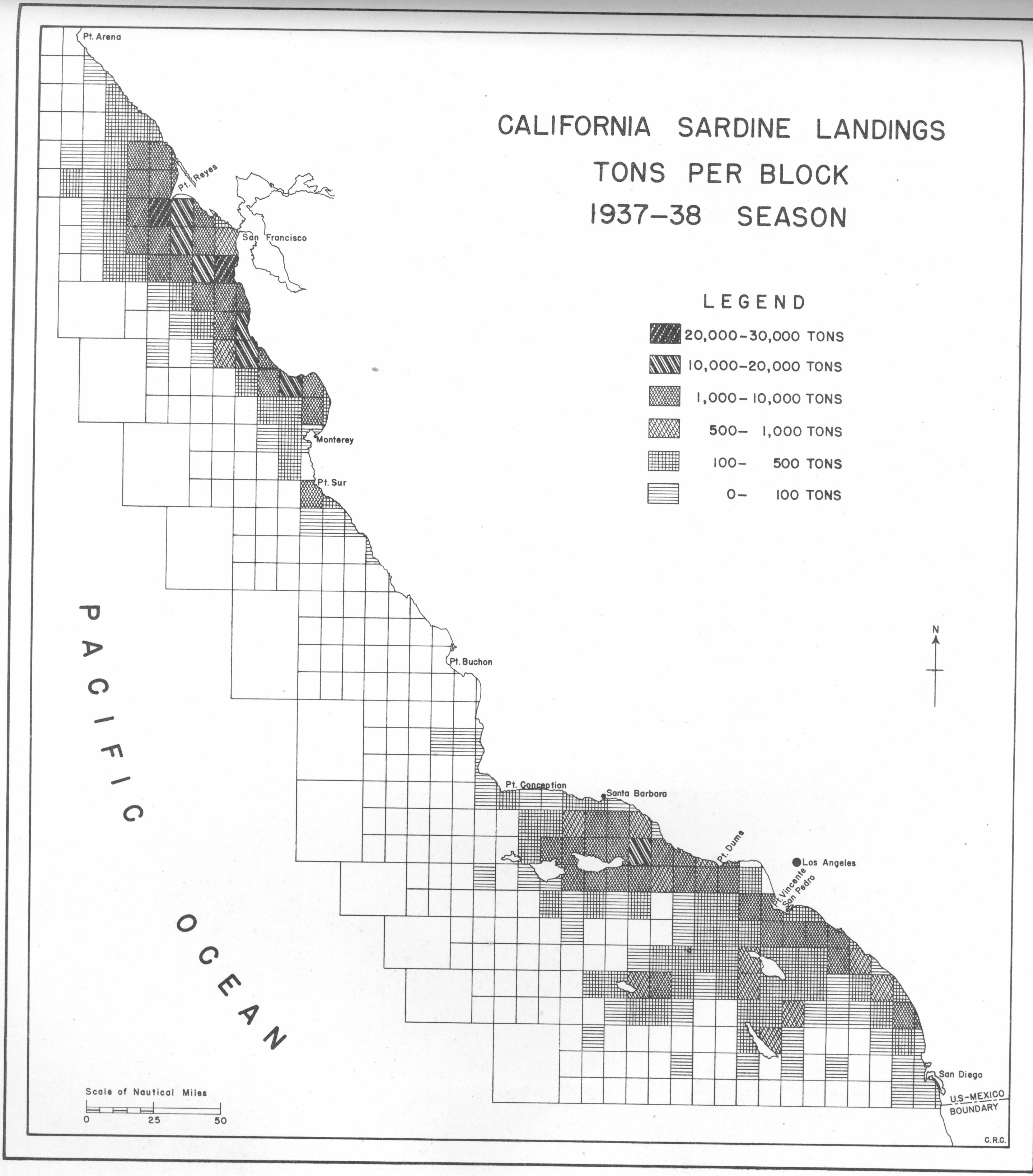
CALIFORNIA SARDINE LANDINGS
TONS PER BLOCK
1937–38 SEASON
LEGEND
20,000–30,000 TONS
10,000–20,000 TONS
1,000–10,000 TONS
500– 1,000 TONS
100– 500 TONS
0– 100 TONS
Pt. Arena
Pt. Reyes
San Francisco
Monterey
Pt. Sur
Pt. Buchon
Pt. Conception
Santa Barbara
Pt. Dume
Los Angeles
Pt. Vincente
San Pedro
San Diego
U.S.-MEXICO BOUNDARY
PACIFIC
OCEAN
N
Scale of Nautical Miles
0
25
50
C.R.C.

FIG. 15

The growth rate of the sardine is slow and from an economic point of view it may be just as profitable for the industry to rely on the smaller, younger adults. This is especially true for the central California fishery where the majority of the fish are taken in the fall months of each season, but in southern California the best fishing has occurred in the winter months and the loss of the winter fishery would be a severe blow to the southern California sardine industry. From a biological point of view the destruction of the larger and older fish may have grave consequences. The number of eggs produced increases rapidly with increase of size of fish and there is a possibility that the smaller fall fish can not produce enough eggs to maintain the sardine population under the present intense fishery.

5. EXTENSION OF THE FISHING GROUNDS

As shown in previous publications of the California State Fisheries Laboratory and further demonstrated by the results of the tagging investigation now under way (Janssen, 1938), the sardine is a migratory fish, making annual movements up and down the Pacific Coast from southern California to British Columbia. For this reason, exploitation in any one fishing region places a strain on the population of all other regions. An extension of the fishing grounds does not, therefore, tap a new and unexploited population, but merely shows that as the demands of the industry increase the fishermen must range over a larger and larger portion of the entire area occupied by the sardine population. This increase in demand for sardines and the corresponding extension of the fishing grounds in California waters is shown by figures 14 and 15. For statistical purposes the waters off the California coast have been divided by the Division of Fish and Game into numbered blocks of 10 minutes of latitude and longitude. In the later seasons the fisherman has reported the number of the block in which he makes his catch. The tons taken per numbered block during the 1937–38 season are shown in figure 15. With this is contrasted in figure 14 the catch of the season 16 years previous, 1922–23. Since 1919–20 the sardine catch has been methodically sampled each season. These samples are the source of the length frequency polygons shown in this report. At the same time that a sample of fish is obtained a limited number of boat captains are questioned about the locality of the previous night's catch. The information thus collected has been used to allot the 1922–23 catch to the numbered blocks now in use.

In 1922–23 the entire sardine catch of California was taken within a few miles of the ports of Monterey, San Pedro and San Diego. Whereas to supply the greatly augmented catch of 1937–38, the California sardine boats were forced to cruise over all the coastal waters from Point Arena southward to the Mexican boundary, with the exception of a limited area in the region of Point Buchon. This section is too far from the ports of Monterey and San Pedro to be extensively fished at present, although the sardine fleet is encroaching on the area more and more.

6. SUMMARY

Four measures point to a decrease in the abundance of the sardine in California waters.

1. The fishermen are now getting less return per unit of effort expended than in former years. Because of the influence of limits placed on each night's catch the return per unit of effort did not measure the availability of sardines previous to 1932–33. By 1932–33 limits were so large as to be of no effect or were not imposed for part or all of each season.

The unit of effort chosen was the total lunar month catch of a boat expressed in percentage of its catch for the comparable lunar month of the previous season. The geometric mean of the series of percentages thus obtained for each season was calculated and the geometric means linked from season to season by the "chain" system. The resulting trends indicate that sardines have been found with increasing difficulty from 1934–35 to 1937–38, and the return per unit of effort in 1937–38 was less than half the return in 1932–33.

2. In the early history of the fishery a superabundant group could be traced through the fishery for a period of six to ten years. Following 1929–30 the duration of each abundant group has been less and less. The present intense fishery appears to wipe out the dominance of a year-class within two or three years after it has entered the fishery. This means that fewer and fewer sardines are growing to large sizes.

3. Because the number of fish which escape to grow to larger sizes is less with each season, the average size of both the fall and winter fish decreased from 1932–33 to 1937–38. If the decrease continues at the present rate the largest winter fish may disappear from the population.

4. To supply the present demand for sardines the fishing boats are now having to cruise over practically all the coastal waters of California from Point Arena south to the Mexican boundary. In the early history of the industry, the demand was met by boats fishing within a few miles of each port.

These measures of sardine abundance indicate that the present population is at a very low ebb. Two explanations may be advanced for this situation: (1) The magnitude of the fishery has been so great as to seriously deplete the supply. (2) Sardines are subject to long term fluctuations in abundance and the decreasing scarcity over the last six to seven years is merely a manifestation of a natural disappearance of the population and would have occurred regardless of the amount of fish caught.

The second explanation constitutes the argument advanced by all people opposed to any type of managed industry. It can not be answered with absolute facts until many years have elapsed and the presence or absence of long time fluctuations has been proved or disproved. The first explanation is backed by the fact that twenty years ago the total sardine catch of California averaged about 60,000 tons a season and in the succeeding two decades, 1918 to 1937, it has doubled every five seasons to a present seasonal average of approximately 500,000 tons. Such a rapidly expanding industry must have taken a dangerously large toll from the population even were its initial size of immense proportions.

But whatever the cause of decreased abundance, the present intense fishery is placing a very severe strain on a badly decimated population and making correspondingly difficult the restoration of that population to anything like its former magnitude. An immediate curtailment of the total catch would more quickly assure a restoration than would the postponement of that curtailment until the population is so depleted that it is no longer profitable to carry on the industry.

The amount of this curtailment can not be stated with absolute certainty. of necessity a trial and error process must be applied. The decrease in total catch should be great enough, however, not only to check the present decline in the sardine population but to build it back as quickly as possible to a higher level. During the ten years, 1918–1927, the size of the total catch apparently had little influence on the abundance of the sardine population. In the next ten years the catch more than doubled and the population was rapidly decimated. A reduction of the total catch (averaging now about 500,000 tons per season from California waters) by one-half seems, therefore, to offer the minimum of curtailment necessary to check the present population decline. To build up the population with any rapidity, an even more drastic cut to perhaps one-third of the present total may be necessary.

7. LITERATURE CITED

Andrews, Carroll B. 1928. Seasonal average length trends at Monterey of the California sardine (Sardina caerulea). Calif. Div. Fish and Game, Fish Bull., no. 13, 12 pp.

Clark, Frances N. 1930. Seasonal changes in the daily average length of the California sardine, (Sardina caerulea). Calif. Div. Fish and Game, Fish Bull., no. 26, 20 pp.

1931. Dominant size-groups and their influence in the fishery for the California sardine (Sardina caerulea). Calif. Div. Fish and Game, Fish Bull., no. 31, pp. 7–42.

1933. Changing abundance of the California sardine, measured by length of scouting time. Calif. Fish and Game, vol. 19, pp. 136–141.

1934. Maturity of the California sardine (Sardina caerulea), determined by ova diameter measurements. Calif. Div. Fish and Game, Fish Bull., no. 42, 49 pp.

1935. A summary of the life-history of the California sardine and its influence on the fishery. Calif. Fish and Game, vol. 21, pp. 1–9.

1936.1. Interseasonal and intraseasonal changes in size of the California sardine (Sardinops caerulea). Calif. Div. Fish and Game, Fish Bull., no. 47, 28 pp.

1936.2. Variations in the number of vertebrae of the sardine, Sardinops caerulea (Girard). Copeia, 1936, no. 3, pp. 147–150.

Conner, Geraldine 1935. Modernizing commercial fisheries statistics. Calif. Div. Fish and Game, Fish Bull., no. 44, pp. 11–36.

Fisher, Irving 1927. The making of index numbers: a study of their varieties, tests, and reliability; 3d ed., rev. Boston and New York, Houghton Mifflin Co. 538 pp.

Hart, John Lawson 1933. Statistical studies on the British Columbia pilchard: vertebra counts. Roy. Soc. Canada, Trans., ser. 3, sec. V, vol. 27, pp. 79–85.

1934. A report on the investigation of the life-history of the British Columbia pilchard. British Columbia Comm. Fish., Rept. for 1933, pp. H54–H59.

Higgins, Elmer 1926. A study of fluctuations in the sardine fishery at San Pedro. Calif. Fish and Game Comm., Fish Bull., no. 11, pp. 125–158.

Hubbs, Carl L. 1925. Racial and seasonal variation in the Pacific herring, California sardine and California anchovy. Calif. Fish and Game Comm., Fish Bull., no. 8, 23 pp.

Janssen, John F., Jr. 1938. Second, report of sardine tagging in California. Calif. Fish and Game, vol. 24, pp. 376–390.

Phillips, J. B. 1937. Sizes of California sardines caught in the different areas of the Monterey and San Pedro regions. Calif. Div. Fish and Game, Fish Bull., no. 50, 31 pp.

Scofield, Eugene C. 1934. Early life history of the California sardine (Sardina caerulea), with special reference to the distribution of eggs and larvae. Calif. Div. Fish and Game, Fish Bull., no. 41, 48 pp.

Scofield, W. L. 1926. The sardine at Monterey: dominant size-classes and their progression, 1919–1923. Calif. Fish and Game Comm., Fish Bull., no. 11, pp. 191–221.

1929. Sardine fishing methods at Monterey, California. Calif. Div. Fish and Game, Fish Bull., no. 19, 61 pp.

Thompson, William F. 1926. Errors in the method of sampling used in the study of the California sardine. Calif. Fish and Game Comm., Fish Bull., no. 11, pp. 159–189.

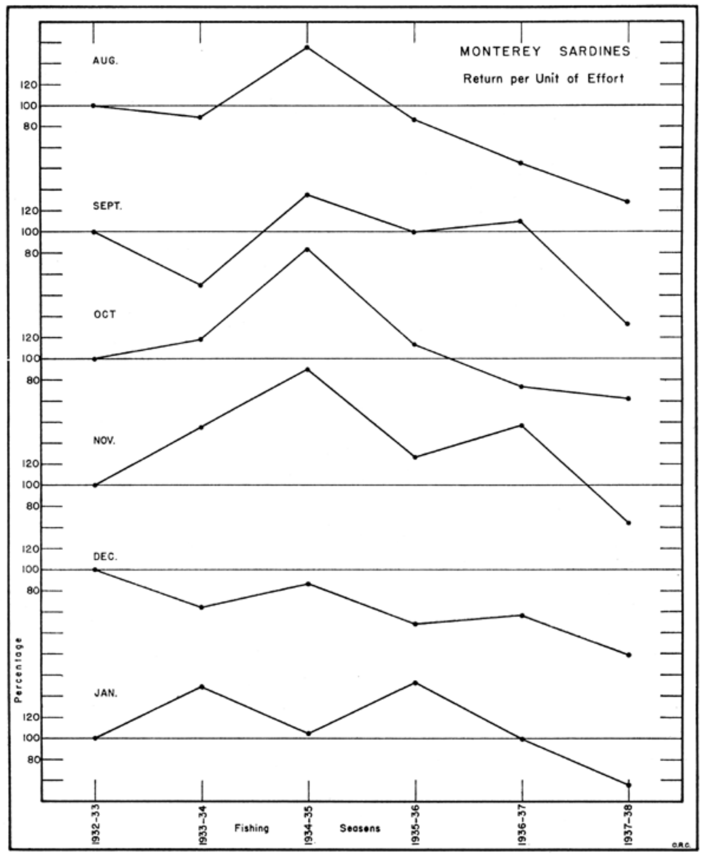

FIG. 16. Comparisons for individual lunar months of the return to the Monterey fishermen per unit of effort expended.

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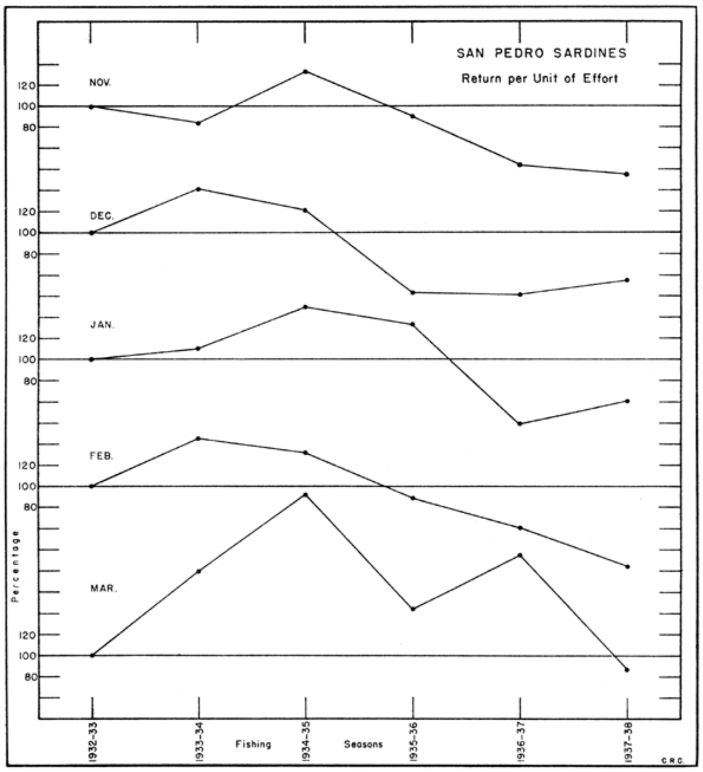

FIG. 17. Comparisons for individual lunar months of the return to the San Pedro fishermen per unit of effort expended.

FIG. 17. Comparisons for individual lunar months of the return to the San Pedro fishermen per unit of effort expended

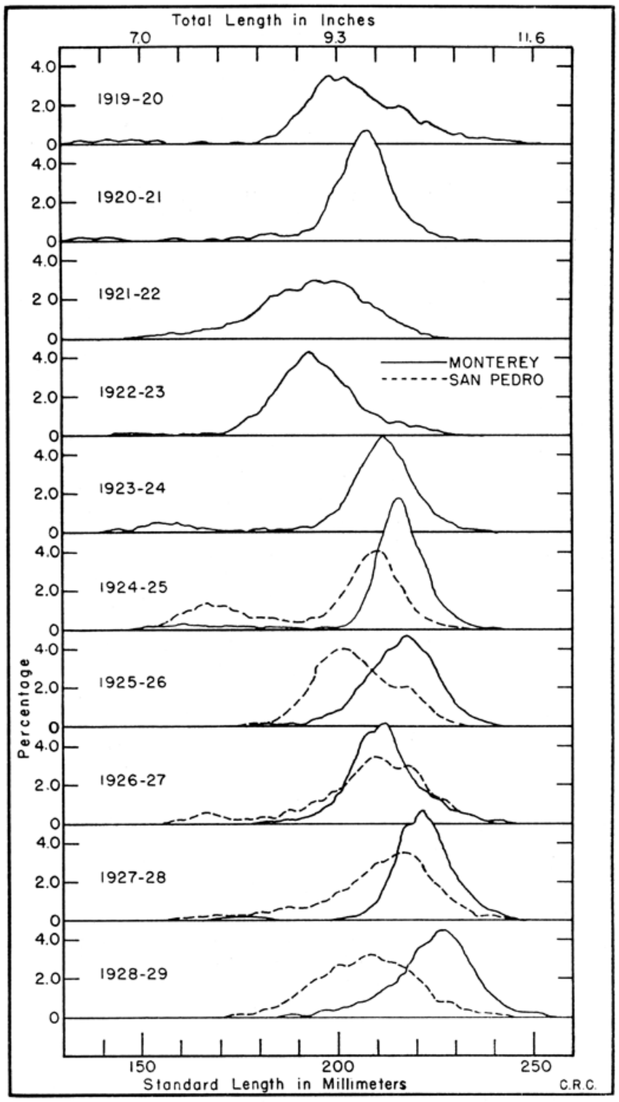

FIG. 18a. Length frequency polygons of sardines taken in the fall fishery, 1919-20 to 1928-29, at Monterey and at San Pedro.

FIG. 18a. Length frequency polygons of sardines taken in the fall fishery, 1919–20 to 1928–29, at Monterey and at San Pedro

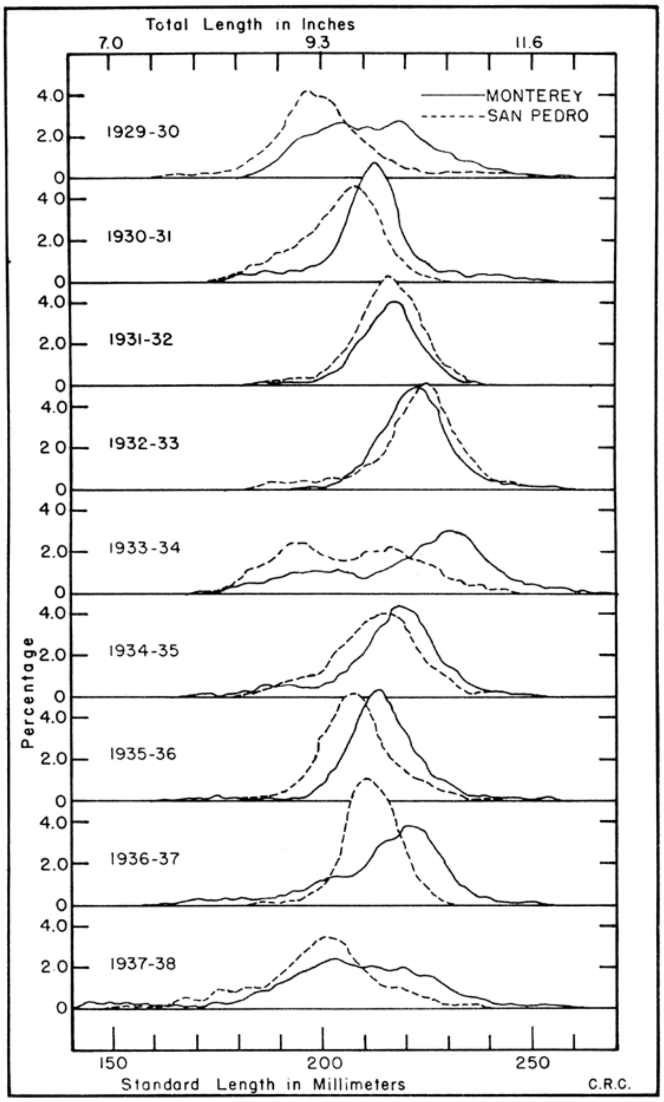

FIG. 18b. Length frequency polygons of sardines taken in the fall fishery, 1929-30 to 1937-38, at Monterey and at San Pedro.

FIG. 18b. Length frequency polygons of sardines taken in the fall fishery, 1929–30 to 1937–38, at Monterey and at San Pedro

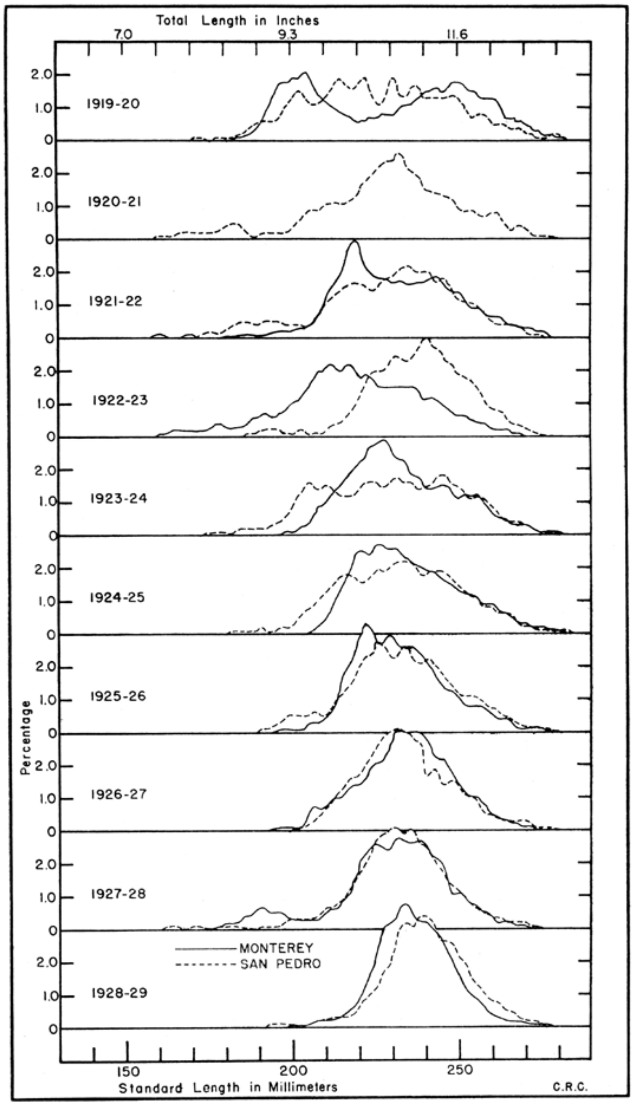

FIG. 19a. Length frequency polygons of sardines taken in the winter fishery, 1919-20 to 1928-29, at Monterey and at San Pedro.

FIG. 19a. Length frequency polygons of sardines taken in the winter fishery, 1919–20 to 1928–29, at Monterey and at San Pedro

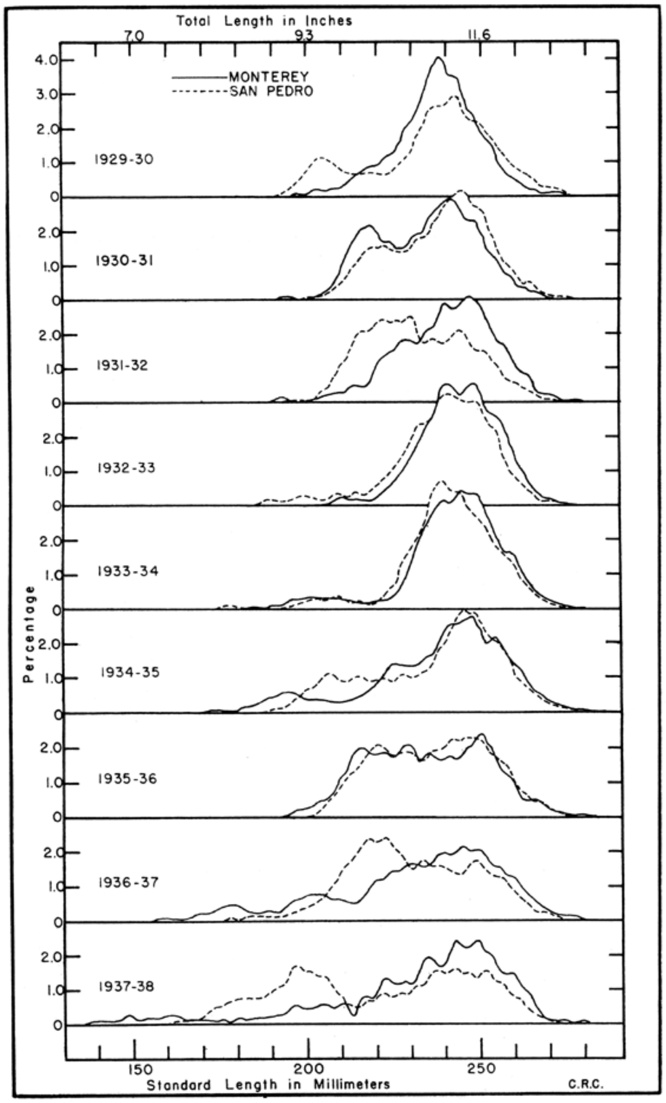

FIG. 19b. Length frequency polygons of sardines taken in the winter fishery, 1929-30 to 1937-38, at Monterey and at San Pedro.

FIG. 19b. Length frequency polygons of sardines taken in the winter fishery, 1929–30 to 1937–38, at Monterey and at San Pedro