DIVISION OF FISH AND GAME OF CALIFORNIA
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The California Halibut (Paralichthys californicus) and an Analysis of the Boat Catches

By
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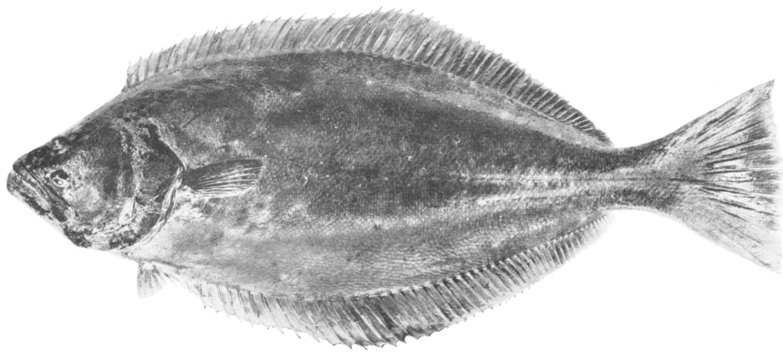

California halibut, *Paralichthys californicus.*

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FOREWORD

This report is presented to aid directly the administrators of the Division of Fish and Game in their conservation program. Herein is given an account of the California halibut fishery and a detailed analysis of the catch in the Los Angeles Harbor district by means of the catch per unit of effort expended. The paper is so arranged that the general and fundamental aspects of the fishery and the results of a catch analysis are briefly given in the first part. For those who may be interested in the details of the fishery some of its life history and methods of boat catch analysis employed, the balance of the paper will be of importance.

The writer wishes to acknowledge his indebtedness to Mr. W. L. Scofield, director of the California State Fisheries Laboratory, and to the staff of this institution for their continual advice and criticism throughout the work; to Professor Holbrook Working of Stanford University for advice on statistical procedure; to Mr. Elmer Higgins of the U. S. Bureau of Fisheries for permission to use his life history data; and to Mr. J. A. Craig of the U. S. Bureau of Fisheries for his aid and criticism, which have been freely given from time to time through the investigation.

December, 1930.

1. GENERAL SURVEY OF THE FISHERY

A market fish of considerable importance, the California halibut (Paralichthys californicus) has held a place among the fine food fishes of southern California as far back as can be traced. At the beginning of the statistical records of California in 1916, we find that this species was found in varying degrees of abundance from the San Francisco Bay region south to and below the United States-Mexican boundary line. This fish has never been taken in large quantities north of Monterey, but a considerable catch is made annually in the coastal waters off southern California; like amounts have been caught in Mexican waters and delivered to California ports.

California halibut, the only species of the genus Paralichthys found in California, is one of the many varieties of flatfishes sold in fresh fish markets of the State, but it is not a true halibut. The species was formerly known as southern halibut, and is often erroneously termed bastard and chicken halibut. Anatomically, this species may be distinguished from other flatfishes by observing that: the lateral line has a high abrupt arch in front, not just curving upward; the pectoral fin on the eyed side of the body is shorter than the head; the maxillary bone reaches to the hind border of the lower eye or beyond it; the dorsal and anal fins slope gradually up to and down from their greatest height; the color is uniform greenish brown, sometimes mottled with darker and lighter shades on the eyed side; the blind side is white; and the fish obtains a weight not greater than sixty pounds, the majority ranging from six to twenty pounds.

Numerous other flatfishes are known as halibut; most, however, have a prefix to their names such as greenland halibut or arrow-toothed halibut but the northern or true halibut (Hippoglossus hippoglossus) of northern waters is the fish with which the name halibut is commonly associated. Halibut derivation: Middle English *hali*=*holy*+*but* or *butte*=flounder; akin to Dutch *bot*, making *heibot*; and also akin to German *butte* to form *heilbutt*; so named because eaten on holidays and was very likely first applied to the north Atlantic species. Because of the resemblance to this species, other flatfishes have been termed halibut, although they have no close generic or specific relationship to the true halibut.

Development of the California halibut fishery is difficult to trace, particularly in the early years, as very little is remembered and nothing has been written concerning this fish except brief discussions of the total catch.[1] In 1916, at the time California first began to gather comprehensive fish statistics, a large halibut fishery was already being carried on in the region from San Francisco southward into Mexican waters. Large catches were made by the San Pedro fleet in local waters, and during the summer months in the off-season the boats invaded the Mexican fishing grounds. Boats operating out of San Diego reaped huge returns both in local waters and in the region south of the international boundary line. Most of the Mexican catch was and still is landed in San Diego because of its close proximity to the fishing banks. Halibut fishing north of Ventura County has never reached such large proportions as the southern areas, but has shown a steady growth up to 1924. Catches made in the vicinity of Monterey and the town of Santa Cruz have been small from the beginning and have never contributed more than 50,000 pounds in one year to the State's total catch.

The seasonal difference of catches made north and south of the international boundary line is an aid to halibut fishermen, as these fish, although taken in both localities the year around, are caught in greatest amounts north of the boundary from January to June, inclusive, while south of the line the largest yield occurs from June to December, inclusive. This seasonal difference of largest catches enables the fishermen to gain maximum returns during the entire year. The San Pedro boats usually make their base at San Diego and fish with the fleet there for Mexican halibut during its season.

Aside from the geographical separations of fishing areas, the California halibut fishery can be segregated into two divisions: the trammel net and the trawl net fisheries.

Trammel nets are, and have been, legal ocean fishing gear since 1915 from the northern boundary of Mendocino County to the California-Mexican boundary line, with the exception of Monterey Bay. Previous to 1915, the use of trammel nets was prohibited in the State in 1911, but in 1913 trammel nets could be legally fished in the coastal waters of the State one mile from shore. In 1919, regulations were made for the use of trammel nets in the Sacramento River and San Francisco Bay districts.

Trawl or drag nets were first prohibited in southern California in 1911, when what was then known as district 6 (coastal waters from the northern boundary of Ventura County to the Mexican line) was closed to trawl net fishing. In 1915, new fish and game districts were created so that the coastal waters from the northern boundary of Santa Barbara County to the Mexican line became district 19, in which possession of trawl nets was prohibited. In this year, the entire State waters were closed to the use of trawl nets, but possession was only prohibited in district 19, so that trawling could be carried on outside of the three-mile limit. In 1917, it became lawful to use trawls in the coastal waters from the Oregon line to the southern boundary of

[1] California Division of Fish and Game, Fish Bull. no. 15, p. 35, 1929; no. 20, p. 54, 1930.

Mendocino County (districts 5, 6 and 7) and from Point Carmel in Monterey County to the northern boundary of Santa Barbara County (district 18). It also became lawful to use drag nets in district 13 for shrimps. District 19 was closed to fishing with trawl nets.

The law enacted in 1915, prohibiting the possession of trawls in district 19 remained on the statutes until 1923, but could not be enforced because the later law passed in 1917 superseded it until 1923. In 1919, the use of drag nets for catching shrimps was permitted in district 12; and the bays in district 18 (Point Carmel to Santa Barbara, northern county line) were closed to trawl net operations. This last act was passed because it was believed that the waters close to shore and in the bays were nurseries for young fish. No new trawl net legislation was enacted until 1923, at which time the possession of drag nets was prohibited in district 19 (coastal waters from northern Santa Barbara County line to Mexican line), in land district 4 (southern Ventura County line to Mexican line), in districts 20 and 20A (Catalina Island and water around the island), and in district 21 (San Diego Bay). This last law was a great help to the enforcement agents of the State in controlling trawl nets in district 19. In order to aid the trawl net fishermen, who maintain they never fished close to shore or took small fish in their nets, Santa Barbara County was taken out of district 19 and placed in district 18 in 1925. The rest of the regulations remained as before. In 1927, after the courts had decided that Monterey Bay and three miles beyond was State territory, it became lawful to fish with trawls in Monterey Bay provided fishing was confined to waters of 25 fathoms or more in depth. In addition, district 2 in the Sacramento River was opened to trawl nets for shrimp fishing. The other regulations remained as they were the previous year. No change in the trawl net law has occurred since 1927.

Trammel netting operations overlap into legal trawl net territory, but each type of gear must be considered separately in any analysis of the catch. Geographical districts, except wherein legal gear is a factor, have become almost without boundaries in this fishery, as boats from southern ports are prone to fish over a much larger area than formerly. Extension of the fishing area is probably due to an increase of the number of boats in the fishery and to a scarcity of fish in local waters.

In this report only the fishery out of San Pedro is considered in detail. However, boats fishing from this port may not confine their activities to local waters but may extend their fishing radii many miles from their home port. A local fishery has grown to one covering a large area. San Pedro fishermen operate as far north as Point Conception, south to Oceanside, westward to the northern islands of Santa Cruz, Santa Rosa, San Miguel and Anacapa, and to the southern islands of Santa Catalina and San Clemente. (See fig. 1.) Halibut caught in Mexican waters are not considered as part of the San Pedro fishery.

Total landings of halibut for the State of California by districts are shown in figure 2. Note the slight increase of the catch of the Los Angeles (San Pedro) district from 1916 to 1922, then the sudden drop which continued until 1929, with only a slight revival in 1928. San Diego has a fluctuating catch; beginning low in 1916 it was extremely high in 1917, low again in 1919, high in 1920, and then fell sharply to 1929, with a slight rise in 1924–1925 and again in 1928. Mexican fish returns show a great fluctuation that is almost an inverse curve to that of San Diego. It would appear that when halibut fishing was good near San Diego, fewer boats went to Mexico to fish, and *vice versa*. Mexican landings reached a very high point in 1919, only to drop off in 1922 to less than half, and then rise again in 1925, only to fall to a

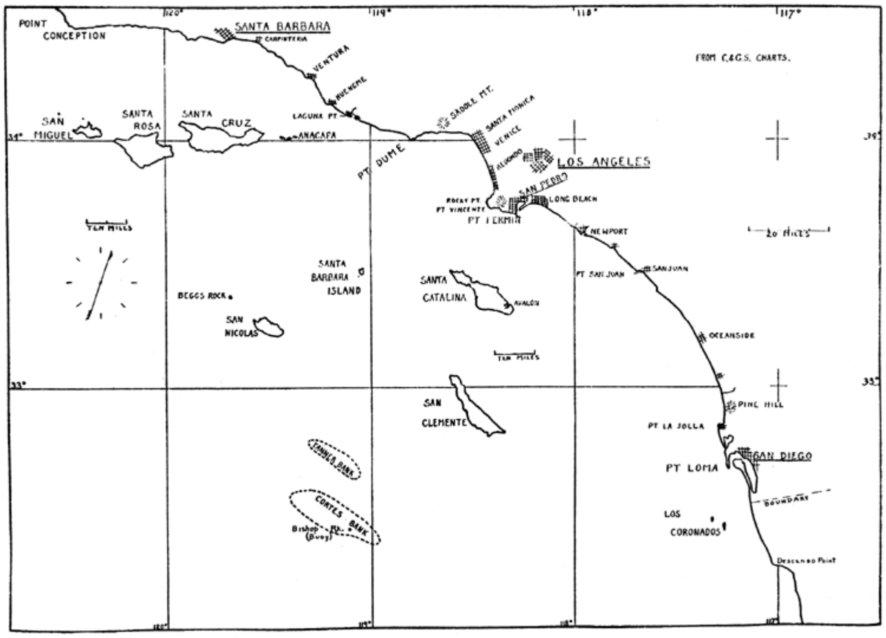

FIG. 1. Map of the southern California coast from Point Conception to the United States-Mexican boundary line.

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low point in 1928. The next year, 1929, the catch increased very little. In the waters off the coast of San Luis Obispo, Santa Barbara and Ventura counties, the catch made a steady climb to a peak in 1924, then declined suddenly for two years; from 1926 to 1929, an almost level trend continued. Landings in Orange County reached their greatest magnitude in 1920 and again in 1924, although the largest catch for a year was not over 100,000 pounds. From 1924 the catch decreased to 30,000 pounds in 1929. California halibut fishing is almost negligible in Monterey and Santa Cruz counties, although Monterey's catch gained in the last two years, 1928 and 1929, reaching almost 50,000 pounds in 1929.

Total catch figures, without other necessary accompanying data, are recognized as almost worthless as a criterion to analyze the correct trend of a fishery. There are so many factors which may change and modify total figures, such as the number of boats, gear, fishing methods or grounds, and natural and artificial causes, *i. e.,* natural fluctuati ons in abundance, weather conditions and price changes, that it is not safe to consider only total landings.

It is not the intention to analyze at this time the halibut catches of each of the above mentioned districts, but they have been presented merely as a background. A boat catch analysis of the halibut fishery of only the Los Angeles Harbor district (San Pedro) is presented in this report.

The total halibut landings of the Los Angeles district shown in figure 2 portray the tremendous decrease of 80 per cent from 1922 to 1929, and even the percentage drop from 1919 to 1929 is about 66 per cent. There are undoubtedly causes which have had some influence on this decline other than the scarcity of fish, particularly when the various factors which make up the total catch of halibut are considered. The total catch is the entire amount of halibut landed in the district regardless of gear used or locality fished. Many of the catches may have been taken by trawl nets in other districts and transported to San Pedro, and in the early years some of the Mexican catches may have been included in this total. In 1923 possession of trawl nets was prohibited in this district; previous to this time the use of such nets was restricted, but before 1923 much illegal fishing with drag nets may have been done when possession of these nets was permitted. This is partly demonstrated by the break in total catch which occurred in 1923. In addition many of the boats have only fished incidentally for

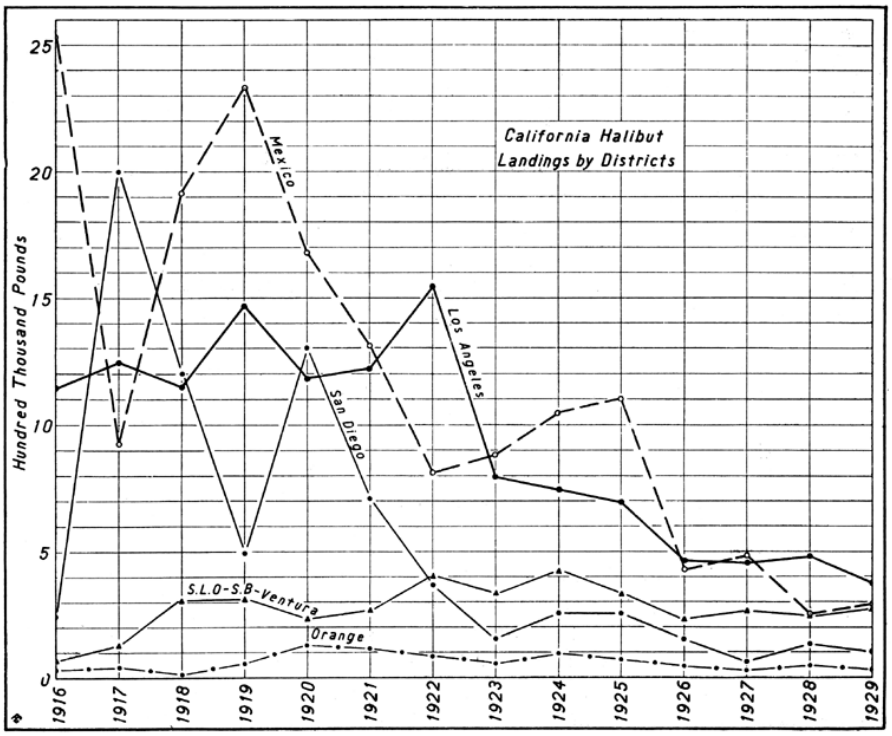

FIG. 2. Total yearly landings of California halibut by districts, including Mexico.

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this species between seasons. In the later years the numbers of these part-time halibut fishermen have fallen off at an increasing rate because the supply has diminished and the fish are not so readily taken, consequently the total catch has decreased more rapidly. There is strong evidence in this case to indicate that the total landings of halibut do not show the correct status of the fishery as there has been an extremely variable effort put forth from 1919 to 1929. A measure of the catch of suitable halibut boats expressed in a constant unit of effort reveals a somewhat different trend of the fishery and certainly a more accurate one.

Only those boats that operated at least two months of the six-month season (January to the end of June, the season selected for use in this analysis) were considered as *suitable* halibut fishing boats. All catch curves presented throughout this report cover this season because from July to December, inclusive, halibut fishing becomes more or less incidental. The boats turn to other more profitable fisheries in the summer and fall.

In an analysis of the boat catches of a fishery some measure of the catch per unit of effort expended must be chosen to assure a constant unchanging unit. From the registration records of boats it was determined that the gear per boat had remained about the same from year to year in this fishery, and as the gear per boat is constant the abundance of fish can be gauged by the catch per boat per time unit. Such a time unit for this fishery is a month, as it is the only one of

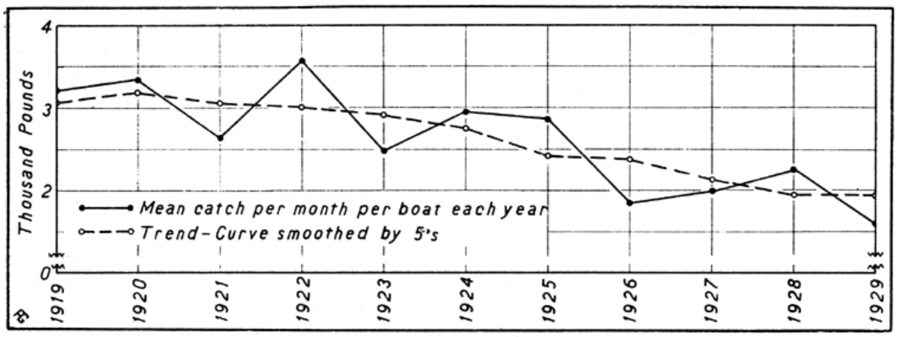

FIG. 3. Mean catch per boat per month each year of California halibut.

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many time units which will accurately illustrate the trend of the halibut fishery, since it eliminates the effect of long trips and enables the yearly averages to be adjusted for the influence of seasonal differences within years.

In order to obtain an average catch per month per boat for each year of all the suitable data, the procedure was as follows:

(1) From the fish receipts or "pink tickets" were obtained all the catches of suitable halibut fishing boats made during January to June, inclusive, which used the same gear (trammel nets) during the years 1919 to 1929, inclusive. (2) The total catch of each boat was obtained together with the number of months each boat fished during each year. (3) All boat totals for each year were added and all fishing month totals for each year were summed. (4) The total annual catch for all boats was divided by the sum of the months during which these boats fished each year. (5) The result is the average catch per month per boat for each year, which is shown graphically in figure 3. This method is based on a knowledge of the fishery,[2] and the resulting curve is computed from all of the data of selected suitable halibut boats by using

[2] There are no marked changes in the size of monthly catches in any given year, indicating very little if any influence of seasonal differences on a yearly average.

the most accurate time unit for this fishery—the boat catch per month. Notice is directed to the gradual 22 per cent decrease of catch from 1919 to 1923, while from 1924 to 1929 there is a sharp 46 per cent decline of the average catch per month, and from 1919 to 1929 a 50 per cent drop occurred. (Percentages were figured from actual values of points.) The percentage decrease of a smoothed trend (curve smoothed by 5's) shows a loss of 36 per cent over the entire period; while not as great as from actual values it is certainly enough to be a warning that the catch per month per boat is falling off at a tremendous rate. Without doubt protection of the California halibut is imperative because of this decreasing catch despite the increase in demand as shown by the rising price for the species. In addition the growing extension of the fishing area in which this fish is taken by the San Pedro fleet without an increase in catch, further indicates a scarcity of fish.

2. SOURCE OF MATERIAL

The data on halibut boat catches that have been used in this analysis have been taken directly from the fish receipts which are made out by fish buyers when the commercial fishermen sell their catches. These receipts are made in triplicate on forms supplied by the California Division of Fish and Game; one copy covering each sale goes to the fisherman, one to the fish buyer, and the third or "pink ticket" to the division for its statistical record. Each receipt gives the date and place of sale, the dealer's name, the fisherman's name, the name of the boat and its U. S. custom house number, and the varieties, weight and price of fish caught.

The total landings of halibut for each district were obtained from the total catch records made up from the receipts, and the individual boat catches were taken directly from the receipts and tabulated by boats, days, months, and years. The tickets also were the source from which the price data on halibut were obtained.

Data on boats, gear and personnel were secured from the registration records of fishing craft, while information regarding fishermen was taken from the applications for commercial fishing licenses.

Information on the construction of gear and boats and on actual fishing methods, location of fishing areas, and history of the fishery was obtained from the halibut fishermen and by personal observation.

Notes on the life history of this fish were taken from data collected and partially worked up by Mr. Elmer Higgins.

3. THE FISHERY

One of the most important steps in the investigation of any fishery is a knowledge of the boats, fishing gear, fishermen, and fishing methods. Constantly questions are arising which may be decided one way or another by a complete understanding of a fishery in every particular, for changes in a fishery may well determine some very basic biological or statistical event. This investigation covers completely only the fishing done out of San Pedro, so the gear and methods of halibut fishing in other districts will not be taken into consideration.

3.1. Apparatus

Fortunately the boats, gear and methods of the halibut fishery have not changed to a marked extent in the period under consideration (1919–1929, inclusive). The boats used by the fishermen are of the larger market type, seldom over 40 feet long and averaging about 35 feet, with a beam of from 8 to 10 feet. Over this entire period of years the average net tonnage was between 4 and 5 tons per boat. However, since 1924 there has been a slight increase in average tonnage due to the enlargement of hold capacity to carry additional ice. Each boat is powered with a gasoline or small Diesel type engine located amidship beneath the deck. There are sleeping accommodations forward for two to four men and cooking apparatus on deck or in the small pilot house. A small skiff is carried on deck, usually resting amidship beside the pilot house. The nets, buoys, anchors and lines are usually piled on deck in the after-part of the craft to the rear of the hold cover. (See fig. 4.)

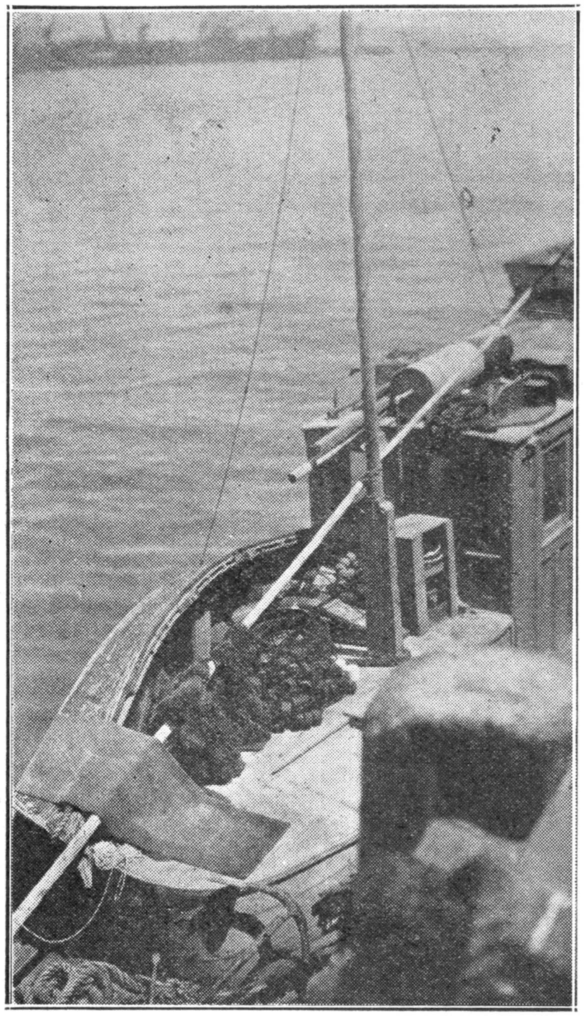

FIG. 4. Top view of a typical California halibut fishing boat. Photo by author, May, 1930

Trammel nets are used exclusively by the San Pedro fleet for it is required by law that no drag net (a successful though perhaps destructive fishing gear for halibut) be used or be in the possession of anyone in that district which comprises the coastal waters off Ventura, Los Angeles, Orange and San Diego counties. Other types of nets, not illegal in the district, could be used to capture halibut, but evidently the trammel net has proven itself the most efficient for it is uniformly employed by halibut fishermen in the district.

A trammel net (*trammel* means to check, hinder or entrap) is a curtain of three nets all suspended from a common cork line and attached to a common bottom lead line. The middle net is of fine mesh loosely hung, while the outside guard nets are of taut large mesh (three times the size of the center net's mesh). (See fig. 5.) These nets are so constructed that a fish striking either side passes through the large mesh, hits the small mesh net, through which it can not pass, causing the loose, small mesh net to go through one of the openings of the opposite outer webbing to form a sack in which the fish is trapped. The weight and struggles of the fish cause the open end of the bag to rest against the strands of the wider guard mesh, thus closing the opening. (See fig. 6.)

Each halibut boat carries from 10 to 50 pieces of trammel net, the average number being about 21. Over the period studied, the San Pedro fishermen have averaged about the same number of pieces per boat, fluctuation range being only 3 pieces. A piece of trammel net is about 40 fathoms long (240 feet); it may, however, vary from 35 to 45 fathoms in length. A man possessing 20 pieces of net each 40 fathoms

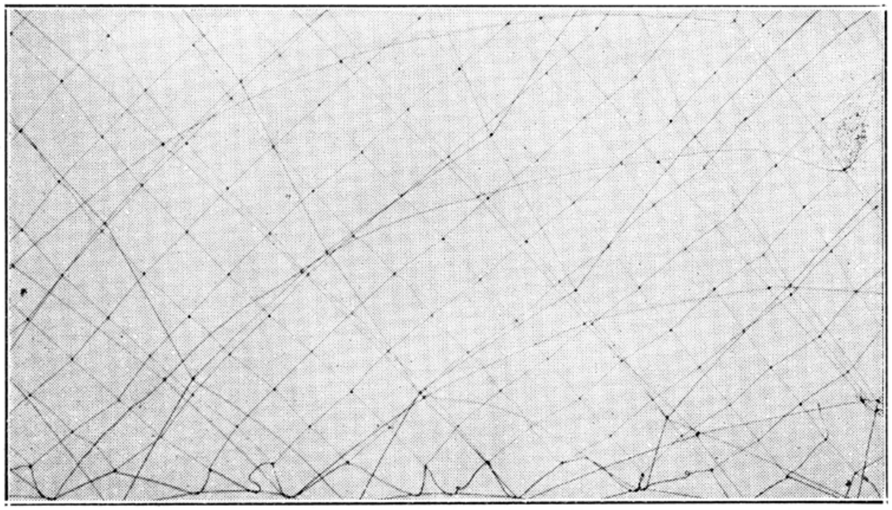

FIG. 5. Photograph of trammel net webbing. Notice the large meshed guard nets and the inner smaller meshed web. Photo by D. H. Fry, Jr., February, 1930.

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long would therefore have 4800 feet of net. The trammel nets used for halibut are approximately 25 to 30 meshes deep, measured on the middle net of 8-inch mesh (stretched measure). As the 20 feet or more of inner net is hung loosely, the depth of the net proper is from 6 to 10 feet. Ordinary wood or cork floats (3 to 4 inches in diameter) are strung to the upper or cork line to keep the net upright in the water. To the lower or lead line are attached lead pieces, usually 2-ounce leads in pairs every 8 to 12 inches, in sufficient quantities to offset the pull of the cork and to hold the bottom of the net on the sea floor. When a net is set the lead line rests on the bottom and the cork line holds the net in a vertical position under the surface.

3.2. Fishermen

A crew on a halibut boat usually consists of 3 men, although some boats carry 2 to 5 men, but 5 is the upper limit, for space on the relatively small boats is cramped and not many men are required to fish the gear. One of the men, who in many cases is also the owner, captains the craft, directs all fishing operations and decides where and when to fish. He is usually an experienced fisherman with a knowledge of good fishing banks for different species of fish. His crew may be either "green" or experienced men; it makes little difference which, for as soon as the newcomers have handled the gear once or twice they are just as efficient as those who have fished halibut before. If the captain is experienced, his boat, manned with green hands, should be just as successful as one that has an experienced captain and crew. On the whole the fishermen are hard working; their livelihood depends on the amount of fish they catch, so they are constantly trying their utmost in order to obtain the maximum returns for their effort.

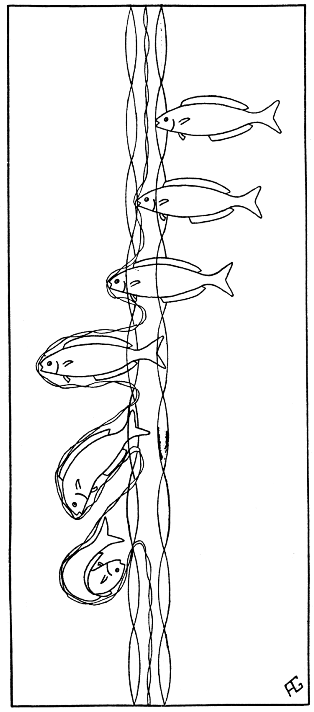

FIG. 6. Diagrammatic drawing to show how fish are entrapped in a trammel net. Fish in different stages of entanglement. The view shows the two outer taut guard nets and the inner loose small mesh net

Fishermen leave port to be gone several days, depending on their success at making catches; the sooner they fill up the hold with halibut, the quicker they return; or if fishing is poor they return when the ice and provisions are almost exhausted. All boats do not follow this practice, for some go out each day and return the same night or make a trip every twenty-four hours; they necessarily go only short distances. Others may spend from two to ten days on one trip. This very fact has been a stumbling block in the latter analysis of the catches. There is no means of knowing or discovering how much fishing was done on a trip of ten days, for example. Was the effort as intense each day or did a storm or engine trouble cause the boat to put into a convenient port, and if so, for how long? This question will be taken up more fully later, but suffice to say that fishermen must be prepared to stay out a number of days each trip. Their nets must all be in perfect repair, likewise their buoys, anchors and lines. In addition it is necessary that they have ample provisions, ice for the fish and motor fuel on each expedition.

3.3. Fishing Operations

When the fishermen reach a favorable fishing ground or bank, they set their nets. The best fishing time is in the early morning and in the evening, as the fish seem more active at these times. Therefore, the fishermen endeavor to have their nets set about the proper time each twelve hours. Nets are put out in gangs of five to seven pieces of trammel tied end to end to form a long string. On both ends of the gang, attached to the cork line, then on down to the lead line, are ropes at the bottom end of which are fastened heavy anchors or weights

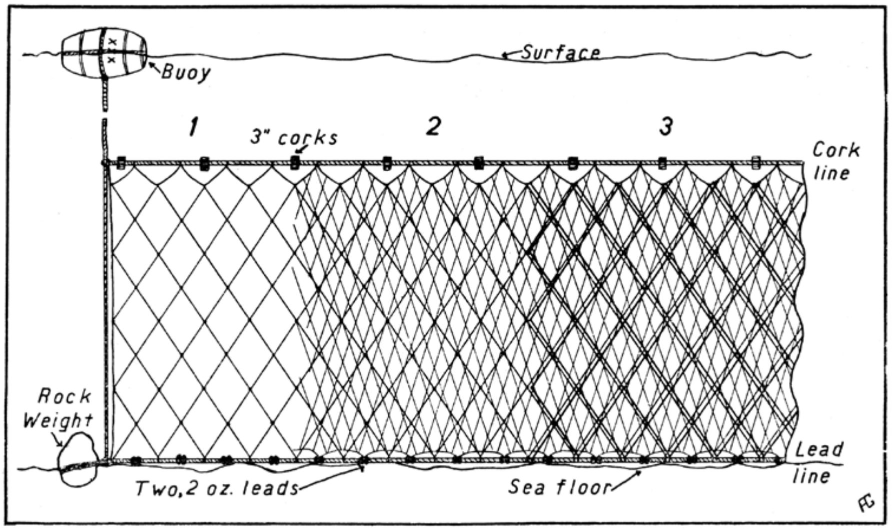

FIG. 7. Diagrammatic drawing of a set trammel net. (1) Shows one of the guard mesh, (2) one guard mesh and the smaller inner webbing, (3) both guard meshes and the inner net in place.

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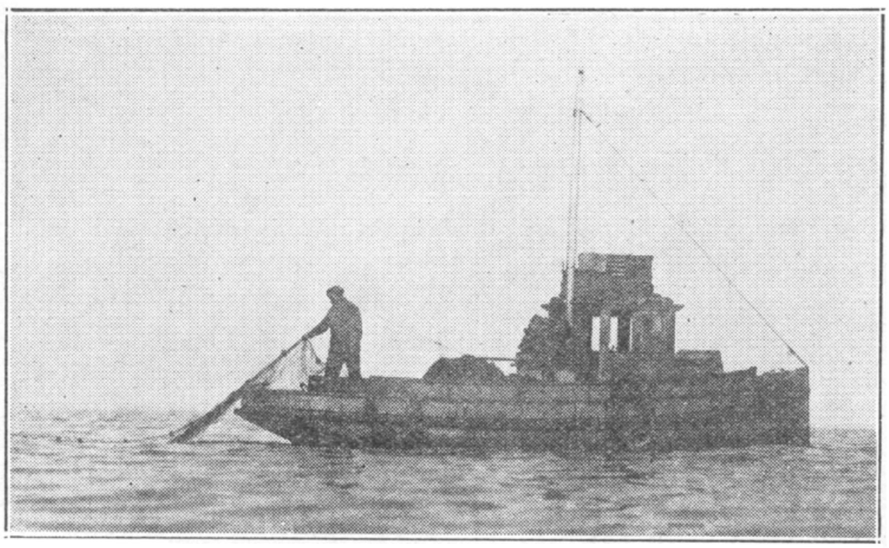

FIG. 8. California halibut fishermen paying out a trammel net. Photo by D. H. Fry, Jr., December, 1929.

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to keep the nets from drifting. From this same stringer, a line at each end of the gang extends up to buoys or floats at the surface to mark the submerged nets. (See fig. 7.) Each gang is set in a favorable location, seldom in water over 20 fathoms (120 feet) deep, and against the tide.

When a gang of nets is set, one end is put out with an anchor and buoy attached; then the nets are thrown overboard gradually, keeping the lead and cork lines separate to prevent entangling. (See fig. 8.) As the nets are paid out, the boat travels along at a slow speed; thus the nets comprising one gang are stretched out in a long line. Finally the last end of the gang is anchored and a marking buoy attached. Usually the nets are left in their respective locations within a few miles of each other for a period of 12 to 24 hours before they are inspected for fish.

In taking up the nets a fisherman takes hold of the buoy and lifts that end of the net and anchor on board; then while he hauls in the cork line another man brings in the lead line, while a third picks the fish from the webbing. If the catch has been good, the gang is replaced on the same fishing grounds, otherwise a new location is sought.

During the intervals between resetting of nets, the boats anchor and the fishermen clean and ice the halibut catch or as much of it as time permits. In previous years when only one-day trips were made, the fish were not iced nor were they always cleaned.[3]

At the termination of a fishing trip all nets are pulled in and placed on deck; then the boat returns to its home port to sell the fish at the prevailing market price. In some cases when boats are near the home harbor, nets are left out for a day while the boats take the previous day's catch to the market, but this is not done when the boats go to distant regions.

Every two or three trips the fishermen bring their nets ashore to dry and to mend them. Repairing nets may take from one to four days, depending on their condition. New nets are always tanned before being used, and later at intervals are treated with preservatives to insure longer usefulness. The number of fishing days lost while mending nets can not be accurately ascertained, but it can be safely assumed that about the same length of time each year is consumed in taking care of the gear.

3.4. Fishing Areas

Halibut fishing areas have enlarged considerably in the period under investigation, 1919–1929, inclusive. In the early years of this span, fishing by San Pedro boats was carried on near the port, and a trip over two days' duration was seldom made. Fish were plentiful. It is reported that boats made catches of 2000 pounds of halibut within an hour's run from San Pedro. Gradually the fishing area extended in all directions because halibut became increasingly difficult to catch in any large amounts in local waters. It is said that a gang of nets now placed in local waters and left there for twenty-four hours would probably yield about five halibut. Different distant fishing grounds are used in the various seasons of the year. In the early winter, fishing for halibut by the San Pedro boats is carried on off the Ventura and

[3] The loss of weight incurred by cleaning halibut (viscera removed with head and tail intact) compared to fish in the round is very small for flatfishes have relatively little viscera. The proportion of cleaned and round fish is almost impossible to determine from catch records or from any other source, as in most cases no distinction is made on the fish receipts. A slightly higher price is sometimes paid for cleaned fish, but this feature can not be used to separate the two classes as prices in one port may vary considerably between dealers on any one day. Therefore, no correction for round and cleaned fish has been made in the catch records.

Santa Monica coasts and south around Oceanside, the nets being set in about 15 fathoms of water. During the months from February to June, inclusive, fishing is conducted close to shore in three to five fathoms and near San Pedro on the theory that during these months halibut come in from deep water to spawn. From July to November, inclusive, fishing is concentrated in deeper water (about 20 fathoms) near the northern and southern island groups and along the coasts of Ventura and Santa Barbara counties as far north as Point Conception. (See fig. 1.)

4. LIFE HISTORY AND CONSERVATION

It is almost imperative that a knowledge of the life history of a species, or at least some understanding of the major factors of the life cycle of a fish be known in order to enact intelligent laws for its conservation. If a fishery needs protection, the catch of a species can be curbed in California by indirectly limiting the amount to be caught in one or more of four ways: (1) by regulating the kind or size of gear, (2) by closing a season or part of a season, (3) by confining fishing operations to certain areas, or (4) by setting a size limit on commercially caught fish.

In order to have on record and to provide a basis for legislation, a summary is given in this report of the work done on the life history of the California halibut by Elmer Higgins, now in charge of the Division of Scientific Inquiry of the U. S. Bureau of Fisheries. In 1919 while with the California State Fisheries Laboratory, Higgins collected and partially analyzed data on about 2500 specimens of this species, but unfortunately the work was not completed or the results published. Full credit for the finding of pertinent facts on the life history of the California halibut is due to Mr. Higgins.[4]

In studying the life history of the species, the following facts are desirable for legislative measures: (1) size at maturity; (2) time of spawning; (3) approximate location of spawning areas; (4) size range of all fish and of mature fish; and (5) approximate age at different sizes.

Much of this early material was collected while fishing with an otter trawl in the waters off the coast of southern California from Santa Monica to San Diego. A record of catch hauls was made as to date, time, locality and depth. In most cases the number of fish taken in a haul or in several hauls in the same vicinity were sufficient to constitute a good sample.

No attempt is made to present tables and graphs of the material collected but merely a summary of the data is given with the express purpose of giving the important facts as set forth above:

(1) The California halibut first reaches maturity at about 9 inches in length. These small fish are probably males as they mature at an earlier age than do the females, and this size includes many fish that have not yet reached the four-pound legal limit. The nine-inch group appears to include the larger fish of the two-year class.

[4] The facts, as here given regarding the life history of the halibut, are those which the writer has interpreted from Higgins' data.

(2) The spawning time, as determined from the data and from information obtained by the writer, occurs from February to July with its greatest intensity in May.

(3) The spawning grounds are not very definitely known, but it would seem that spawning takes place near the shore in shallow water, 3 to 10 fathoms in depth. Fishermen have told the writer that the halibut come in from deep water to shallower water to spawn, at which time the best catches can be made.

(4) The specimens of halibut collected by Higgins, range from about 3 to 35 inches in length. A frequency distribution of sizes of all classes shows several prominent modes, probably due to age groups. In this collection of specimens the size range of mature fish extends from the minimum mature size of 9 inches to the maximum of a about 35 inches.

(5) As interpreted from the raw data, the approximate size range of different age groups are: one-year fish, 1–5 inches; two-year fish, 4–9 inches; three-year fish, 6–15 inches; four-year fish, 10–16 inches; five-year fish, 11–17 inches. The growth rate of the fish is very slow and the sizes in age groups overlap to a large extent, so that the modes of the older fish are probably obscured in any frequency distribution of sizes.

5. ANALYSIS OF BOAT CATCHES

5.1. Effort and Time Units

5.1.1. Effort

In order that fish abundance may be accurately determined, it is of primary importance that the effort expended in catching fish be constant. If in any fishery the boats, gear, fishing methods, personnel, price, fishing area, fishing time and all other factors which might affect the catch remained constant from year to year, then the total catch of that fishery would demonstrate the true status of abundance of that species. of course the above state of affairs rarely happens so that it is difficult to find constant effort year after year within an entire fishery, as the apparatus, personnel, etc., are continually changing. Therefore, in order to measure the abundance, the fluctuations in gear and time per boat must be determined and that depends on all the factors mentioned above. If it is found that the effort per boat of all boats is constant from year to year, then the catches of all craft or a representative sample of those boats may be used to portray the abundance of fish. But if on the other hand some of the boats in the fishery show a considerable change in effort, due to any one of the factors mentioned, they obviously are not comparable with other boats which have a uniform effort. In many cases it is therefore necessary to make a selection of all those boats which show constant effort, and if the data are plentiful, these records will accurately portray the abundance of the species. This latter method has been employed in the halibut data because as mentioned above many boats were only incidental in the fishery. Therefore only those boats that fished continually for halibut were used in the analysis.

At times corrections can be made for changes in effort, such as size of boat, gear, changes in methods or in time spent in fishing, but very often such corrective measures are difficult to apply with accuracy.

Effort is not one single item but many, and all factors of effort must be considered when the effort put forth in a fishery is being determined. For instance, if the unit of gear to be used is a net of constant dimensions from year to year, the catch per net per fishing time insures a constant effort even though the numbers of nets increase, but only if other factors which may have a bearing on the catch, such as size of boats, personnel, fishing methods, *etc.*, remain constant. If we use boats as a measure, the boats may remain the same size and have the same capacities, but the gear each uses may change periodically.

In order to determine whether or not the fishing effort per boat has remained fairly constant from one year to the next in the halibut

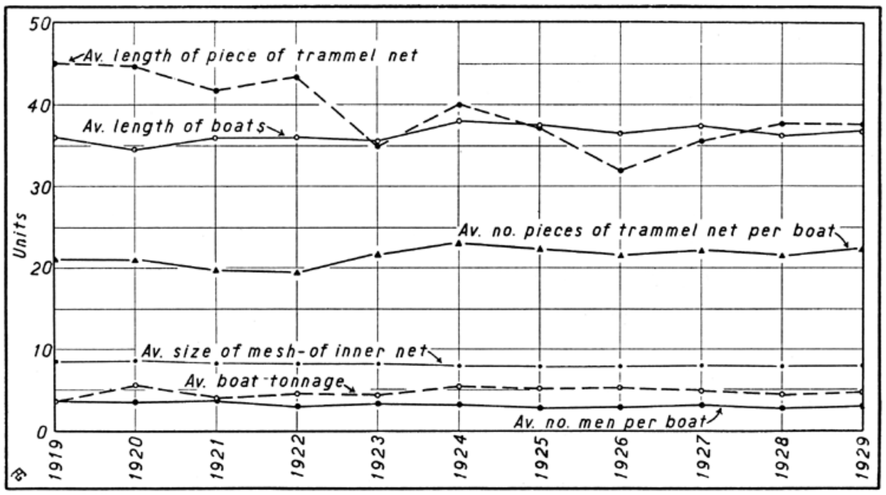

FIG. 9. Graphic representation of the average length of a piece of trammel net in fathoms, average length of boats in feet, average number of pieces of trammel net per boat, average size of mesh of inner net in inches, average boat tonnage, and average number of men per boat.

FIG. 9. Graphic representation of the average length of a piece of trammel net in fathoms, average length of boats in feet, average number of pieces of trammel net per boat, average size of mesh of inner net in inches, average boat tonnage, and average number of men per boat

fishery, information was derived from the registration cards regarding each California halibut boat as to type and size of boat, gear used, and number of men employed on the boat at different times of the year. These registrations are inaccurate and not complete enough for use in determining the exact data required of any one unit of effort, but they do give an approximation of the trends of each of the items that affect the effort as a whole.

It would appear from the registration data that the amount of gear per boat used in catching halibut during the years 1919 to 1929, inclusive, has remained about the same or has increased slightly. (See fig. 9.) The average length of a piece of trammel net fluctuates from year to year but the length is about the same over a period of years, while the average number of pieces of trammel net per boat increased in 1923 from 20 to 22; no change occurred thereafter. The average length of boats, the average tonnage, the average size of net mesh, and the average number of men on each boat, have all remained practically the same from one season to another.

The effect of fishing time lost, because of time spent in port, is very apt to be about the same in this fishery from one year to another. Fishing time eliminated because of labor conditions and storms will be different each year, but will tend to average out over a period of years so that these factors need not trouble us much when determining constant effort, except wherein by a knowledge of such facts as economic conditions or severe storms in a given year, we are able to interpret happenings in the fishery.

The demand for California halibut, as shown by the price, has increased. Figure 10 gives the average price paid to the fishermen for each year, weighted by the number of pounds caught monthly by the sample boats used to determine the average price. It will be noticed

Fig. 10. A comparison of the yearly average price per pound of California halibut with the index numbers of wholesale prices as given by the U. S. Bureau of Labor Statistics.

FIG. 10. A comparison of the yearly average price per pound of California halibut with the index numbers of wholesale prices as given by the U. S. Bureau of Labor Statistics

that from 1919 to 1923, inclusive, the average price increased from 8.7 cents to 16.9 cents per pound, while it fell in 1925 to 13 cents, only to rise again in 1926 to 16.8 cents. In 1928, the price declined again to 14.5 cents, but still was much higher than in 1925; however, in 1929 the average increased to 15 cents per pound. A trend over the series of years (1919 to 1929, inclusive) shows a decided increase while the average catch per month (see fig. 3) shows a decline. This rise in price is not due to a similar rise in commodity prices as can be seen by comparing the average halibut prices with the index numbers of wholesale prices[5] for each year. In 1920 commodity prices were high, but in 1921 they dropped considerably, and since 1922 these index numbers have not fluctuated greatly but have remained on an almost level trend. Attention is called to the fact that the price curve has been quite sensitive to fluctuations in catch; for instance,

[5] U. S. Department of Labor, Bureau of Labor Statistics.

whenever the catch is low the price is high, and vice versa. Correlation of price with average catch per month results in a Pearsonian coefficient of correlation, *r*,-.735, with a standard error of ± .138.

It is therefore seen that price is influenced by the amount of catch in this case, and most certainly shows the increased demand for halibut. Likewise, the incentive for fishermen to catch this species becomes greater as the price advances; consequently, the fishing effort increases or at least remains constant. As a still further indication of increased effort the extent of fishing areas has been constantly growing, since the catch in local waters has failed.

5.1.2. Time Units

As the gear and personnel per boat are reasonably constant, as shown in preceding pages, the abundance of halibut can be measured by the catch per boat per time period. It is desirable that a time unit be as small as possible and still correctly portray the abundance of fish to the fishermen, for a short time unit enables one to show the influence of period catches within any year. There are numerous time standards by which the catch can be measured; some are suitable under certain conditions, others applicable under different provisions. From the standpoint of the California halibut most time units are not usable. One time measurement is the yield of fish per boat per each day's fishing; this had to be discarded because as a rule the fishermen do not deliver their catches daily as their fishing trips last from one day to two weeks. No log of fishing operations was kept by the boat captains so no information as to exact fishing time, especially for ten years back, was available. The above reasons discredit the accuracy of a catch per delivery to the markets, or in other words the catch per trip. However, methods using this unit will be presented and their discrepancies will be shown. This time unit is affected by the fact that the average number of trips have varied from year to year, gradually decreasing in number per year as the years progressed, indicating in the suitable halibut boats increased length of trips. If the average number of deliveries (consequently, the length of trips) had remained constant from year to year the unit could have been applied in this fishery in order to express the true condition of the supply of halibut available to the fishermen.

Two methods remain that may be used in an analysis of this fishery: the average catch per boat per year, and the average catch per month per boat for each year. The first of these is a gross method subject to the inaccuracies of any large time unit, and one from which it is impossible to show seasonal changes in each year wherein important fluctuations may hide. Otherwise, the unit gives fair results, and as it happens in the California halibut, the findings are almost identical with those of the catch-per-month unit which has been selected as the best and most accurate time standard for analyzing the California halibut fishery. The month as a unit is not affected by the length of trips as are the day and delivery methods, and it enables us to ascertain the influence of short time fluctuations of each season on the yearly average by using monthly periods. Finally the ready comprehension and the comparative ease of calculation enable this unit to stand superior to the others suggested.

5.2. Analysis of Data

It is our intention to present the work accomplished in this analysis, beginning with the simple methods and working toward the more complex and accurate, and finally presenting the method selected as that which best portrays the California halibut abundance as to accuracy and simplicity.

In order that the reader may follow the progressive steps and compare the numerous methods employed, an analysis, which is very similar to the final and most exact method, has been presented. This is the arithmetic mean catch per month per boat for each year, and will be called the "check curve." (See p. 12, and fig. 3.)

5.2.1. Types of Averages

In each method of analysis, two types of averages—the arithmetic and geometric—have been used. The arithmetic mean is the one most commonly used and understood by the majority of people. It is calculated in its simplest form by totaling all the items in any series and dividing that sum by the number of items making up the total. The geometric mean, which is less widely used, is the *nth* root of the product of *n* values; in other words, suppose we have two items, 10 and 20 (*n*), of which we wish to obtain a geometric mean, we would multiply 10 by 20 and take the square root of the product

$$\sqrt{10 \times 20} = \sqrt{200} = 14.14 \text{ — the geometric mean;}$$

EQUATION

or if we have 500 items we would get the product of the 500 numbers and take the 500th root of the result. In calculating many items, to make the procedure easy, logarithms are used. The product of the items is the same as the sum of their logarithms, and instead of taking the root, the total of the logarithms is divided by the number of items. The result then is the logarithm of the geometric mean, which when converted to a natural number is the geometric mean.[6] Like the arithmetic mean the geometric average is affected by the size of all items in a series, but unlike the arithmetic type it is less influenced by the extremely high values.

The California halibut data, when plotted as a frequency of size of catches, have a strong tendency to crowd toward the zero end of the scale with a long tapering off toward the high catches. This was particularly true of a frequency array of the size of individual deliveries, but not as much with monthly boat catches, and was even less evident in yearly boat catches. The use of the geometric mean under such a frequency distribution skewed to high values gave a truer average than the arithmetic mean, and has been used in the calculations in many of the methods.

5.2.2. Total and Average Catch per Boat

Usually total catch figures of a fishery are used to show the fluctuations in the catch of a species of fish. Sometimes these total catch records of each district are erroneously employed to show depletion

[6] Chaddock, Robert Emmet. Principles and methods of statistics. New York, p. 125, 1925.

or abundance in various areas. It is realized that total landings are not sufficient except when accompanied by supplementary data, for use as any accurate measure of abundance. The total catch of suitable[7] halibut fishing boats for each year is shown in figure 11, in comparison with the "check curve." The total catch curve as it happens shows the essential trend of the fishery although the fluctuations are exaggerated, as can be seen when the curve is compared with the "check curve." If the data had not been taken from suitable halibut boats the difference between the curves would be more noticeable. (See fig. 2.)

Now if the total catch figures, as presented in figure 11, are divided by the number of suitable boats that fished halibut each year the result is the average catch per boat per year (shown in fig. 12) in comparison with the "check curve," and the similarity between the two can readily

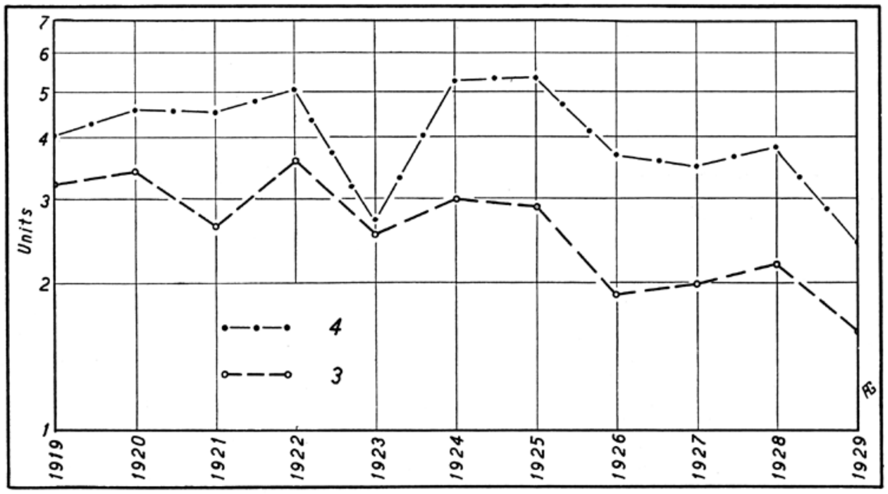

FIG. 11. Total catch of suitable halibut boats in hundred thousand pounds (4), and the arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3).

FIG. 11. Total catch of suitable halibut boats in hundred thousand pounds (4), and the arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3)

be seen for they have identical fluctuations with almost the same percentage increases and decreases. The two curves are so alike because the average number of months fished each year per boat is almost the same. With the exception of a method for seasonal variation, the average boat catch per year would perhaps have been as good a measure as the "check" standard used, but of course this was not known definitely until the more refined method of catch per month had been calculated. As has been stated above, the frequency distributions of the sizes of catches indicate that the best measure of central tendency would be the geometric mean. Although this was not as prominent in the distribution of yearly boat catches, it was evident enough to warrant its calculation for comparison with the arithmetic mean of the same data. (See fig. 12.) The geometric mean shows only a few changes in percentages from point to point from those of the arithmetic mean curve; the most evident is between 1919 and 1920 and from 1928 to 1929.

[7] "Suitable" is used in this report in the sense that the halibut boats considered in this analysis fished at least two months out of the six-month season.

However, the trend over the period is less steep in the geometric curve than in the other. The best measure for the catch per boat is probably the geometric mean since from the distribution of catches it is evident that this is the better gauge of central tendency.

5.2.3. Average Catch per Trip

A time unit, that upon first examination appeared to have possibilities of being accurate, subject to seasonal treatment and easy to

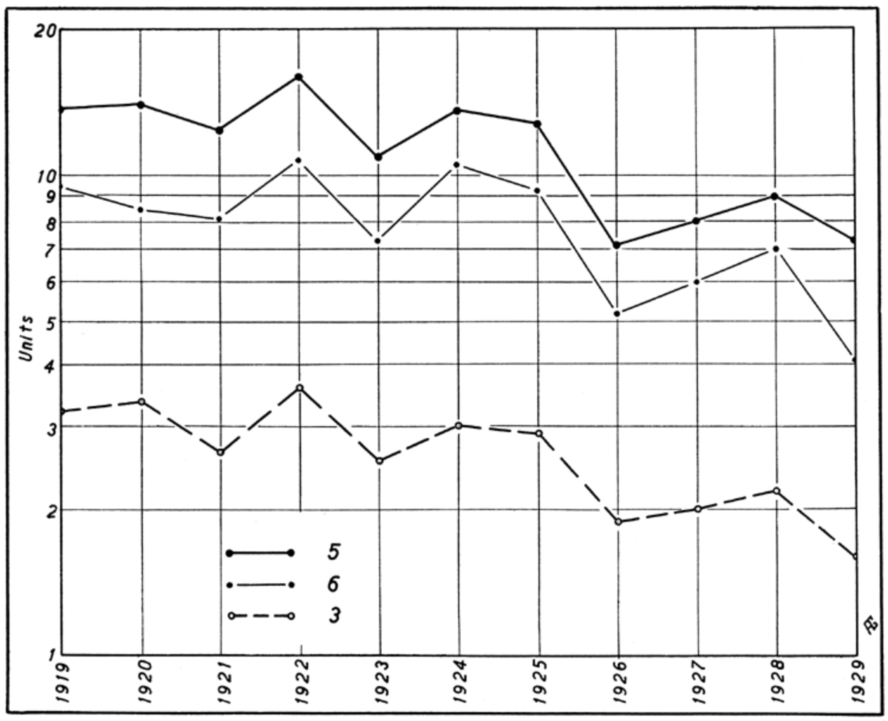

FIG. 12. Arithmetic mean catch per boat per year in thousand pounds (5), geometric mean catch per boat per year in thousand pounds (6), and the arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3).

FIG. 12. Arithmetic mean catch per boat per year in thousand pounds (5), geometric mean catch per boat per year in thousand pounds (6), and the arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3)

handle, has been used a great deal in the experimentation of different methods of treating the data. This standard, the catch per delivery (trip) per boat, was soon found to be inaccurate because as the fishery developed the deliveries were made less frequently. In the early years of the fishery, halibut were more plentiful, so it was not difficult for a boat to make a good catch each day and to return to port with fish. An average trip then was made in a day or two. As time went on, the trips became of longer duration each year; consequently, the deliveries were less frequent. If the average catch per delivery (trip) were to be used, naturally it would be erroneous. What constituted a boat catch for a daily trip would not be comparable to a five-day or a two-week catch as made in later years. Individual boats may have varied in length of trips made, for even now some boats make a delivery each day, but the average length of trips made by all boats increased from 1919 to 1929, inclusive. If a trip was of a day's duration, the boat would make thirty trips each month; if of seven days' duration, there would be approximately four trips a month, *etc.* It is readily seen from figure 13 that the average number of trips each month fluctuates from year to year although the trend over the years is downward. It was impossible to make a correction so that trip catches could be placed on a day basis, because information on the exact time consumed on a trip was not available. A most significant fact, however, stands out as a result of the trial and error experimentation with this unit, and that is: despite the steady lengthening of trips, the catch per trip of California halibut has decreased as shown by this measurement.

Regardless of the fact that the trip catch is a poor unit of measurement many methods of calculating the data, which have been very beneficial, were worked with this standard to demonstrate the use of the various methods of calculation. The average (arithmetic mean) catch per trip per boat for each year is shown in figure 13 in comparison with the "check curve." In addition, on the same graph is shown the average number of trips per month. The average catch per trip

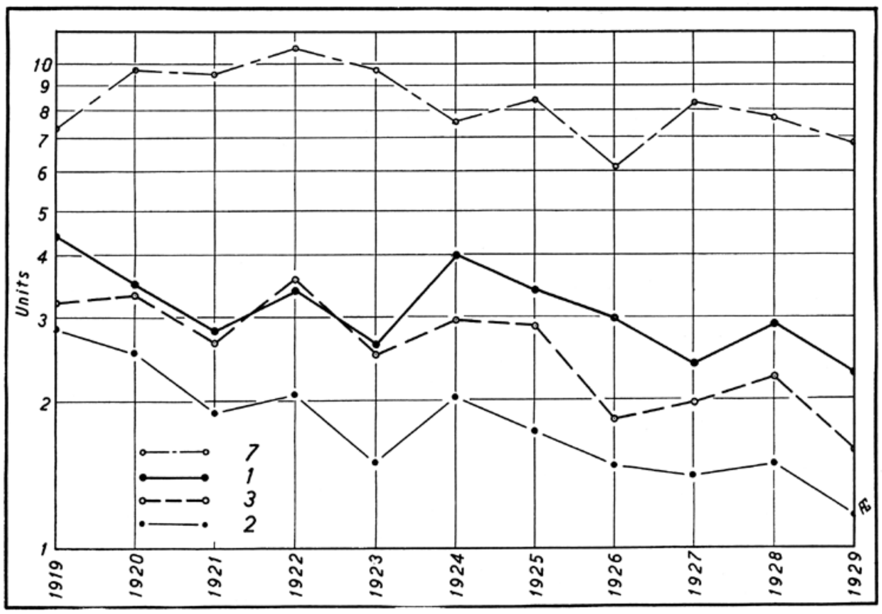

FIG. 13. Average number of trips per month per boat each year (7), arithmetic mean catch per trip per boat each year in hundred pounds (1), arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), and geometric mean catch per trip per boat each year in hundred pounds (2).

FIG. 13. Average number of trips per month per boat each year (7), arithmetic mean catch per trip per boat each year in hundred pounds (1), arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), and geometric mean catch per trip per boat each year in hundred pounds (2)

was obtained by totaling all the annual trip catches of all suitable boats and dividing each year's sum by the number of trips in that year. It will be noticed that the average catch per trip, with the exception of the first year (1919) coincides with the trend of the "check curve" to 1924. In that year the trip curve diverges from the other and continues on at a higher level. The average number of trips per month for each boat in 1919 was low; consequently, the length of a trip was increased, naturally making the average catch per trip high. However, in 1920 to 1923, inclusive, the average number of trips per month was almost constant; thus between these years the trends of the two curves were the same, but in 1924 to 1929, inclusive, the length of trips increased so that the average catch per trip rose. This graph clearly demonstrates the fact that the unit of a trip is not particularly accurate

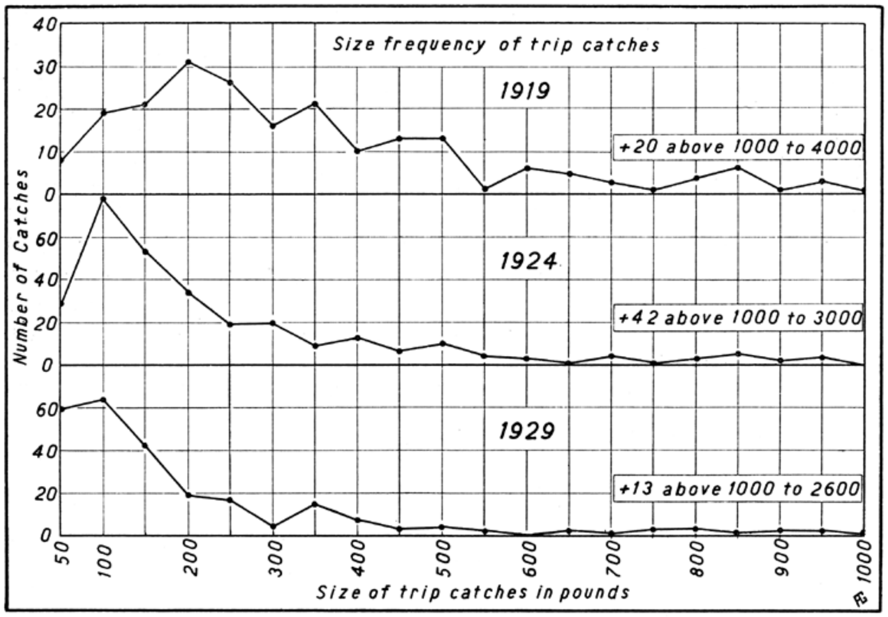

FIG. 14. Size frequency of trip catches in pounds from suitable halibut boats for the years 1919, 1924 and 1929.

FIG. 14. Size frequency of trip catches in pounds from suitable halibut boats for the years 1919, 1924 and 1929

although the trip curve does descend somewhat during the period of years used, but certainly not as fast as the "check curve."

Because one of the most outstanding items in the trip data is the wide range of the sizes of trip catches, the arithmetic mean was not considered the best method to measure the central tendency for this distribution. A frequency distribution of the size of catches for any one year showed a grouping of the majority of the items near the zero end of the scale with a long extension towards the higher values. (See fig. 14.) From the three frequencies shown of a representative sample in representative years, one readily notes the wide distribution of catches especially when the plotted frequency curves only show from one-fourth to one-half of the range. (See fig. 14.) Obviously a mean, which is influenced by the extreme values, is not a correct measurement of central tendency for this distribution. Therefore the geometric mean was calculated which gave less weight to the scattered high catches. In figure 13 is shown a comparison of the geometric and arithmetic mean catch per trip and the "check curve." Attention is directed to the fact that the geometric mean does not eliminate the error caused by the longer trips, but merely makes the error less pronounced.

If the arithmetic mean catch per trip for each year is arbitrarily weighted by the average number of trips per month (multiply the value for the mean catch each year by the average number of trips per month of the same year), the result will almost coincide with the "check curve." (The two curves would exactly coincide if averages were not used for weighting.) This bears out the statement made above that most of the difference between the mean catch per trip and the mean catch per month ("check curve") is due to the error caused by longer trips. When the length of trips is the same, the trend of the curve will be similar regardless of weighting, as is shown by the years 1920 to 1923, inclusive; but when the catch per trip is high, due to the error of longer trips, as from 1924 onward, and the length of trips has increased, the weighting has the effect of discounting or correcting the error. (See fig. 15.) Likewise, if the same method of weighting is applied to the geometric mean catch per trip each year, the effect is about the same. It will be seen, however, that the latter curve has a steeper decline than the other, due perhaps to the greater reliability of the geometric mean as an average for the data, and to its secondary use of placing boat catches on a nearly equal basis as shown below.

5.2.4. Equalization of Size of Boat Catches

As is often the case when a number of boats are exploiting a certain fishery, some boats will habitually make larger catches than others, and the average catch per boat is affected accordingly. Either

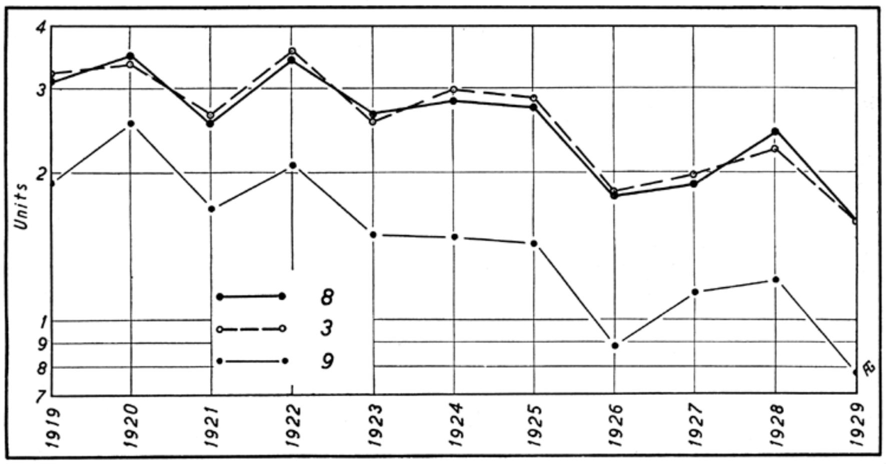

FIG. 15. Arithmetic mean catch per trip multiplied by average number of trips per month in thousand pounds (8), arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), and geometric mean catch per trip multiplied by average number of trips per month in hundred pounds (9).

FIG. 15. Arithmetic mean catch per trip multiplied by average number of trips per month in thousand pounds (8), arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), and geometric mean catch per trip multiplied by average number of trips per month in hundred pounds (9)

a division of the boats into size classes of catch must be made or some method employed which will give all boats equal weight in determining the final outcome of the average, whether they consistently make large or small catches. It would seem most reasonable that boats making consistently small deliveries are as significant in determining the trend of the catch as boats making large catches. If the same boats, operated by the same captain, fished over the entire period, 1919–1929, inclusive, the catches of all the boats could be raised to the level of the highest average boat catch during this time or lowered to equal the lowest average boat catch. However, in the halibut data, only a very few boats have fished during this entire period, so some other means of putting the boat catches on a par had to be devised.

The most advisable method in this case seemed to be a percentage basis, that is, of selecting a common time base point and expressing the individual annual boat catches as a percentage of the boat's base. In this way each average catch per trip per boat each year would be on an equal standing with every other boat average catch per trip per year. It is then a simple matter to average the relative changes from the base of all boats for a given year to obtain a single figure for the year, which would be a percentage of the common time base. This system of making boat catches equal is akin to index numbers, such as are employed in economic research. For instance, in obtaining index numbers for a list of commodities, the prices of bread and automobiles could not be averaged on an equal footing, as the high price of the car would overshadow that of the bread. Therefore, price relatives for these articles are used, that is, the bread price relative is found by obtaining in a given year its percentage of a former year (the base); this method also applying to the automobile price relative—of course the same time base is used. Now the two items are equal. Suppose the relative for cars is .80 and for bread .70; averaging the two, we get .75, which is the relative price change or the index number of automobiles and bread from the base. This principle may be applied to boat catches. Suppose two boats take the place of the commodities and the catches replace the prices, then we obtain the catch relative of each boat from their common time bases in order to average them and obtain the average catch change from the base period.

This exact procedure of equalizing boat catches could not be utilized because not all the boats fished continually during 1919–1929, inclusive, but a modification along the same principle was used for the halibut data—the chain relative index number. This method enables one to remove and substitute commodities or boats when feasible, in order to keep the data representative. Each boat catch relative is calculated, using its preceding year as a base. For instance, if 10, 7, 5, and 2 are average catch per trip values of a boat in successive years, the relative for the second year, using the first as base, is 7 ÷ 10 = .70; the third relative is 5 ÷ 7 = .71; *etc.* The first year in the series is necessarily lost, and over eleven years (1919–1929, inclusive), there may be as many as three boat substitutions, so that a loss of data may result, but which may compensate when using much data. After the relatives of all average boat catches per trip are found, each year's relatives are averaged using a geometric mean (the approved average of rates of change). The result is a logarithm which, when converted to a natural number, is the geometric mean of the catch relatives (link relatives) for any given year. These links are then chained to a fixed base (in the analysis of the halibut fishery to the first year 1919). Suppose that the link relatives for the years 1920 to 1923, inclusive, were: 40, 60, 50, and 70 (the first year, 1919, necessarily being lost). The year 1919 is to be the base, 100 per cent, so in order to find the chain relative for 1920, 100 is multiplied by 40=.4000 or 40 per cent; the chain link relatives for 1921 would be .40 X 60 or 24 per cent; for 1922, .24 X 50 or 12 per cent; and for 1923, .12 X 70 or 8.4 per cent. The chained link relatives for the years 1920 to 1923, inclusive, then would be .40, .24, .12, and .084. All percentages are of the base year, 1919, to which the links were chained, and show the percentage or relative annual change of the average catch per trip. This method, which places all average catches per trip per boat on an equal footing, gives a more correct picture of the catch per trip than the simple arithmetic mean. But to further strengthen the chain relative curve, the relatives for each boat were weighted by the number of trips made by that boat for each year. As the relatives were calculated from the catch per trip of each boat, all boats regardless of the number of trips made, would have the same weight, but when weighted by the number of trips in a year, the boats which made the most trips would have more influence on the average of the relatives. This is as it should be in catch per trip calculations for the boat that makes more deliveries is a better index than a boat making only a few trips. The original boat relatives were converted to logarithms in order to calculate the geometric mean, and the logarithms were multiplied by the number of trips made annually by each boat. The weighted relatives for a given year were then summed and the total divided by the sum of the weights to obtain the link relative for the year.

However, the link relative process does not eliminate the error caused by the longer trips, and perhaps the chain relative introduces another factor in the loss of certain year catches from substituted data. But, the geometric mean catch per trip accomplishes the same purpose as

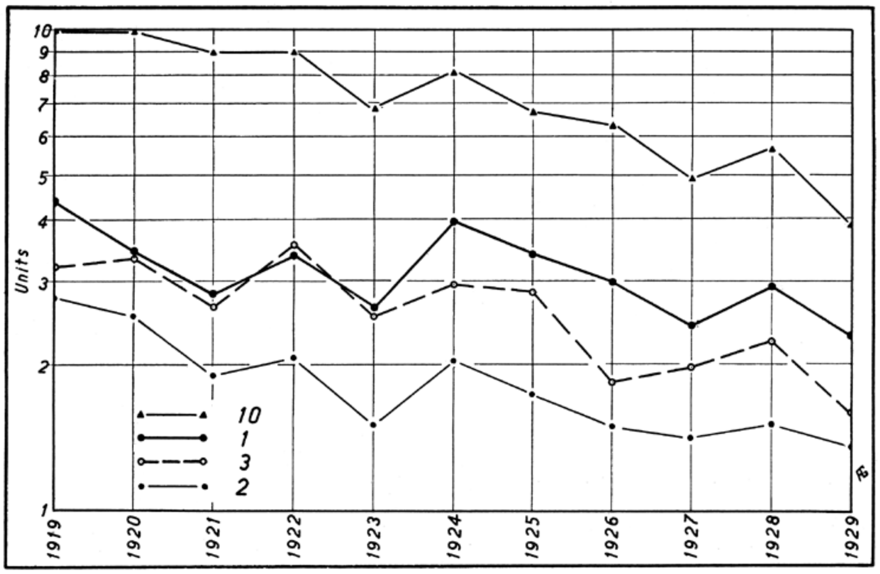

FIG. 16. Chain relative index numbers of the geometric mean catch per trip per boat each year weighted by number of trips per year (10), arithmetic mean catch per trip per boat each year in hundred pounds (1), arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), and geometric mean catch per trip per boat each year in hundred pounds (2).

FIG. 16. Chain relative index numbers of the geometric mean catch per trip per boat each year weighted by number of trips per year (10), arithmetic mean catch per trip per boat each year in hundred pounds (1), arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), and geometric mean catch per trip per boat each year in hundred pounds (2)

the chain relative by putting the size of boat catches on an equal footing, so it would appear that the loss of data in substituted boats in the chain relative was not an important factor in the halibut data. If these two curves are compared (see fig. 16) their similarity is at once noted. Their fluctuations and trends are almost identical. The geometric mean of a series expressed as a percentage of the first year as a base will exactly coincide with a chain relative of the same data if the number of items each year remains constant. (See p. 47–48.) As the chain relative may be subject to a loss of data, perhaps the geometric mean catch per trip would be a better method to show as accurately as possible the catch by this standard.

5.2.5. Seasonal Catches

So far in this discussion of catch measurements, short time fluctuations, that is, fluctuations between periods within any year, have not been considered. In this analysis the month has been used as the short time fluctuation period because it was the smallest time unit that could be accurately employed, as the occurrence of daily, weekly or biweekly catches was so variable, due to length of trips, that the monthly period was found to be the only feasible unit.

If there are differences between the sizes of monthly catches, these differences have a varying influence on any average that is calculated for a given year. However, if the year's monthly catches were the same or if they fluctuated very little, the influence of monthly catches on the yearly average would be negligible, other conditions remaining constant.

For instance, if in any one year, catches are high during the period of normally large yield, they will have a greater influence on the yearly average than the same percentage increase will have during the normally low catch periods. Conversely, if during the periods of normally large returns the catch for any year is low, it will affect the yearly average to a greater extent than the same proportional decrease during the periods of normally low catches. Similarly, if during the periods of small catches, the size of catches increases or decreases, it will have less effect on the yearly average than an equal percentage change occurring during periods of normally large catches.[8]

Since the above principle is true, a method whereby each month will have equal weight in size of average catch is needed in order to obtain the correct percentage change for a given year.

The method of obtaining equal weight for each monthly period catch was as follows: (1) A normal or standard year by months to be used as a base, was calculated by procuring the geometric mean[9] catch per trip for each month *during all years*. For example, the geometric mean of all January trip catches *for all years* was calculated in order to obtain a norm for January. This same procedure was used for each month. (2) The logarithmic differences between the monthly geometric mean catch per trip of all suitable boats *for each year* and their corresponding monthly averages in the standard year

[8] Craig, J. A. An analysis of the catch statistics of the striped bass (Roccus lineatus) fishery of California. California Division of Fish and Game, Fish Bull. no. 24, p. 16, 1930.

[9] It has been determined above that the geometric mean minimizes the effect of large catches as well as places all boat catches on an equal basis.

were obtained. (3) These logarithmic differences were weighted by the number of trips made during each month of each year. (See page 30, on discussion of chain relative weights for explanation of weighting.) (4) The geometric means of the weighted logarithmic differences were obtained, and the results were the average of the logarithmic differences from the normal year. These logarithms were changed to natural numbers and expressed in percentages of the normal year.

Figure 18 shows these percentages from the standard by years in comparison with the simple geometric mean catch per trip and the "check curve." It is readily seen that the percentage from the normal curve differs only slightly from the simple geometric mean catch per

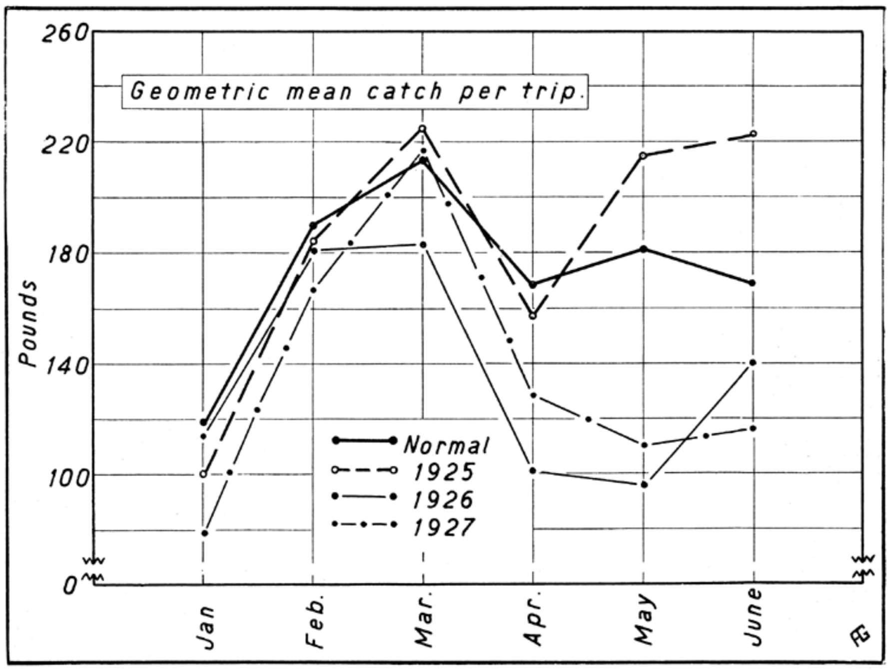

FIG. 17. Normal monthly geometric mean catch per trip per boat for the 11 years, 1919–1929, compared to the 1925, 1926 and 1927 figures by months to show in which month they differ from the normal.

FIG. 17. Normal monthly geometric mean catch per trip per boat for the 11 years, 1919–1929, compared to the 1925, 1926 and 1927 figures by months to show in which month they differ from the normal

trip, principally in the years 1925–1927, inclusive. Since there were differences in the years 1925–1927, inclusive, between the simple geometric catch per trip and the percentages from the normal year, it was thought advisable to discover the cause of these differences. In figure 17 are presented graphically the normal monthly geometric mean catch per trip and the same curves for 1925, 1926 and 1927. The 1925 curve follows the norm closely until May and June at which time it rises over the normal curve. Upon examination of the curves in figure 17, it was found that the figure for 1925 in the percentage curve was higher in relation to other years than it was in the simple geometric mean curve. In the simple curve the increase over normal at the periods of normally low catch was not sufficient in actual numbers to offset the influence of the rest of the months in order to raise the yearly average. But in the percentage method, where each month had equal weight in size of average catch, the increase in May and June had the power to raise the yearly average to its proper position, in relation to other years. Similarily the points for 1926 and 1927 can be explained, but in these cases the catches were lower than normal during the normally low periods. Therefore, not until each month was given equal weight in

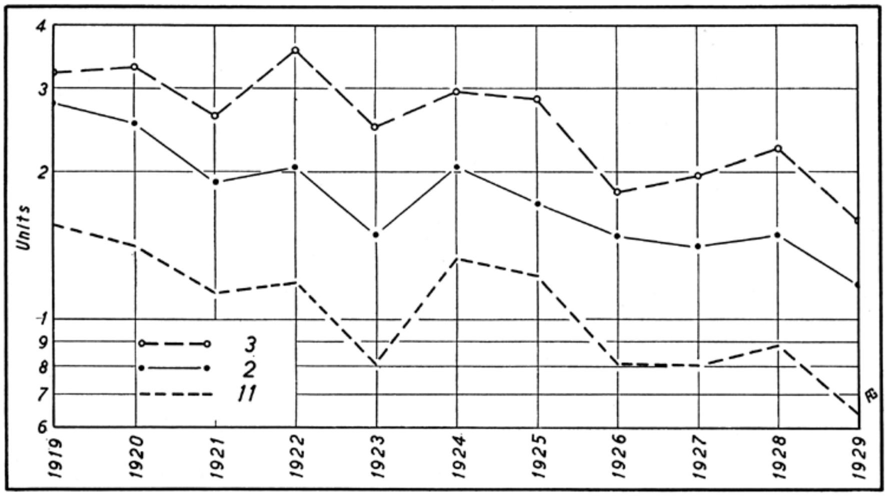

Fig. 18. **Arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), geometric mean catch per trip per boat each year in hundred pounds (2), and geometric mean catch per trip per boat percentage of geometric mean catch per trip normal (11).**

FIG. 18. Arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), geometric mean catch per trip per boat each year in hundred pounds (2), and geometric mean catch per trip per boat percentage of geometric mean catch per trip normal (11)

size of catch could these decreases exert their proper influence on the yearly averages.

The differences between the simple curve and the percentage curve were extremely small (see fig. 17), hardly enough to cause any change in a trend of the average boat catch of the fishery over a period of years. However, the method employed—percentages from the normal—gives the best results of the catch per trip per boat, for it embodies all corrections heretofore mentioned and allows the catch per trip to measure the abundance with some degree of accuracy.

5.2.6. Selected Sample

Heretofore all available halibut data have been utilized in calculating the measurements by the various methods, but now an analysis is presented giving a small select sample of boats chosen because of their almost continual fishing for halibut with the same amount of gear and under the same direction during the period 1919–1929, inclusive. There are eleven boats in the sample, two of which operated during the entire eleven years, three fished for ten years, three for nine, two for eight, and one for seven years. These boats were scattered throughout the period so that no portion of the span was slighted. While it is realized that the sample is not exceptionally good, it is interesting to compare the results of the analysis with those of data from all suitable halibut boats. Figure 19 is the arithmetic mean catch per trip per boat by years of the selected sample, compared with the same curve for all data and with the "check curve." The curve for the boat sample is not unlike that of all data, in some years, but differs greatly in the points for the years, 1924–1929, inclusive. Evidence points towards inadequacy of the sample material or an inequality of the boat catches comprising the sample.

In order to test this inequality the boat catches were all raised to a common basis, *i. e.*, to the average catch of the high boat. The average catch per trip of each boat over the series of years it fished was obtained, and the boat which had the highest average was given the weight of *one*. Then all the other boats were given weighting factors by dividing the average catch per trip of each boat into that of the high boat to get the factor by which each of the catches had to be multiplied to raise the catches to a par with those of number *one* boat. For instance, if the high boat average was 400 pounds, and that of another boat was 200, then 400 ÷ 200 = 2, the factor by which all of the catches of the number *two* boat must be multiplied to be equal to those of number *one*. In this manner each boat had equal weight in determining the average for any year. Boats making consistently high or low catches should have equal consideration in the determination of yearly averages, for the one group should be just as true an indication of the fishermen's success or failure as the other. The above procedure of raising boat catches of the selected sample was followed, and the result presented in figure 20, in comparison with the "check curve," and with the geometric mean catch per trip of all data (geometric mean catch per trip itself places catches on equal basis as shown above). It is readily noticed that the selected sample arithmetic

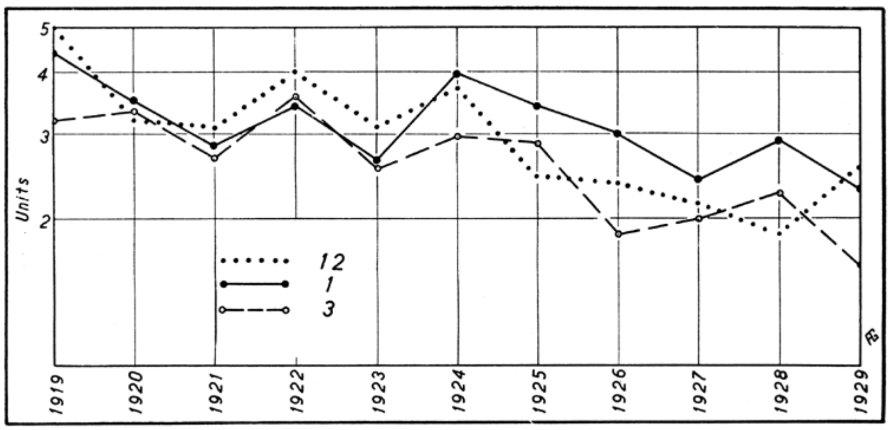

FIG. 19. Arithmetic mean catch per trip per boat each year in hundred pounds of a selected sample of boats (12), arithmetic mean catch per trip per boat each year in hundred pounds of all suitable boats (1), and arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3).

FIG. 19. Arithmetic mean catch per trip per boat each year in hundred pounds of a selected sample of boats (12), arithmetic mean catch per trip per boat each year in hundred pounds of all suitable boats (1), and arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3)

curve, when all boat catches are equal, does not follow the geometric mean trip catch of all data. This perhaps can be attributed to the mechanics of the two types of averages, for if the simple geometric mean of the selected sample is plotted with the same curve for all data, it is perceived that the two are closely allied in fluctuations and in trends.

Since in the halibut data there is an accumulation of trip catches around the small end of the scale with a long tapering out toward the high values, both in individual boats each year and by groups of boats for any one year, the geometric mean may be considered the best measurement of central tendency for the material. If the arithmetic mean is used, the mode of the items is often distant from the calculated

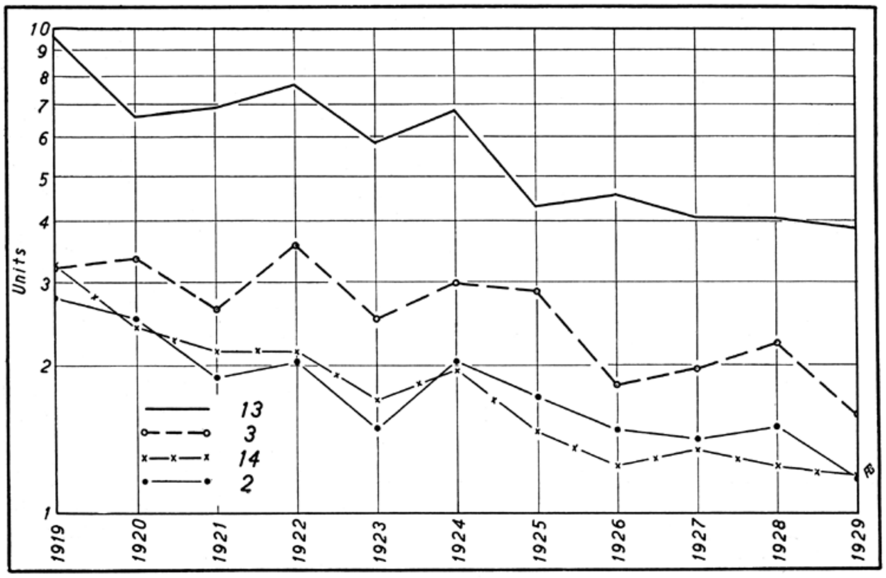

FIG. 20. Arithmetic mean catch per trip per boat of selected sample—all boat catches raised to the highest boat—in hundred pounds (13), arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), geometric mean catch per trip per boat of selected sample in hundred pounds (14), and geometric mean catch per trip per boat of all suitable boats in hundred pounds (2).

FIG. 20. Arithmetic mean catch per trip per boat of selected sample—all boat catches raised to the highest boat—in hundred pounds (13), arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), geometric mean catch per trip per boat of selected sample in hundred pounds (14), and geometric mean catch per trip per boat of all suitable boats in hundred pounds (2)

mean. This grouping may differ somewhat from year to year, which might produce an exaggerated mean.

In figure 20, it appears that the selected sample, if calculated by the geometric method, was sufficient to portray the annual condition of the halibut fishery. However, to complete the analysis of the samples, it would be necessary to take into consideration the possible differences of period catches within a season, but that procedure was waived. Since the results of the method, which takes into consideration period catches, for all data were similar to the results of the procedure by years, it is assumed that there would be little difference between a period catch yearly curve of the sample and a simple annual curve. In addition, since the purpose of an analysis is not only to determine the trend of the fishery for a given period but also to work out a method whereby, if the conditions remain the same, the analysis could be continued from year to year, it was thought best not to carry this sample further. Therefore a sample of selected boats which operated over a period of years, in all probability would not be the same sample five years hence. The unit of gear would very likely undergo a change which would make the future data incomparable to the earlier material.

5.2.7. Random Sample

With this in mind a random sample of every fourth boat of all data was subjected to analysis. As the geometric mean catch per trip has been ascertained to be more accurate than the arithmetic mean for the halibut data, it is the only one presented in comparison with the same curve for all data and the "check curve." (See fig. 21.) Unlike the comparison with the selected sample the random sample does not closely coincide with the geometric mean catch per trip of all data except in the trend over the entire period. The fact that the random sample acts in an opposite way from all the other curves presented in this report, in the two major flunctuations, *i. e.*, the rise from 1923 to 1924 and the drop from 1924 to 1926–27, would seem to indicate that the analysis of such a small random sample[10] is somewhat doubtful as a measure of the abundance of halibut.

5.2.8. Average Catch per Month

Since the trip as a time unit can not be used as an accurate measurement of effort for gauging the halibut supply, a standard, eliminating the effect of longer trips, must be used—preferably a time unit that exceeds the longest trip. As some of the fishing expeditions last for three weeks, the applicable space of time will be a month. The month, as a time unit of measurement, eliminates the length of trips and has practically all the advantages of a smaller unit, besides possessing superior qualities over other time units for this analysis. (See p. 23.)

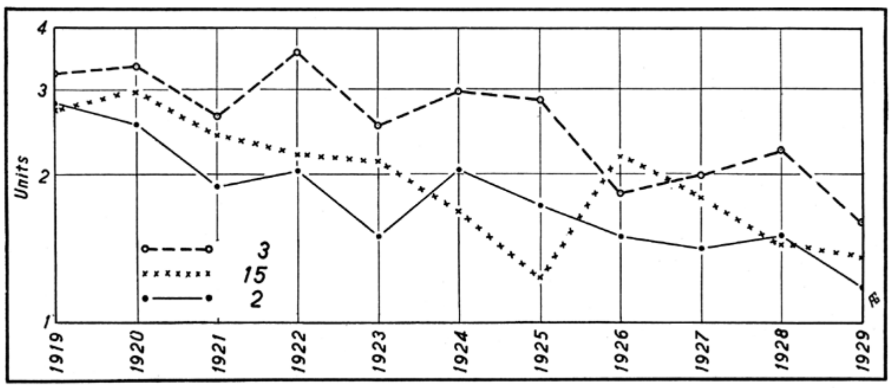

FIG. 21. Arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), geometric mean catch per trip per boat each year of a random sample of boats in hundred pounds (15), and geometric mean catch per trip per boat of all suitable boats in hundred pounds (2).

FIG. 21. Arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), geometric mean catch per trip per boat each year of a random sample of boats in hundred pounds (15), and geometric mean catch per trip per boat of all suitable boats in hundred pounds (2)

In the halibut data, the month is the only time unit that can be ascertained which shows a fairly constant fishing time per boat over the period, 1919–1929, inclusive. The average number of fishing months per boat during each year for all data, has been almost the same (see fig. 22), as over this span of years the variation of the range in the number of fishing months per boat has been eight-tenths

[10] Half or three-fourths of the suitable boat data might be adequate. However, the data are not extensive, only thirty to fifty boats a year, so it was thought advisable to use all suitable boat data.

of a month, the trend for the eleven years being practically horizontal. Examination of the number of boats fishing each month each year, reveals that more boats fished from February through May and less in January and June. However, the important item is that the relative number during each month of each year were approximately the same for the period 1919–1929, inclusive. Therefore, there was no concentration

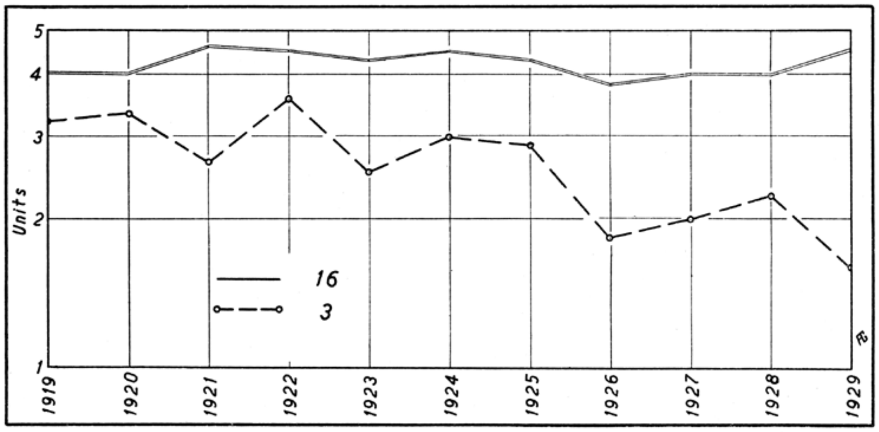

FIG. 22. Average number of months fished per boat each year (16), and arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3).

FIG. 22. Average number of months fished per boat each year (16), and arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3)

on one part of the season one year and grouping on another part another year.

As the average catch per month utilizes the same data employed in calculating other time units, the effect of the gear and type of boats of the fishery will be the same for the month unit, *i. e.*, it will show constant effort per boat.

5.2.9. Arithmetic Mean Catch per Month

The arithmetic mean catch per month per boat for each year is shown in figure 22. The mean for each year was obtained by summing all the catches of suitable halibut fishing boats for each year and dividing by the number of months which made up each year's total. This resulted in the mean catch per month per boat for each year, which is shown in the curve described in the introduction of this report. (See p. 12, and fig. 3.)

It has already been determined that the month is the best unit of time that could be found to fit the halibut data in order to obtain the most accurate results. Now we shall attempt to demonstrate why the arithmetic catch per month per boat has been used as a comparison or "check curve" with other methods and units to show the availability of the fish to the fishermen.

5.2.10. Geometric Mean Catch per Month

It will be recalled that the trip catches, when arranged in a frequency distribution of size, congregated toward the lower end of the scale. This was also true of the size frequencies of monthly catches, but to a lesser degree (see fig. 23), especially in the tapering off to larger catches. The size of monthly catches shows a crowding of catches near the zero end of the scale, but a relatively abbreviated stringing out of higher values. Still the central tendency of this type of a distribution may be best gauged by a geometric mean, but such a mean may not differ much, as far as long time trends are concerned, from those of the arithmetic mean of the same distribution. Figure 24 is a graph of the geometric mean catch per month per boat per year compared with the arithmetic mean catch per month ("check curve"). The two curves have exactly the same fluctuations except between the years 1924 and 1925, when the geometric curve rises slightly while the arithmetic curve drops a little. The annual trends, percentage increase and decrease are similar, but are more pronounced in the geometric than in the arithmetic curve, while the decrease during the period 1919–1929, inclusive, calculated from the starting point to the terminating, is 59 per cent for the geometric and 50 per cent for the arithmetic. Since the geometric mean is considered the better measurement of the central point of each year's distribution, and since it tends to put all monthly boat catches on an equal basis, it is considered the more exact method of treating the data. However, the two curves, arithmetic and geometric, are so nearly alike that it makes very little difference which is used. Such being the case, the arithmetic

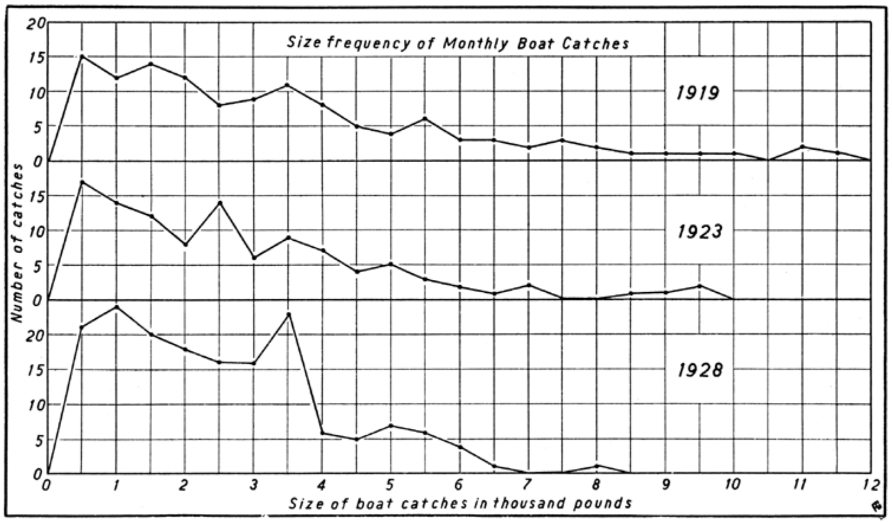

FIG. 23. Size frequency of monthly boat catches in thousand pounds for the years 1919, 1923 and 1928.

FIG. 23. Size frequency of monthly boat catches in thousand pounds for the years 1919, 1923 and 1928

mean catch per month per boat during each year has been used constantly; first, to give the preliminary statement of the condition of the fishery, and secondly, to compare with other curves of different methods.

5.2.11. Selected and Random Samples

It is quite obvious that if a selected sample, using a trip as a unit, were suitable data (which was true in this case) for catch analysis, then the same sample would likewise be appropriate, employing a month as a standard. Since it was found that the small random sample employed was inadequate for the trip average, it would likewise be inappropriate for a month's average. For this reason the question of samples of the halibut data was not treated by the month as a unit of measurement.

5.2.12. Period Catches

The effect of period catches on the yearly average have been negligible in the monthly boat catches. It will be recalled how the procedure for the method of determining the influence of period changes within years in the trip analysis was followed. The only change in the procedure was that when using the month time unit, the monthly catches were used to calculate the geometric normal year and the geometric mean catch per month instead of the trips as before. The

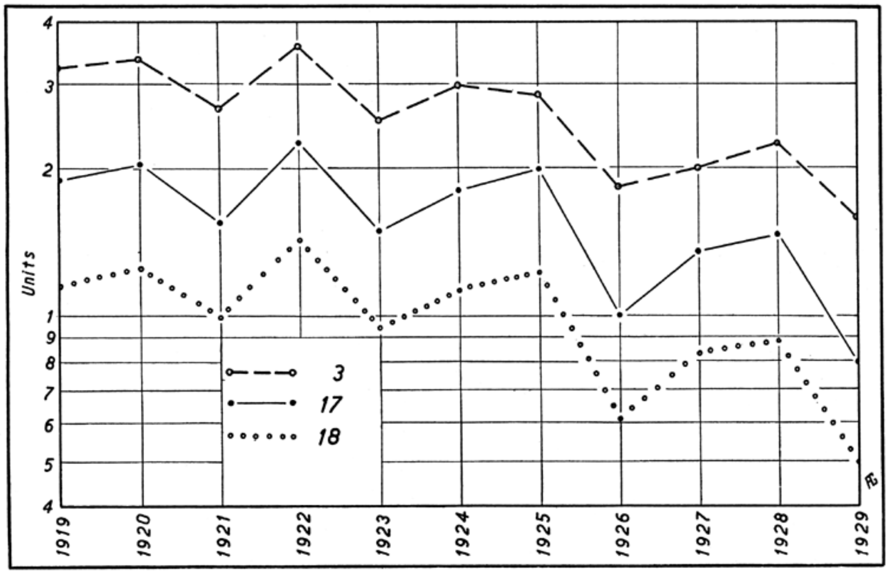

FIG. 24. Arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), geometric mean catch per month per boat each year in thousand pounds (17), and geometric mean catch per month percentage of geometric mean catch per month normal (18).

FIG. 24. Arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3), geometric mean catch per month per boat each year in thousand pounds (17), and geometric mean catch per month percentage of geometric mean catch per month normal (18)

logarithmic differences were then weighted by the number of months fished by all boats instead of by the trips as previously done. The result of this method is, of course, the percentage that each year is of the normal (base) year. These percentages are the true relationships of one year to another as they embody: (1) all data; (2) the geometric method which corrects for extreme catches and for the differences of the size of individual boat catches; and (3) the average percentage that each year is of the normal year by months to give each month of each year equal weight in size of catch in determining the final annual percentage.

In figure 24 is shown the average percentages of each year's geometric mean monthly catch per boat of the geometric mean normal year, in comparison with the arithmetic mean catch per month per boat for each year ("check curve") and with the geometric mean catch per month per boat per year. The percentage curve is almost an exact duplicate of the geometric curve in annual fluctuations and trends. The three curves shown in this graph are so similar that it seems that any one of the three might be used to illustrate the condition of the fishery; although it is realized that the percentage curve is the most accurate measure of the availability of halibut to the fishermen. The use of the arithmetic mean catch per month ("check curve") as a comparison for other data seems reasonable when it is shown that it is so similar to the most exact method—the percentage from the normal year—and also when the advantages of calculation and the comparative ease of comprehension of the method is considered.

5.2.13. Standard Errors of Means

The relative ease of handling the arithmetic mean catch per month per boat each year becomes apparent when the standard errors of the means and of the difference of means are computed. If the standard error of a mean or of a difference between any two means is more than half of the means or of the difference of means, they (means and differences) may not be considered significant. That is, if a mean of any year is over twice its standard error we may consider that statistically the data are an adequate sample of the availability of fish to the fishermen. Likewise, if the standard error of the difference of two means in two different years is over one-half of the difference, the change from one mean to the other may not be regarded as significant, but if the difference of any two means is over two times the standard error of the difference the change may be considered as an actual variation in the catch. The following table presents the standard errors of means and of differences of means of the arithmetic mean catch per month of halibut by the formulae: standard error of the mean

$$\sigma_m = \frac{\sigma}{\sqrt{n}}$$

and standard error of the difference of the means

$$\sigma_{(m_1-m_2)} = \sqrt{(\sigma_{m_1})^2 + (\sigma_{m_2})^2}.$$

Standard Errors of Means and of the Differences Between Means of the Arithmetic Catch Per Month Per Boat for Each Year

Year	*Means*	σ_m	$\frac{M}{\sigma_m}$	*Difference of means*	$\sigma_{(m_1-m_2)}$	$\frac{m_1-m_2}{\sigma_{(m_1-m_2)}}$
1919	3204	257	12.5			
				137	363	---*
1920	3341	257	13.0			
				709	305	2.3
1921	2632	163	16.1			
				933	285	3.3
1922	3565	234	15.2			
				1067	309	3.5
1923	2498	202	12.4			
				466	270	1.7*
1924	2964	179	16.6			
				100	234	---*
1925	2864	150	19.1			
				1008	192	5.2
1926	1856	120	15.5			
				142	169	---*
1927	1998	119	16.8			
				251	170	1.5*
1928	2249	121	18.6			
				649	179	3.6
1929	1600	132	12.1			

* Not statistically significant.

All these means are over twelve times greater than their standard errors, but the differences of the means do not show such reliability. If we refer back to the curve (fig. 23) we notice that only in those years between which distinct rises and falls occur, are the differences between means significant. This is to be expected, for where there are marked changes between years there is liable to be a range into which the points of these years will fall in any other like sample of the same data. However, five of the differences are significant, having a standard error of less than half the distance; two are almost significant, while three are decidedly not. The standard error of the differences of the means of the first year, 1919, and the last year, 1929, is ± 293, when the numerical difference is 1604 or 10.9 times the standard error.

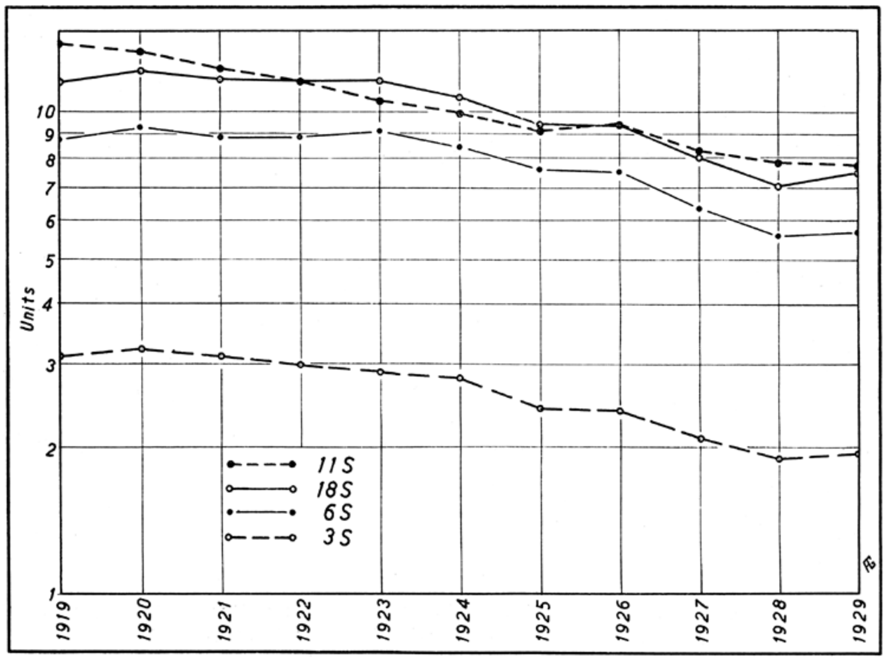

FIG. 25. Smoothed trends of previous curves. Curves smoothed by 5's once. Geometric mean catch per trip per boat percentage of a geometric mean catch per trip normal in percentage (11S), geometric mean catch per month per boat percentage of a geometric mean catch per month normal in percentage (18S), geometric mean catch per boat per year in thousand pounds (6S), and arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3S).

FIG. 25. Smoothed trends of previous curves. Curves smoothed by 5's once. Geometric mean catch per trip per boat percentage of a geometric mean catch per trip normal in percentage (11S), geometric mean catch per month per boat percentage of a geometric mean catch per month normal in percentage (18S), geometric mean catch per boat per year in thousand pounds (6S), and arithmetic mean catch per month per boat each year (check curve) in thousand pounds (3S)

5.2.14. Smoothed Trends

Each of the various time units employed in the analysis has been presented with different methods, and the most accurate measurement for each standard has been determined for the yearly trip and monthly figures. It has also been ascertained that the month as a time unit will give the best accurate results in analyzing the catch of the California halibut. Figure 25 shows the trends (averages smoothed by fives) of the best curve for each unit and in addition the trend of what has been termed the "check curve." The average yearly catch per boat figures are presented in a trend of the curve which is the geometric mean catch per boat per year. This trend is almost level to 1924, at which point it declines to 1928, and rises slightly in 1929; the rise being caused by the process of smoothing. On the other hand, the trend of the geometric mean catch per trip percentages from the geometric mean catch per trip normal year decreases from the start and levels off slightly at the end. The geometric mean catch per month percentage from the geometric mean catch per month normal year has a trend that is very similar to the yearly curve trend, which is also demonstrated by the "check curve."

The percentage decrease of the yearly trend from starting point to terminating point is 35 per cent, that of the percentage curve from normal of the trip catch is 43 per cent, that of the "check curve" is 36 per cent, and that of the most exact of all curves (the percentage from the monthly normal) is 33 per cent. Three curves (the geometric mean catch per boat per year, the geometric mean catch per month per boat percentage from the normal, and the arithmetic mean catch per month per boat for each year or the "check curve"), stand out as being very similar in trends and in the decreases of their trends; all are within 3 per cent of each other.

From the above statistical analysis of the catch, it is readily seen that a decided decrease in the availability of halibut to the fishermen is apparent over the period from 1919 to 1929, inclusive. In the face of such strong evidence of depletion it is high time that steps be taken to protect this fishery so that it may not die to extinction as a commercial fishery.

5.2.15. Summary of the Analysis of Boat Catches

(1) Total catch records of the California halibut were not sufficient to determine accurately the condition of the fishery.

(2) More refined methods of the measurements of catch per unit of fishing effort were necessary to use in this analysis. A complete knowledge of the fishery in its many aspects, together with an investigation of the economic, natural and artificial conditions affecting the catch, was necessary to interpret correctly the trend of the fishery.

(3) The month was found to be the time unit of measurement best fitted to illustrate accurately the halibut supply (available fish to the fishermen), as compared to other time units such as a year or trip catch per boat.

(4) The use of index numbers, *i.e.*, chain relatives, and the use of the geometric mean aided materially in placing the boat catches on an equal footing. The geometric mean was also the best measure of central tendency in analysing the halibut data.

(5) The best method to portray accurately the availability of halibut to the fishermen from the data at hand was the method in which: the month was used as a time unit; the data from all suitable halibut boats were utilized; the geometric mean was used; and like seasonal parts of each were compared. (See p. 40 for method.)

6. EFFECT OF FACTORS OTHER THAN FISHING ON THE POPULATION AND CATCH

Certain biological or artificial factors may have had an effect on the population and catch of halibut that are not shown by this investigation. For instance it can be noticed from the boat catch curves, that every high point is succeeded every three years by another peak, but lower than the preceding one. This periodicity may be due to a succession of successful spawning periods at fairly regular intervals. There is no proof of this, but only an indication as shown by the curves. Long cycle changes in the fishery likewise might affect a study of the halibut supply. If the investigation has taken place during a period of natural scarcity, due to movements of the fish out of the area, the measure of the abundance of the population by means of the boat catches is not accurate. It measures merely the availability to the fishermen of the existing population of halibut in the district. However, if it is true that the entire population is not present, then protection of what is present is needed until it is known that the supply has returned to normal numbers. Migrations of the California halibut appear to be limited to the inshore spawning movements, but there may be a migration at times in or out of the comparatively restricted area studied, although extensive investigation would have to be carried out to establish the fact.

It is doubtful whether an economic force has affected the catches except to assure a constant demand for the species, as the price of halibut has been steadily increasing year after year.

There has been only one legal restriction, that of limiting the size and amount of small halibut taken, which might have affected the supply in any way. This size limit first went into effect in 1915, at which time it became unlawful to catch any halibut under four pounds in weight. Later, in 1921, the law was amended so that it became unlawful to have in possession over fifty pounds of undersized halibut. This law should have shown some benefit to the supply, as it was supposed to limit the numbers of small fish taken in order to allow them time to gain weight and mature. However, it does not seem that this regulation has been of sufficient benefit. Perhaps the decreasing catch would have been even more marked if it had not been for this restriction. Without doubt, there is a need for further protective legislation for the California halibut in the San Pedro district.

7. CONCLUSIONS AND RECOMMENDATIONS

From the preceding account of the California halibut the following conclusions are drawn:

(1) Depletion of the halibut in the San Pedro fishing district is shown: by the decreasing catch per unit of effort over the period 1919–1929, inclusive; by the constant extension of fishing grounds; by the increasing price for the species indicating a greater or unfilled

demand; by the desertion from the halibut fishery by fishermen to other fisheries in which larger catches can be made.

(2) Some evidences of depletion of the California halibut in the other fishing districts of California, *viz*: San Diego, Orange, San Luis Obispo-Santa Barbara-Ventura, and Monterey Bay are indicated by the tremendous drop in total catch figures without an apparent change in fishing effort and by the character of the fisheries. In the San Diego and Orange districts the halibut fisheries are very similar to that of San Pedro, although they show a greater decrease in total catch figures; 95 per cent decrease for San Diego from 1919–1929, inclusive, and for Orange an 80 per cent decrease from 1920–1929, inclusive. In the San Luis Obispo-Santa Barbara-Ventura and the Monterey Bay districts the fishery is similar to San Pedro's in that part of the fishing is done by trammel nets, and dissimilar because much of the fishing is done with drag nets. In the San Luis Obispo-Santa Barbara-Ventura area the decrease in total catch figures has been 12 per cent from 1924–1929, inclusive, and in the Monterey Bay district the decline has been 29 per cent from 1917–1929, inclusive.

(3) Although it is realized that the total catch figures for halibut in these areas do not present such conclusive evidence of depletion as does the detailed study of the San Pedro fishery, they together with our general knowledge of the fishery, do strengthen the conclusion that the whole California halibut fishery is in need of protection from overfishing. Aside from the need of protection, a uniform law on California halibut for the State would greatly aid enforcement.

(4) Additional protective measures are needed to conserve the existing population so that it may build itself up and insure the commercial fishing interests a better catch over an extended period.

(5) The spawning period of California halibut begins the latter part of February and continues to the end of June; the greatest number spawn in April and May. The best catches of halibut are made during the spawning season as the fish move into shallow water to spawn and thus become more available to the fishermen.

(6) Fishing for California halibut is carried on during the whole year, but from January to June, inclusive, 80 per cent of the State's total catch is landed while from July to December, 20 per cent is caught. Halibut fishermen do not concentrate on halibut during the last part of the year (July–December) but only during the first half (January–June). The catch of the two months, April and May, constitutes 26 per cent of the State's yearly total catch of halibut, 6 per cent more than the six months' period from July to December, inclusive.

From the above conclusions it is recommended that commercial fishing for California halibut be prohibited during the months of April and May of each year in the coastal waters of the entire State of California. Thus while curtailing the catch the spawning fish will receive some protection.

8. REFERENCES

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9. APPENDIX

To prove that the percentage relationships of the geometric means of boat catch values of each year to a common base is the same as the percentage relationships of link relatives chained to the same time base, if the number of items remains constant: Let $a_1\ b_1\ c_1 \ldots n$=boat catches in any years.

Then by the first method (geometric mean of boat catches) the percentage relationships to base Year 1, are:

$$\text{For Year 1} \quad \sqrt[n]{a_1\ b_1\ c_1 \cdots n_1} = (\text{base})$$

$$\text{Year 2} \quad \sqrt[n]{\frac{a_2\ b_2\ c_2 \cdots n_2}{a_1\ b_1\ c_1 \cdots n_1}}$$

$$\text{Year 3} \quad \sqrt[n]{\frac{a_3\ b_3\ c_3 \cdots n_3}{a_1\ b_1\ c_1 \cdots n_1}}$$

$$\text{Year 4} \quad \sqrt[n]{\frac{a_4\ b_4\ c_4 \cdots n_4}{a_1\ b_1\ c_1 \cdots n_1}}$$

EQUATION

In the second method (link relatives) chained to Year 1 as follows:

$$\text{Year 1} \quad \sqrt[n]{a_1\ b_1\ c_1 \cdots n_1} = (\text{base})$$

Simplifying:

$$\text{Year 2} \quad \sqrt[n]{\frac{a_2}{a_1} \cdot \frac{b_2}{b_1} \cdot \frac{c_2}{c_1} \cdot \frac{\cdots n_2}{\ldots n_1}} = \sqrt[n]{\frac{a_2\ b_2\ c_2 \cdots n_2}{a_1\ b_1\ c_1 \cdots n_1}}$$

$$= \text{result of Year 2 by first method.}$$

$$\text{Year 3} \quad \Bigg(\overset{\text{(Link)}}{\sqrt[n]{\frac{a_3}{a_2} \cdot \frac{b_3}{b_2} \cdot \frac{c_3}{c_2} \cdot \frac{\cdots n_3}{\cdots n_2}}}\Bigg) \quad \Bigg(\overset{\text{(Link)}}{\sqrt[n]{\frac{a_2\ b_2\ c_2 \cdots n_2}{a_1\ b_1\ c_1 \cdots n_1}}}\Bigg)$$

$$= \sqrt[n]{\frac{(a_3\ b_3\ c_3 \cdots n_3)\ (a_2\ b_2\ c_2 \cdots n_2)}{(a_2\ b_2\ c_2 \cdots n_2)\ (a_1\ b_1\ c_1 \cdots n_1)}}$$

Dividing by $a_2\ b_2\ c_2 \cdots n_2$:—

$$\sqrt[n]{\frac{a_3\ b_3\ c_3 \cdots n_3}{a_1\ b_1\ c_1 \cdots n_1}} = \text{result of Year 3 by first method.}$$

EQUATION

$$\text{Year 4}\ \overset{\text{(Link)}}{\left(\sqrt[n]{\frac{a_4\ b_4\ c_4 \cdots n_4}{a_3\ b_3\ c_3 \ldots n_3}}\right)}\ \overset{\text{(Link)}}{\left(\sqrt[n]{\frac{a_2\ b_2\ c_2 \cdots n_2}{a_1\ b_1\ c_1 \cdots n_1}}\right)}\ \overset{\text{(Link)}}{\left(\sqrt[n]{\frac{a_3\ b_3\ c_3 \cdots n_3}{a_2\ b_2\ c_2 \cdots n_2}}\right)}$$

$$= \sqrt[n]{\frac{(a_4\ b_4\ c_4 \cdots n_4)\ (a_2\ b_2\ c_2 \cdots n_2)\ (a_3\ b_3\ c_3 \cdots n_3)}{(a_3\ b_3\ c_3 \cdots n_3)\ (a_1\ b_1\ c_1 \cdots n_1)\ (a_2\ b_2\ c_2 \cdots n_2)}}$$

Dividing by $a_2\ b_2\ c_2 \cdots n_2$ and by $a_3\ b_3\ c_3 \cdots n_3 =$

$$\sqrt[n]{\frac{a_4\ b_4\ c_4 \cdots n_4}{a_1\ b_1\ c_1 \cdots n_1}} = \text{result of Year 4 by first method}$$

EQUATION

TABLE 1

Arithmetic Mean Catch per Month per Boat Each Year

1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
3,204	3,341	2,632	3,565	2,498	2,964	2,864	1,856	1,998	2,249	1,600

TABLE 1
Arithmetic Mean Catch per Month per Boat Each Year

TABLE 2

Averages from Boat Registration

Year	Average length of boats (in feet)	Average number of men per boat	Average number of pieces of trammel net per boat	Average length of trammels (fathoms)	Average size of mesh (inches)	Average boat tonnage
1919	36.0	3.6	21.1	45.0	8.5	3.5
1920	34.5	3.3	21.0	44.6	8.5	5.6
1921	36.0	3.6	19.8	41.7	8.3	3.9
1922	36.0	2.9	19.5	43.3	8.2	4.5
1923	35.6	3.2	21.6	35.0	8.2	4.3
1924	38.0	3.1	23.0	39.9	8.0	5.5
1925	37.5	2.6	22.3	37.1	7.8	5.1
1926	36.6	2.8	21.6	32.0	7.9	5.1
1927	37.3	3.0	22.0	35.6	7.9	4.9
1928	36.2	2.8	21.5	37.8	7.9	4.4
1929	36.9	3.0	22.4	37.8	8.0	4.9

TABLE 2
Averages from Boat Registration

TABLE 3

Year	Index numbers of wholesale prices—U. S. Labor statistics	Average weighted prices of California halibut in cents per pound
1919	138	8.7
1920	153	10.7
1921	97	10.7
1922	96	11.9
1923	100	16.9
1924	98	13.9
1925	104	13.0
1926	100	16.8
1927	95	16.3
1928	98	14.5
1929	97	15.0

TABLE 3

TABLE 4

Total Catch of Suitable Halibut Boats

Year	Pounds
1919	403,702
1920	464,369
1921	452,765
1922	513,323
1923	269,827
1924	530,571
1925	536,581
1926	369,245
1927	345,734
1928	377,792
1929	243,231

TABLE 4
Total Catch of Suitable Halibut Boats

TABLE 5

Year	Arithmetic mean catch per boat each year	Geometric mean catch per boat each year
1919	13,457	9,550
1920	13,658	8,511
1921	12,237	8,110
1922	16,041	10,495
1923	10,793	7,261
1924	13,264	10,351
1925	12,479	9,183
1926	7,101	5,212
1927	8,040	5,984
1928	8,965	7,014
1929	7,154	4,112

TABLE 5

TABLE 6

Year	Arithmetic mean catch per trip per boat each year	Average number of trips per month per boat	Geometric mean catch per trip per boat each year
1919	440	7.3	276
1920	347	9.6	250
1921	279	9.4	191
1922	341	10.5	206
1923	260	9.6	148
1924	397	7.5	205
1925	342	8.4	175
1926	302	6.1	147
1927	241	8.3	139
1928	294	7.7	149
1929	231	6.9	113

TABLE 6

TABLE 7

Year	Arithmetic mean catch per trip x average number trips per month	Geometric mean catch per trip x average number trips per month
1919	3,080	1,932
1920	3,470	2,500
1921	2,511	1,719
1922	3,410	2,060
1923	2,600	1,480
1924	2,779	1,435
1925	2,736	1,400
1926	1,812	882
1927	1,928	1,112
1928	2,352	1,184
1929	1,617	784

TABLE 7

TABLE 8

Chain Relatives of Geometric Mean Catch per Trip per Boat Weighted by Number of Trips per Boat Each Year

1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
100	98	89	89	68	81	67	63	49	57	39

TABLE 8
Chain Relatives of Geometric Mean Catch per Trip per Boat Weighted by Number of Trips per Boat Each Year

TABLE 9

Month	Geometric mean catch per trip per boat normal year	Geometric mean catch per trip per boat for 1925	Geometric mean catch per trip per boat for 1926	Geometric mean catch per trip per boat for 1927
January	119	100	114	79
February	190	184	181	167
March	214	225	183	217
April	169	157	101	129
May	181	215	96	110
June	169	222	140	116

TABLE 9

TABLE 10

Geometric Mean Catch per Trip per Boat percentage of the Geometric Mean Catch per Trip per Boat Normal Year

1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
155	139	110	116	81	113	102	81	80	88	64

TABLE 10
Geometric Mean Catch per Trip per Boat percentage of the Geometric Mean Catch per Trip per Boat Normal Year

TABLE 11

Arithmetic Mean Catch per Trip per Boat of Selected Sample

1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
500	318	308	400	308	369	242	235	213	187	251

TABLE 11
Arithmetic Mean Catch per Trip per Boat of Selected Sample

TABLE 12

Year	Arithmetic mean catch per trip per boat of selected sample (all boat catches raised to a common level by factoring)	Geometric mean catch per trip per boat per year of selected sample
1919	953	323
1920	660	238
1921	690	216
1922	772	217
1923	590	172
1924	677	197
1925	427	144
1926	461	122
1927	409	132
1928	409	122
1929	377	116

TABLE 12

TABLE 13

Geometric Mean Catch per Trip per Boat Each Year of Random Sample

1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
269	296	238	221	214	171	127	218	182	141	133

TABLE 13
Geometric Mean Catch per Trip per Boat Each Year of Random Sample

TABLE 14

Average Number of Months Fished per Boat Each Season

1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
4.2	4.1	4.6	4.5	4.3	4.5	4.3	3.8	4.0	4.0	4.5

TABLE 14
Average Number of Months Fished per Boat Each Season

TABLE 15

Year	Geometric mean catch per month per boat each year	Geometric mean catch per month per boat percentage from the geometric mean catch per month per boat normal year
1919	1,897	112
1920	2,056	123
1921	1,545	99
1922	2,281	140
1923	1,489	94
1924	1,832	109
1925	2,004	120
1926	1,002	61
1927	1,330	84
1928	1,452	88
1929	800	50

TABLE 15

TABLE 16*

Year	Percentage of geometric normal geometric catch per month per boat	Percentage of geometric normal geometric catch per trip per boat	Geometric mean catch per year per boat	Arithmetic mean catch per month per boat each year
1919	111	135	8,724	3,063
1920	118	130	9,166	3,189
1921	113	120	8,785	3,051
1922	113	112	8,946	2,997
1923	112	104	9,080	2,902
1924	105	99	8,500	2,751
1925	93	91	7,598	2,437
1926	92	93	7,549	2,387
1927	80	83	6,303	2,118
1928	70	78	5,585	1,930
1929	74	77	5,706	1,952

*Data smoothed by 5s once.

TABLE 16

DIVISION OF FISH AND GAME OF CALIFORNIA
FISH BULLETINS

* No. 1. Report on Fish Conditions. 1913; 48 pp., 3 figs. Contains:

The Abalone Industry in California. By Charles Lincoln Edwards.
The Towing of Salmon and Steelhead Fry from Sacramento to the Sea in a "Live Car." By N. B. Scofield.
The Problem of the Spiny Lobster. By Bennet M. Allen.
Investigation of the Clams of California. By Harold Heath.
Investigation of the Life History of the Edible Crab (*Cancer magister*). By F. W. Weymouth.
A General Report on a Quinnat Salmon Investigation Carried on During the Spring and Summer of 1911. By N. B. Scofield.
Trout and Black Bass Planting and Transplanting in the San Joaquin and Southern Sierra Districts. By A. D. Ferguson.

* No. 2. The Scientific Investigation of Marine Fisheries as Related to the Work of the Fish and Game Commission in Southern California. By Will F. Thompson. 1919; 27 pp., 4 figs.

* No. 3. The Spawning of the Grunion (Leuresthes tenuis). By Will F. Thompson, assisted by Julia Bell Thompson. July 15, 1919; 29 pp., 9 figs.

* No. 4. The Edible Clams, Mussels and Scallops of California. By Frank W. Weymouth. Jan. 10, 1921; 74 pp., 19 pls., 26 figs.

* No. 5. A Key to the Families of Marine Fishes of the West Coast. By Edwin C. Starks. March 3, 1921; 16 pp., 4 figs.

* No. 6. A History of California Shore Whaling. By Edwin C. Starks. October, 1922; 38 pp., 22 figs.

* No. 7. The Life History and Growth of the Pismo Clam. By Frank W. Weymouth. 1923; 120 pp., 15 figs., 18 graphs.

* No. 8. Racial and Seasonal Variation in the Pacific Herring, California Sardine and California Anchovy. By Carl L. Hubbs. February, 1925; 23 pp., 4 pls.

* No. 9. Preliminary Investigation of the Purse Seine Industry of Southern California. By Tage Skogsberg. 1925; 95 pp., 23 figs.

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No. 11. The California Sardine. By the Staff of the California State Fisheries Laboratory. 1926; 221 pp., 74 figs.

Thompson, Will F. The California Sardine and the Study of the Available Supply.
Sette, Oscar Elton. Sampling the California Sardine: A Study of the Adequacy of Various Systems at Monterey.
Higgins, Elmer H. A Study of Fluctuations in the Sardine Fishery at San Pedro.
Thompson, Will F. Errors in the Method of Sampling Used in the Study of the California Sardine.
Scofield, W. L. The Sardine at Monterey: Dominant Size Classes and their Progression, 1919–1923.

No. 12. The Weight-Length Relationship of the California Sardine (Sardina caerulea) at San Pedro. By Frances N. Clark. 1928; 58 pp., 11 figs.

No. 13. The Seasonal Average Length Trends at Monterey of the California Sardine (Sardina caerulea). By Carroll B. Andrews. 1928; 13 pp., 6 figs.

No. 14. Report on the Seals and Sea Lions of California. By Paul Bonnot. 1928; 61 pp., 38 figs.

* No. 15. The Commercial Fish Catch of California for the years 1926 and 1927. By the Bureau of Commercial Fisheries. 1929; 94 pp., 52 figs.

No. 16. The Life-History of the California Jack Smelt, Atherinopsis californiensis. By Frances N. Clark. 1929; 22 pp., 12 figs.

No. 17. Sacramento-San Joaquin Salmon (Oncorhynchus tschawytscha) Fishery of California. By G. H. Clark. 1929; 73 pp., 32 figs.

No. 18. The Pismo Clam: Further Studies of its Life-History and Depletion. By William C. Herrington. 1930; 67 pp., 16 figs.

No. 19. Sardine Fishing Methods at Monterey, California. By W. L. Scofield, 1929; 61 pp., 27 figs.

* Out of print.

* No. 20. The Commercial Fish Catch of California for the Year 1928. By the Staff of the Bureau of Commercial Fisheries. 1930; 109 pp., 62 figs.

No. 21. Analysis of Boat Catches of White Sea Bass (Cynoscion nobilis) at San Pedro, California. By S. S. Whitehead. 1930; 26 pp., 20 figs.

No. 22. A Bibliography of the Tunas. By Genevieve Corwin. 1930; 103 pp.

No. 23. Success of the Purse Seine Boat in the Sardine Fishery at Monterey, California (1929–1930 Fishing Season). By J. B. Phillips. 1930; 28 pp., 19 figs.

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No. 25. Fishing Areas Along the California Coast for the Sardine (Sardina caerulea). By the California State Fisheries Laboratory. 1930; 44 pp., 25 figs.

No. 26. Seasonal Changes in the Daily Average Length of the California Sardine (Sardina caerulea). By Frances N. Clark. 1930; 20 pp., 11 figs.

No. 27. The Ring Net, Half Ring Net, or Purse Lampara in the Fisheries of California. By Donald H. Fry, Jr., 1930; 65 pp., 28 figs.

No. 28. Handbook of Common Commercial and Game Fishes of California. By Lionel A. Walford. 1931; 183 pp., 137 figs.

No. 29. The Striped Bass of California. By Eugene C. Scofield. 1931; 82 pp., 46 figs.

No. 30. The Commercial Fish Catch of California for the Year 1929. By the staff of the Bureau of Commercial Fisheries. 1931; 133 pp., 75 figs.

No. 31. Studies of the Length Frequencies of the California Sardine (Sardina caerulea). By the California State Fisheries Laboratory. 1931; 53 pp., 24 figs.

No. 32. The California Halibut (Paralichthys californicus) and an Analysis of the Boat Catches. By G. H. Clark. 1931; 52 pp., 25 figs.

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