

UC San Diego

Fish Bulletin

Title

Fish Bulletin No. 18. The Pismo Clam : Further Studies of its Life History

Permalink

<https://escholarship.org/uc/item/22n7p5qx>

Author

Herrington, William C

Publication Date

1929-03-01

DIVISION OF FISH AND GAME OF CALIFORNIA
FISH BULLETIN No. 18
The Pismo Clam
Further Studies of its Life History
and Depletion



By
WILLIAM C. HERRINGTON

CONTENTS

	PAGE
1. INTRODUCTION	3
Description of the fishery.....	3
Yield	5
2. PROGRAM OF INVESTIGATION.....	6
Previous work	8
Scope of present report.....	8
3. METHODS USED IN THE COLLECTION AND TABULATION OF DATA.....	10
Annual census	10
Commercial catch data.....	11
Methods of age determination.....	11
4. REPRODUCTION	13
Spawning habits	13
Relation between the size of the clam and the number of eggs produced....	15
5. GROWTH	16
Effect of dominant year classes on growth.....	16
Effect of selective fishing on the apparent growth rate.....	21
Rate of growth on different beaches.....	26
6. FLUCTUATIONS IN ABUNDANCE.....	28
Source of material.....	29
Evidence of fluctuations in abundance.....	30
Causes of fluctuations in abundance in the intertidal zone.....	32
Causes of fluctuations in abundance of the commercial catch.....	39
Evidence of a periodic recurrence in abundant year classes.....	48
The question of depletion.....	50
Causes of present scarcity.....	52
Natural causes of mortality.....	52
Effect of man.....	54
Present conditions	55
7. SUMMARY	57
8. BIBLIOGRAPHY	57
9. APPENDIX	59

1. 1. INTRODUCTION

On the open sandy beaches of California there is found a large heavy-shelled clam, *Tivela stultorum* (Mawe), commonly known as the Pismo clam. This clam thrives only on the exposed beaches subject to the constant washing and pounding of the surf and if transplanted to sheltered water where the active surf is absent will soon die.

Tivela occurs on nearly all the favorable beaches from Half Moon Bay in the north, where a few specimens are found, to Socorro Island, Lower California, in the south. At Monterey Bay it is found in sufficient numbers to support a considerable commercial fishery, especially near Moss Landing, but the clams are found so far out in the surf that they are usually dug only by experienced clammers during the low tides. On the beaches of San Luis Obispo County at Pismo, Oceano and Morro, *Tivela* is at present found in the greatest abundance north of Lower California. Practically the entire commercial catch shown by the records of the Division of Fish and Game of California comes from this region. Farther south, at Long Beach and Anaheim Landing, the Pismo clam was formerly abundant, but is at present only occasionally found. On the coast of Lower California it is reported by fishermen to occur in some places in great numbers, and small amounts have occasionally been brought into southern California ports from Turtle Bay by some of the fishing boats.

1.1. Description of the fishery

On the beaches in which *Tivela* occurs in sufficient numbers to be of commercial importance the clams are found distributed across the beach from the intertidal zone out into the surf for an unknown distance. The outer limit of the distribution has been placed by various diggers and observers at points ranging anywhere from the surf line to several miles off shore. It seems probable, however, from what we know of the life history of the clam, that the outer limit of the distribution can not be much beyond the surf line.

The commercial clammers and other experienced diggers usually obtain their catch almost entirely from the sand bars. These bars are continually shifting, are exposed to the full force of the open surf and are covered by water to a depth of from one to four or five feet, except at the lowest tides. They are usually separated from the beach by deep channels filled by treacherous currents, and can be reached only at a single point where the channel is partially bridged by a spit, the location of which must be kept in mind by the fisherman when returning from the bar. Because of the dangers and difficulties associated with digging on the sandbars, the majority of the inexperienced clammers, including most of the noncommercial diggers, obtain their catch from the intertidal zone, where conditions are less difficult and dangerous, but where the large clams are usually less numerous.

The equipment of the commercial digger usually consists of a drag or sack and either a clam fork or rake. The drag is a long sack made of netting, which is secured to the belt by a snap, so that it can be easily detached in case the digger is washed from his feet into deep water. When a clam is secured, it is dropped into the drag, and as the bag of the drag rests upon the ground it throws the weight of the clams on the digger only when he moves from place to place. Some diggers, instead of using a drag, wear a coat similar to a hunting jacket and



FIG. 1. Commercial digger showing the use of the clam rake. The digger backs along parallel to the surf line dragging the rake through the sand by means of the chain from the rake to his belt. This digger had just returned from the outer beach, where he was digging with the surf up to his shoulders. Photo by G. R. Chute

place their clams in the large pockets of the garment. This procedure is occasionally fatal, for, if the clammer is washed into deep water, the weight of the clams holds him down, unless he is able to crawl out of his coat. Other diggers carry their clams in a bag which they carry slung over their shoulder.

When using the fork for locating and securing his quarry, the commercial digger works along parallel to the beach, thrusting his fork into the sand every few inches until he locates a clam. When using a rake, he covers the ground in the same direction, dragging the rake through the sand by means of a rope or chain running from the lower end of the rake to his belt. (See fig. 1.) The rake is considered the most effective implement, but in fine, hard-packed sand it is difficult to

operate, and in such places the fork is usually used. At Pismo, Oceano and Morro, where the sand is fine and hard, we observed both forks and rakes in use, but at Moss Landing and Monterey Bay, where the sand is coarser, all of the diggers we observed were using rakes.

For a more complete description of the habits and appearance of *Tivela*, and of the methods employed in the fishery, the reader is referred to Weymouth (1920).

1.2. Yield

On the beaches at Oceano, Pismo, Morro and Monterey Bay, *Tivela stultorum* is found in sufficient numbers to be of considerable commercial importance. At Monterey Bay the commercial catch is disposed of locally or shipped by truck to nearby cities, but, as there is no record of the amount thus taken, we can only estimate the importance of the fishery on this beach. At Pismo, Oceano and Morro a large number of clams are used by the restaurants and chowder houses in the vicinity of the beaches, and there again we can only estimate the amount used. In addition, large numbers of clams were at one time shipped from the latter beaches by the commercial diggers to outside markets at Los Angeles, San Francisco and other cities. We have records of these shipments up to July, 1927, when a law went into force prohibiting the shipment of Pismo clams. Our only record of the commercial importance of the Pismo clam fishery, therefore, is from the amounts thus shipped from Pismo, Oceano and Morro beaches.¹

TABLE 1
Mollusks Marketed in California ^a

Species	Weight in pounds					
	1917	1918	1919	1920	1921	1922
Abalone.....	748,853	602,919	759,203	806,716	1,481,170	1,523,394
Oyster (eastern).....	574,200	1,362,500	1,516,000	1,121,500	767,200	743,300
Pismo clams.....	489,175	687,322	402,510	295,075	217,618	191,881
Soft-shell clams.....	342,857	305,622	302,576	233,124	177,058	343,260
Mussels.....	348,058	48,319	35,095	33,117	9,582	43,872
Mixed clams.....	115,346	129,084	66,744	54,318	59,832	35,291
Cockle.....	104,792	44,933	24,777	18,054	14,262	31,564
Oyster (native).....	34,402	39,279	20,230	59,741	6,760	-----
Totals.....	2,757,683	3,219,978	3,127,135	2,621,645	2,733,482	2,912,562

Species	Weight in pounds					
	1923	1924	1925	1926	Total	Yearly average
Abalone.....	1,555,134	2,241,812	2,352,861	2,060,770	14,132,823	1,413,283
Oyster (eastern).....	688,103	526,775	569,003	610,422	8,479,003	847,900
Pismo clams.....	237,108	293,114	323,185	274,317	3,411,305	371,131
Soft-shell clams.....	283,095	242,665	264,056	245,962	2,740,275	274,027
Mussels.....	60,026	49,223	25,942	12,957	666,191	66,619
Mixed clams.....	25,048	49,379	61,764	31,838	628,644	62,864
Cockle.....	36,117	6,341	2,991	16,554	300,385	30,038
Oyster (native).....	-----	-----	165	-----	160,577	16,058
Totals.....	2,884,631	3,409,309	3,599,967	3,252,820	30,519,212	-----

^a The mixed clams consist of about one-third soft-shell and two-thirds Washington clams. Data from California Fish and Game Commission reports.

¹ Beginning late in 1927 all local dealers have been required to keep a record of clam purchases on the same triplicate receipt forms as are used in California for reporting the sales of other fish, mollusks and crustacea.

TABLE 1
Mollusks Marketed in California

¹ Beginning late in 1927 all local dealers have been required to keep a record of clam purchases on the same triplicate receipt forms as are used in California for reporting the sales of other fish, mollusks and crustacea.

In table 1 we have shown by years the amounts shipped from these beaches since 1916, together with records of the amounts of other shell fish marketed in California. The Pismo clam for the period shown ranks first in importance among the clams, and among the mollusks is exceeded only by the abalone and eastern oyster.

If the amateur catch is also taken into consideration Tivela assumes greater importance, especially on the Pismo-Oceano Beach, which has produced the major part of both the amateur and commercial catch. An analysis of this fishery (Herrington, 1926) indicated that during the period 1923–1925 the commercial catch on the Pismo-Oceano Beach, as represented by our records of clam shipments, probably amounted to much less than 10 per cent of the number of clams taken out by the amateur diggers. Further work done since that time has substantiated this estimate.

During favorable low tides in the summer months of recent years, hundreds and occasionally thousands of automobiles were to be seen parked on the long sandy beaches at Pismo, Oceano and Morro, while their owners were engaged in digging this prized mollusk. The crowds were made up, for the most part, of tourists and campers from all parts of the state, who found this sport a delightful addition to the other attractions of the beach.

The abalone, on the other hand, is at present found in abundance chiefly in deep water, where it is accessible to the diver alone, and is consequently taken in large numbers only by the commercial fishermen. The eastern oyster is of little importance except commercially, for it has never succeeded in establishing itself on this coast and can be raised only from imported spat planted on the oyster beds.

These considerations suggest that, although in recent years, in our records of mollusks marketed in California, the abalone and eastern oyster take precedence over the Pismo clam, yet to the noncommercial digger of the state the latter may be of greatest importance.

2. 2. PROGRAM OF INVESTIGATION

The California Fish and Game Commission² in 1917 inaugurated a program for the scientific investigation of the commercially important fishes of the state. This program was worked out and developed by Will F. Thompson, director of investigations for the Commission, supervised and supported by Norman B. Scofield, head of the Commercial Fisheries Department.³ It provided for the study of the commercially important fisheries of the state for the purpose of developing regulations which would permit the greatest use of these natural resources without destroying the future supply. This program is given in full by Thompson (1919).

In this paper Thompson proposes the study of marine fisheries through the collection and study of a comprehensive series of catch statistics combined with the study of the natural history of the species and hopes through the analysis of dominant year classes, depletion, growth rate, and maturity to arrive at some understanding of the fluctuations in the fishery as reflected in the commercial catch.

² In July, 1927, the title was changed to Division of Fish and Game.

³ In November, 1928, the title was changed to Bureau of Commercial Fisheries.

In accord with this general program the Commission in 1919 obtained the services of Frank W. Weymouth for the study of the Pismo clam fishery of California. This mollusk was selected for investigation as it was a representative California bivalve of considerable commercial importance and was apparently experiencing a decided depletion, as was evidenced by the demands for increased protection.

These demands for increased protection had resulted in increasingly stringent protective laws, beginning in 1911 with a minimum size limit of thirteen inches in circumference and a bag limit of two hundred per person, to the present time with a minimum size limit of five inches and a bag limit of fifteen to one person. In 1911 the minimum legal size limit below which no clams might be taken was fixed at thirteen inches circumference (equivalent to 4# inches maximum diameter), and the bag limit was fixed at two hundred per person per day. In 1915, due to demands for increased protection, the bag limit was reduced to fifty per day, but the minimum size was changed to twelve inches circumference (equivalent to 4½ inches diameter). In 1917 the minimum legal size was changed from twelve inches circumference to 4¾ inches maximum diameter, an increase of about one-fourth of an inch. In 1919 the bag limit was further reduced to thirty-six per day and in 1921 to fifteen per person per day. The most recent legislation was enacted in 1927, when the minimum size was increased to five inches diameter and all shipping of clams by common carrier prohibited.

Throughout this investigation the detection of the presence and causes of depletion and the formulation of measures to best conserve the species have been held of primary importance, but in order to realize these objectives it is first necessary to possess some knowledge of the life history of the mollusk. Thus an economic and biologic study of the species must go hand in hand. As expressed by Weymouth (1923, p. 6) in the introduction to his paper on the Pismo clam: "While the problems selected for attack are those believed to be of the most immediate importance for the conservationist in maintaining the economic value of the species, it will be evident that they are also problems of fundamental biological significance."

But once the supposed depletion is determined and corrective measures applied, the work of the state does not end. A continued record of the fishery is essential in order to show the effect of the protective measures applied and to permit of their intelligent modification should they prove unsatisfactory or insufficient.

There are other features of the Pismo clam problem which lend it particular interest and importance. The accessibility of the clams to sampling and the relative immobility of the individuals have made the population particularly susceptible to a quantitative study of the effects of dominant year classes, overfishing, selective fishing and success of spawning seasons. Such problems are much more difficult of approach in the average fishery with a highly mobile population from which it is almost impossible to obtain a true quantitative and qualitative sample. For this reason any information obtained on such questions is of importance because of its bearing on the Pismo clam population and also because of the light it may throw on the study of fishery problems in general.

2.1. Previous work

Weymouth began the study of the Pismo clam fishery in 1919, and in 1923 published his results in Fish Bulletin No. 7 of the California Fish and Game Commission. In this work Weymouth laid especial emphasis on growth physiology and conclusively proved that the age of the clams could be determined from the annual rings shown in the shell structure. He also made a study of the life history and of the fluctuations in abundance of different year classes. At the conclusion of his work Weymouth (1923, p. 95) made the following recommendations to the Board of Fish and Game Commissioners: "1. That the present laws fixing a size and a bag limit be retained unchanged at least until such time as we have more adequate information concerning the natural fluctuations in abundance and possible depletion." "2. That adequate protection be afforded the young. This should include a campaign of education aimed particularly at the summer tourist and camper, through newspapers and by posting the beach; a more rigorous enforcement of existing laws; and a vigorous policy regarding the wastage of oil at and near Port Harford." "3. That, in order to follow the actual conditions of the species, in addition to the collection of the data on the commercial shipments, a census of the young by the method of cross-sectioning the beach be carried out at least once each year." "4. That, in order to relieve the strain not only on the Pismo clam but upon other native species of mollusks, steps be taken to foster the cultivation of clams. For this purpose, as the writer pointed out in the previous report, the soft-shell clam (*Mya*) is by far the best fitted. There exist, in a number of bays along the California coast, acres of suitable tideland which can be made highly productive, and since the "farming" of this species has been developed on the east coast for a number of years, it would not be an experiment here. The first step in building up such an industry is the fixing of the legal status of such grounds and the establishment of a system of leasing which will assure to a person engaged in clam culture a definite and dependable control similar to that which the oystermen have over their grounds. Such an industry would prove profitable to those taking it up, would supply to the markets a valuable and appetizing food, and would materially reduce the strain of the commercial fishery on forms like the Pismo clam in which, from the habits, "farming" is impossible. The writer considers this the most constructive suggestion arising from the work which he has carried out on the mollusks of the state and that it merits careful consideration."

In accord with the general policy of the scientific work of the California State Fisheries Laboratory, and as has also been done in the case of the sardine and albacore fisheries, the Pismo clam fishery has been kept under continuous observation since the completion of Weymouth's work. The members of the staff of the state laboratory have continued the annual cross-sectioning of the various Pismo clam beaches begun in 1919, for the purpose of obtaining a census of the clam population in the intertidal zone. In addition, samples have been obtained from the commercial catch for the analysis of its composition and fluctuations. In 1926 the writer made a short report in *California Fish and Game* on some of the more important results of the cross-sectioning work. This had chiefly to do with the effect on the fishery of the highly dominant year class of 1919 and its success in surviving after reaching legal size.

2.2. Scope of present report

The present report has for its object the analysis and presentation of the data collected since 1923, in their bearing on the conservation

and biology of the species. Some of the problems which have been considered are: (1) Determination of the extent and cause of depletion; (2) Effect of present protective measures in preserving the abundance; (3) Relation of dominant year classes to fluctuations in abundance; (4) Age at sexual maturity; (5) Relation between size and number of eggs spawned; (6) Growth rate on different beaches; (7) Deviations from the normal in the growth of individual year classes.

The material upon which this report is based came principally from cross-sections made annually on the different beaches from 1923 to 1926, inclusive. The standard annual sections were at Pismo, Oceano and Morro, and were made in the fall in order to obtain a census of the young of the year, in addition to the data on the older year classes. A census was also made at Oceano in July, 1926, and at Monterey Bay in April, 1927. In addition to the material from the cross-sections, samples were collected from the commercial catch and general information was collected from the clam diggers and local residents. A complete tabulation of the results of the cross-sections is given in the appendix of this bulletin.

During the present work, the writer has received much valuable assistance in the collection of material and helpful advice and criticism in preparing the report and wishes to gratefully acknowledge his indebtedness to the following: To Dr. F. W. Weymouth, professor of physiology, Stanford University, for advice and criticism throughout the work and for the data from his files which he made freely available. To Mr. Will F. Thompson, former director of the California State Fisheries Laboratory and at present director of investigations for the International Fisheries Commission, for advice in handling the data and suggestions in revising the manuscript. To Mr. W. L. Scofield, director of the California State Fisheries Laboratory, for assistance and cooperation in the field work and in preparing this report. To Dr. J. O. Snyder, professor of zoology, Stanford University, for suggestions in carrying out the work and for facilities and laboratory space provided at Stanford University. For assistance in making the cross-sections and collecting and tabulating the data, acknowledgment is due the various members of the California State Fisheries Laboratory staff⁴ who participated. Acknowledgment is also due to Miss Geraldine Conner of the laboratory staff for assistance in preparing the manuscript and to Miss Annie Gillespie for some of the calculations and tables. The work was carried out in part at the California State Fisheries Laboratory in charge of Mr. W. L. Scofield, in part at the Laboratory of Zoology, Stanford University, and was completed at the laboratory of the International Fisheries Commission, Seattle, Washington.

⁴ The annual cross-sections were made by members of the scientific staff of the California State Fisheries Laboratory. In 1923 the party consisted of F. W. Weymouth, O. E. Sette and W. L. Scofield; in 1924 of F. W. Weymouth, W. F. Thompson and W. C. Herrington; H. C. McMillan, who was working on the razor clam, also provided some much appreciated assistance. A second trip was made in 1924 by W. A. Selle and W. C. Herrington. In 1925 W. L. Scofield, C. B. Andrews and W. C. Herrington made the sections. In 1926 a trip was made in July by W. L. Scofield and W. C. Herrington and a second trip in November by W. L. Scofield, S. S. Whitehead, V. G. Russell and W. C. Herrington. A trip was also made in April, 1927, to Monterey Bay by W. L. Scofield, Carl Jackson and W. C. Herrington.

While the analysis in this paper of abundance, distribution and growth is in large part statistical, it has been borne in mind that a correct interpretation of the results of such an analysis can be reached only through a knowledge of the biology of the species. As expressed by Thompson (1919, p. 27) in a discussion of the use of statistics in the analysis of the relative abundance of fish: "It is also true that knowledge of the biology of the species is absolutely necessary. In fact, it must guide the collection of statistical facts, corroborate them, suggest remedial measures for overfishing, and explain the fluctuations present in the fisheries. *A biological study of the species concerned is, therefore, inseparable from the statistical studies*, and must be concentrated on those features of the fisheries which bear an immediate relationship to the questions at issue in the preservation of the fisheries."

3. 3. METHODS USED IN THE COLLECTION AND TABULATION OF DATA

3.1. Annual census

Since 1922 the most important part of the work in connection with the Pismo clam problem has been the annual census of the clam population on the more important beaches. The habitat and life history of the Pismo clam make it peculiarly adapted to the method of sampling



FIG. 2. Cross-section construction, Oceano Beach, November, 1926. The man in the center is running the sand through a screen to obtain the small clams. The one on the left is recording the data. The rope running across the beach from the lower left to the middle right is used to mark off the trench in three-meter segments.

FIG. 2. Cross-section construction, Oceano Beach, November, 1926. The man in the center is running the sand through a screen to obtain the small clams. The one on the left is recording the data. The rope running across the beach from the lower left to the middle right is used to mark off the trench in three-meter segments which has been adopted. The young, after presumably floating freely during the egg and larval stages, settle in the intertidal zone of the beach, and remain there with comparatively little horizontal movement until dug by clammers or washed into deeper water by severe storms. Therefore a trench of uniform width and of a depth sufficient to secure all clams in that area, if constructed across the beach from the upper limit of the intertidal zone out to the water line at extreme low tide, will give a representative cross-section of the clam population in that part of the beach.

Such cross-sections have been made at definitely located points on the various beaches during the low fall tides of each year. The locations have been determined by measurements from piling in the beach, from permanent retaining walls, or from other fixed objects.

The trench is laid off by means of a manila rope marked at three-meter intervals with red yarn and secured at each end by means of a stake driven firmly into the sand. The cross-section is then constructed, using a standard fork of 15 cm. spread. The sand is run through a screen of quarter-inch mesh and all clams found in the trench or projecting half way or more from the sides are saved and wrapped in squares of cheese cloth for future examination. The clams from each three-meter segment are wrapped separately and with them is placed a tag stating the number of the segment in which they were found, the number of clams found in that segment and the serial number of the cross-section from which they were taken. On a separate piece of tabulating paper is kept a record of the date, location of the cross-section, segment number as measured out from a fixed datum point, number and estimated age of clams from each segment, distance of last previous high tide mark from the datum point, the same for the low tide mark, water temperature, condition of surf and any additional information thought relevant, such as presence of oil, coarse sand, etc. The material is then shipped to the laboratory, where the clams can be examined as to age, size, distribution, etc.

3.2. Commercial catch data

In addition to the material from the cross-sections, there has been collected from the commercial catch for the years 1924–1926 an annual sample of several hundred shells. These have been shipped to the laboratory for analysis to determine the age and size composition of the commercial catch. During the annual census trips there is also collected and tabulated all available information as to the condition of the beach, abundance of clams on the sand bars, and similar data which can be obtained from the diggers or by personal observation.

3.3. Methods of age determination

In the analysis of the material from the cross-sections, the determination of the age of the various individuals is of much importance. This can in most cases be accomplished by the proper examination of the shell, for the Pismo clam carries in its shell a series of annual rings forming a record of the winters through which it has passed. Weymouth, in his paper on the Pismo clam, has described the structure of the clam shell, and the formation of the annual rings, so it will suffice here to state that in the winter the growth of the clam is very slow, and during this period the shell formed is darker in color and more translucent than the summer formation. There can, therefore, be seen in the Tivela shell a series of dark, somewhat translucent rings showing the size and shape of the mollusk during the successive winters. In figure 3 we have shown a photograph of the Pismo clam shell showing the winter rings and the general appearance of the shell.

Some of the rings are very indistinct and it sometimes is difficult or impossible to differentiate between the winter rings and false checks formed in the shell because of an injury. It is also found that in the

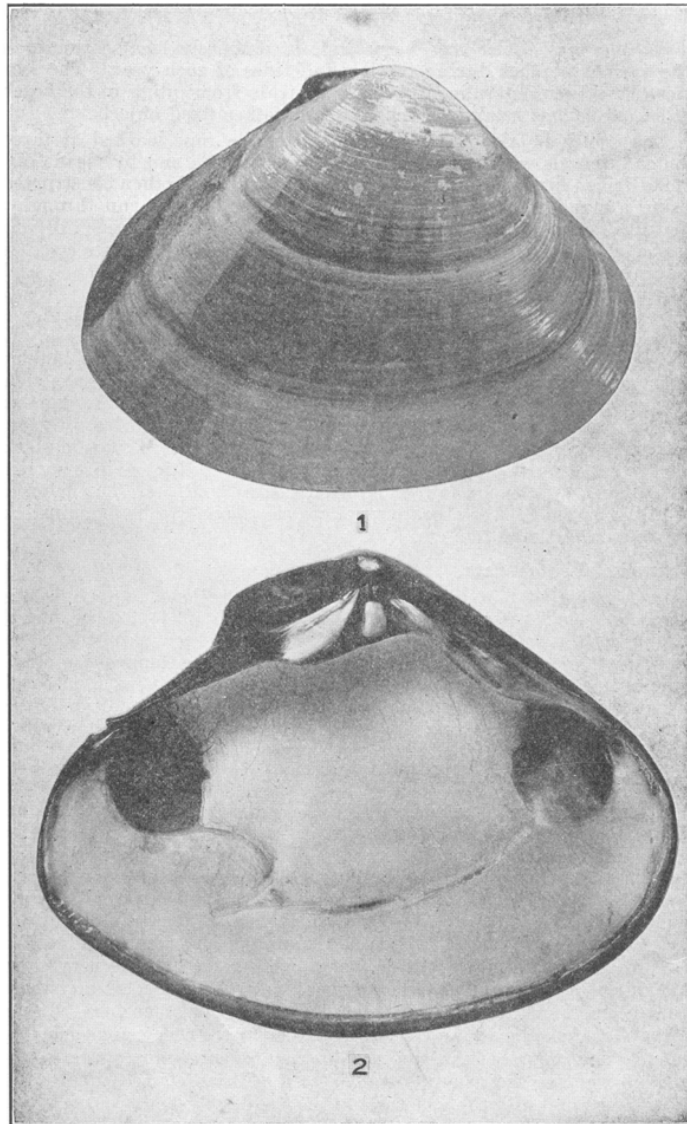


FIG. 3. Pismo clam shell in fourth summer. The upper view shows the annual rings on the exterior. Reproduced from Weymouth, 1923.

FIG. 3. Pismo clam shell in fourth summer. The upper view shows the annual rings on the exterior. Reproduced from Weymouth, 1923

older shells the annual rings are much more opaque and may become indistinguishable in this respect from the rest of the shell. Because of these and other difficulties it was found advisable and in some cases necessary to use several methods of age reading to supplement and check each other. The methods used will be briefly described.

The shells were first examined on the exterior for the indications of rings as shown by the darker pigmentation. After the best age reading possible was obtained in this way, they were subjected to an operation similar to the one used to test eggs by candling. The shell was placed over an opening in a box or reflector in which had been placed a strong electric light. When it was thus examined in a dark room the position of the rings could usually be determined by the transmission of light through the translucent winter rings. In some of the older shells in which the winter rings near the edge were very close together it was impossible to obtain an accurate count either by candling or by surface indications, but it was found that by making an even break in the shell at right angles to its edge, the position of the rings could be determined in the fracture by the appearance of the shell formation. In cases where the age could be obtained by none of these methods the specimen was not used, but such instances were comparatively few and were confined almost entirely to the older clams from the commercial catch.

The shells when examined and candled in a fresh condition were found to show the position of the annual rings most clearly. When they became dry the periostracum cracked and broke off, the rings became less distinguishable and in some cases entirely lost their translucency. It was found that by soaking such shells in water for several days the translucency was partly restored. However, it was more satisfactory to use the fresh shells whenever possible.

4. 4. REPRODUCTION

Because of the difficulty in obtaining adequate material only a limited amount of work has been done on the breeding habits of the Pismo clam. In order to determine the time and extent of the spawning season it would be necessary to examine the gonads of a large number of clams over an extended period, to insure that the entire spawning season of the species was included. In the Pismo clam fishery the commercial catch is all handled and sold alive; there is a bag limit of fifteen clams a day, and the catch is worth from one to several dollars a limit. It is, therefore, difficult and expensive to obtain a sufficient series of observations to accurately determine the spawning season. In addition, the eggs and sperm of this clam are so small that a compound microscope and laboratory conditions are necessary for satisfactory examination.

4.1. Spawning habits

For the work that has been done on the breeding habits of *Tivela* we are indebted to Weymouth (1923). The following paragraph gives a short summary of the results which he obtained.

Tivela stultorum is hermaphroditic, producing eggs and sperm from the same gonad, but probably in succession. The eggs are very small, averaging .07 mm. (about 1/360 of an inch) in diameter, and the numbers are consequently enormous. The average number of eggs, as estimated

from three specimens, two of them seven and one ten years old, was 75,000,000 per clam, with the smallest clam producing the fewest eggs. The spawning season occurs in the late summer. In 1921 it extended from the middle of July to the middle of September. Our knowledge of the larval life is a blank, the earliest record of the young clams coming when they are first found in the sand of the intertidal zone in the early fall.

We are able to add but little to the knowledge of the breeding habits of *Tivela*, for the annual census of the beaches, when most of our material was collected, has been made late in October or November when the spawning season is long past. On one occasion, July 10–11, 1926, an early census was made at Oceano to determine the effect on the clams of the severe storms of the winter of 1925–1926. On that occasion an examination was made of the gonads of the specimens collected, and their contents were preserved for future examination at the laboratory. The gonads were found much distended by the eggs, but the contents were not fluid, indicating that active spawning had not yet begun.

Material from the gonads of eighteen specimens was examined at the laboratory by means of a compound microscope. A summary of the results obtained is given in table 2. The number of clams containing

TABLE 2
Clams Collected on July 12, 1926

Number of frings	Length of clam in cm.	Weight in gm.	Average egg diameter in mm.	Volume gonads in cc.
I	3.3	8.0	None	
II	4.4	16.5	None	
II	5.2	31.5	None	1.7
II	6.5	59.0	0.063	
II	6.9	66.5	0.071	
II	7.3	87.5	0.067	
III	8.1		None	
IV	8.4	132.0	0.074	
IV	10.6	273.0	None	
IV	11.4	378.0	0.074	18.0
V	9.2	231.0	0.073	12.0
VI	13.2	594.0	0.081	19.0
VII	12.0	404.0	0.071	
VII	13.0	548.0	0.076	26.0
VII	13.9	727.0	0.070	24.0
VII	14.8	844.0	0.072	44.0
XXIV +	15.8	966.0	0.076	43.0

TABLE 2
Clams Collected on July 12, 1926

few or no mature eggs was about the same as the number containing numerous eggs. One clam was examined which was one year old (in its second summer) and as far as could be determined from a cursory examination contained no ovarian tissue. of the five two-year-old clams examined, three contained eggs and two none. These eggs averaged nearly as large as the eggs from spawning specimens, indicating that the clams would spawn during the approaching season. The gonads of most of the older clams examined contained eggs in greater or less numbers. The average size of the eggs measured was a little more than .07 mm., a value which agrees with the results obtained by Weymouth for eggs from spawning clams.

The material from the gonads was not in a fluid condition and when examined through a medium power lens, appeared to be composed of numerous eggs imbedded in a semi-transparent substance. Some of the eggs when freed from the rest of the tissue were encased in a transparent envelope averaging in thickness about one-fourth the diameter

of the egg. Weymouth makes no mention of this envelope and has informed us that he did not find it present in his material, which was obtained during the time of active spawning.

4.2. Relation between the size of the clam and the number of eggs produced

There is a great difference in the number of eggs developed by clams of different sizes, the larger clams producing the greatest number of eggs. In order to determine the degree of the relationship between size and number of eggs, we have calculated the correlation coefficient r between (1) age of clam and volume of gonads, (2) length of clam and volume of gonads, and (3) weight of clam and volume of gonads. These values are given in table. 3.

TABLE 3
Correlation Between Size of Clam and Volume of Gonads

Correlation r between	r	P.E.	No. Spec.
Age and volume of gonads.....	.665	$\pm .113$	11
Length and volume of gonads.....	.867	$\pm .051$	11
Weight and volume of gonads.....	.934	$\pm .031$	8

TABLE 3
Correlation Between Size of Clam and Volume of Gonads

We have used the volume of the gonads in these calculations instead of the number of eggs for two reasons. First, the volume of the gonads approximately represents the relative number of eggs present as is evinced by the fact that the eggs found in the clams of all sizes averaged nearly the same in diameter. Secondly, because of the extreme minuteness of the eggs (about 1/360 inch in diameter) it would be difficult to obtain an accurate estimate of the number of eggs present in each case. It would be necessary to employ some such method as is used in making blood counts. In view of the small number of samples available this accuracy was not considered justified.

The correlation values shown in table 3 indicate, as might be expected, that the size of the clam, as shown by its weight, is the most important factor in determining the number of eggs produced, and that the rate of increase in weight of the clam is about the same as the rate of increase in number of eggs. The regression b_{12} of weight of clam in grams on volume of gonads in centimeters is 20.50 ± 1.86 ; in other words, when the clam increases about twenty grams in weight the gonads increase approximately one cubic centimeter in volume.

Because of the small number of specimens available for which complete data had been collected, the probable error is not a dependable criterion of reliability and the differences obtained in our correlation ratios can not be considered of mathematical significance. The high correlation between weight and volume of gonads, however, emphasizes the value of the large clams as breeders.

These observations on the spawning habits of the Pismo clam have demonstrated that the clams have, in so far as can be determined by the presence of mature eggs in the gonads, reached sexual maturity and begun to spawn by the third or fourth summer, that is, when about two or three years old. They have also indicated that the number of eggs produced is very closely related to the weight of the clam. Our observations also show that in the summer of 1926 spawning at Oceano had not commenced by July 12. At that time the eggs appeared to be mature in size, but the contents of the gonads were not in the fluid condition which is found during active spawning.

5. 5. GROWTH

A thorough study of the age and rate of growth of *Tivela stultorum* was made by Weymouth in his work on this mollusk. Since the time his paper was published, we have collected material from our cross-sections which has a bearing on various special phases of growth study. In this paper we will consider some of these problems, such as the effect of certain factors, as selective fishing and dominant year classes, on the rate of growth; the difference in growth rate in the intertidal zone and other areas; and a comparison of the rate of growth on different beaches.

Weymouth found, from a study of approximately seventeen hundred young clams over a period of two years, that the growth of *Tivela* shows a distinct seasonal rhythm most rapid in summer and very slow in winter. During the slow winter growth the deposit put down by the mantle of the clam is darker and more translucent than material deposited during the remainder of the year. As a result a ring is formed each winter around the edge of the shell, which appears darker and more translucent than the material of the surrounding parts. Sometimes an injury to the clam causes the growth to be retarded and a dark ring or false check is found in the shell. Such false checks occur infrequently and can usually be detected by additional evidences of injury to the shell.

An examination of a clam, therefore, enables one in nearly all cases to determine its age, and in addition to determine its size at the time any winter ring was formed. This fact enables us to follow the growth of any clam through the successive years and is of great value in studying the various problems connected with growth.

When measurements were made of the diameters at corresponding ages of individuals from various groups of clams, it became immediately apparent that there was a considerable difference in some of these groups. For instance, the average length of a clam in its sixth winter, as shown by Weymouth's growth curve, is 11.07 ± 0.065 cm., as determined by our measurements of clams from the 1919 class at Oceano it is 11.60 ± 0.047 cm., and as shown by measurements of clams from the commercial catch, it is 12.31 ± 0.136 cm.⁵ Such differences might possibly be due to the effects of dominant year classes, selective fishing, habitat or other factors.

5.1. Effect of dominant year classes on growth

Investigations of growth, which have been carried on by various workers, have indicated that the growth of fishes may be affected by the extent to which they are crowded on certain banks. The plaice of the North Sea is a well known example of this. (Allen, 1916; Garstang, 1926.) The slower growth on crowded banks has generally been assigned to the greater competition for food which takes place when overcrowding occurs on a limited feeding area.

In examining the effect of crowded conditions on the growth of *Tivela* we have been fortunate in having available, material from the

⁵ Weymouth's figures are from an extensive series of measurements of clams collected from the Pismo-Oceano Beach and include both ring lengths and total winter lengths of clams of a large number of ages and year classes. Our figures for the 1919 class are from the total lengths of 103 clams collected from the Pismo-Oceano Beach at Oceano on November 25, 1924, and the figures for the commercial catch are from ring lengths and total lengths of clams collected by a number of commercial diggers at Pismo and Oceano in November, 1926.

TABLE 4

Growth of Clams From Different Year Classes*

Ring No.	Weymouth's norm					1919 class					1924 class					P. E. D.		
	No.	Mean length M _s	P. E. M.	σ	Annual growth	No.	Mean length M ₁₉	P. E. M.	σ	Annual growth	No.	Mean length M ₂₄	P. E. M.	σ	Annual growth	M _s M ₁₉	M _s M ₂₄	M ₁₉ M ₂₄
I.....	241	2.166	±0.021	0.048	2.166	103	2.529	±0.007	0.558	2.529	143	1.879	±0.015	0.268	1.879	±0.013	±0.056	±0.040
II.....	251	4.534	±0.031	0.709	2.368	103	4.887	±0.041	0.619	2.364	78	4.263	±0.036	0.477	2.384	±0.051	±0.048	±0.055
III.....	259	6.547	±0.042	1.009	2.013	103	7.250	±0.046	0.692	2.343	.....	.....	.....	.....	.....	±0.052	.....	.....
IV.....	257	8.448	±0.047	1.128	1.901	103	8.563	±0.057	0.702	1.725	.....	.....	.....	.....	.....	±0.066	.....	.....
V.....	287	10.228	±0.045	1.150	1.780	103	10.428	±0.045	0.684	1.475	.....	.....	.....	.....	.....	±0.064	.....	.....
VI.....	119	11.099	±0.055	1.055	0.811	103	11.609	±0.047	0.715	1.172	.....	.....	.....	.....	.....	±0.080	.....	.....
VII.....	63	12.009	±0.071	0.834	0.537	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
VIII.....	83	12.945	±0.061	0.821	0.536	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
IX.....	9	12.978	±0.109	0.485	0.033	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
X.....	53	12.930	±0.098	0.924	0.852	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
XI.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
XII.....	48	14.317	±0.065	0.671	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
XIII.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
XIV.....	40	14.725	±0.087	0.814	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

* All measurements in centimeters.

TABLE 4

Growth of Clams From Different Year Classes

exceedingly numerous year class of 1919. These clams before they were materially affected by the fishery were so numerous that at Oceano, in the central part of the intertidal zone, they formed a veritable pavement a few inches below the surface of the sand. In the fall of 1920, when they were in their second summer, our cross-sections show that throughout the range of their distribution in the intertidal zone at Oceano the clams averaged about 120 per square meter, while in the area of greatest concentration they averaged about 340 per square meter. We would therefore expect that if the growth rate of *Tivela* is affected by the degree of concentration, it should be evident in the growth of the 1919 class.

We have made a series of measurements of 103 clams of the 1919 class from our 1924 cross-sections. The averages of these measurements for each winter ring are shown in table 4 compared to the corresponding ring diameters obtained by Weymouth, and the two series have been plotted in figure 4 to facilitate the comparison of the growth curves for the two samples. Weymouth's averages were made from an extensive series of measurements from clams of a large number of sizes and year classes collected at Pismo and Oceano. From these two curves it can be clearly seen that the size of the clams of the 1919 class at any age was distinctly greater than the value obtained by Weymouth.

In the same figure we have shown the average ring diameters for clams of the 1924 class as determined by measurements of between 80 and 140 specimens. This class is much less numerous than was the 1919 class at a corresponding age, but it is at present the dominant group in the intertidal zone at Oceano. In contrast to the 1919 class the clams of the 1924 class are definitely smaller at any age than the value shown by Weymouth's norm.

These measurements based on the ring lengths do not necessarily represent the actual yearly growth of the clam, inasmuch as the time at which the rings are formed may vary four or five months from year to year.

We can find evidence of this variability in the time at which the winter ring is formed. For instance, the length of ring I as determined from 998 clams of the 1919 class collected in 1920 was 2.984 cm., while the total lengths of clams of the 1919 year class as determined from samples collected at Oceano every month during the fall, winter and spring of 1919–1920, did not reach 2.984 cm. until the latter part of March, 1920. In other words, the first winter ring of the 1919 class must have been laid down about March, 1920. (Data from Weymouth, 1923.) Compared to this, ring II of the 1919 class was apparently formed as early as November, 1920. That is, the average length of ring II of the 1919 class from 41 clams collected at Oceano in 1921 was 5.215 cm., and the total lengths of 1919 clams from samples collected monthly from this beach during the fall and winter of 1920–1921 reached this size during November, 1920. Because of the very inadequate material these results can do nothing more than suggest the degree of variability in the time at which the winter rings may be formed.

Because of this variability the difference between the lengths of successive winter rings does not usually represent one year's growth. If one ring is formed in March, 1920, and the next in November, 1920, the

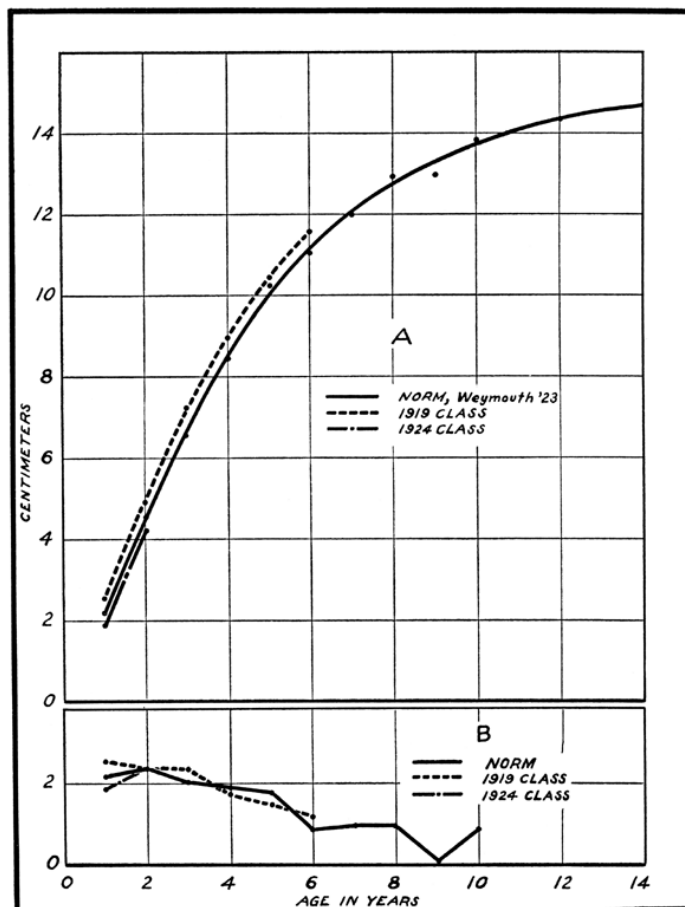


FIG. 4. Growth of clams from different year classes.
A—Average length of annual winter rings.
B—Annual increase in length.

FIG. 4

ring lengths represent the growth for eight or nine months rather than for twelve. Similarly the difference may represent the growth for fifteen months. It is true that the growth during the winter months is much less rapid than during the summer, but it is sufficient to produce a considerable difference from this cause.

As a result a growth curve constructed from the successive ring lengths of a single year class does not represent year by year the actual growth of the clams. However, because of the compensating nature of the variability (*i.e.*, long period between formation of rings one season must be preceded and followed by shorter periods), the trend of the curve over a considerable number of years will approach the true growth of the sample used.

Consequently the growth of the 1919 class as determined from ring measurements of a sample collected in 1924 should approximate in trend the actual growth of these clams. The data for the 1924 class on the other hand are for but two years, and are therefore much less significant.

To obtain an actual measure of the annual growth of any year class it would be necessary to measure at the same time each year an adequate sample of the clams. Unfortunately, we have not been able to do this, but we do have material available for samples collected in October and November of several years. This material is given in table 5.

TABLE 5
Ring Lengths Compared to Total Winter Lengths

1919 class							
Ring No.	Ring length collected in 1924			Total length			
	No.	M.	P.E.M.	Collected	No.	M.	P.E.M.
I.....	103	2.523	± 0.037	Nov. 7- 8, 1919	101	2.384	± 0.017
II.....	103	4.887	± 0.041	Oct. 9-11, 1920	141	4.956	± 0.031
III.....	103	7.230	± 0.046				
IV.....	103	8.953	± 0.047				
V.....	103	10.428	± 0.045	Oct. 24, 1923	325	10.631	± 0.026
				Nov. 25, 1924	169	11.635	± 0.034
1924 class							
I.....	143	1.879	± 0.015	Nov. 25, 1924	65	1.772	± 0.023
II.....	78	4.263	± 0.036	Oct. 30, 1925	54	4.126	± 0.035
III.....				Nov. 17, 1926	41	5.666	± 0.074

TABLE 5
Ring Lengths Compared to Total Winter Lengths

The averages, as might be expected, differ in some cases considerably from the ring diameters of the corresponding year classes. They agree with the ring diameters, however, inasmuch as in every case these lengths are greater in the case of the 1919 class and less for the 1924 class than those shown by Weymouth's norm. The differences found between the total diameter and ring diameter for the same year class might be expected, as the winter ring may have been formed several months after the date of collection of the sample used for determining the total diameter or it may have been forming at that time. It also must be considered that the samples were taken over a period of three and six years and will consequently show, to a varying degree, the effect of sampling errors and of selective fishing.

This comparison of the growth of the 1919 and 1924 classes with Weymouth's norm fails to show any marked effect on the mollusk of the dense population in the beach, especially during 1919 to 1924. The trend of the growth of the 1919 class appears to be about the same as the average, with difference in length at any age apparently due to a somewhat greater growth during the first three years.

5.2. Effect of selective fishing on the apparent growth rate

In the Pismo clam fishery, where a small bag limit is in force and the catch is sold by the pound, the large clams are at a premium and there is consequently a constant selection for size. This selection is particularly severe when the clams are reaching legal size, for at that time the larger individuals of any year class reach this size first and may be taken by the diggers long before the smaller clams are available.

As a result, our determinations of growth made from one to four-year-old clams are based on measurements of individuals not yet of legal size, which have consequently experienced little such selection. The remainder of our determinations are based on measurements of older clams which, for a varying length of time, have been exposed to the fishery where there is taking place this constant selection, especially pronounced during the time when the clams were first reaching legal size.

The result is that in any year class the fast growing clams are taken more rapidly than the slow growing individuals, with a consequent decrease in the average size of the remaining population.

In 1923 and 1924 we obtained from our cross-sections at Oceano, samples of a population which was undergoing such selective fishing as its members were passing the size of legal protection. In 1923 but a small part of the numerous 1919 class was of legal size, but by the summer of 1924 a large proportion had reached a sufficient size to be subject to the fishery. Consequently, our cross-sections made in the fall of 1923 and 1924 gave us samples from a population before and after the selective fishing in 1924 took place.

Unfortunately no material is available for 1922, and in 1925 the numbers of the dominant 1919 class had been so depleted that an adequate amount of data is not available for the study of the effect of selection. We have, however, been able to determine the growth of this class during the first two years, from material collected by Weymouth in 1921, and therefore before the clams had been subject to the fishery.

We have shown in table 6 and figure 5 the results obtained from the examination of these data. The 1921 curve was obtained from the tables given by Weymouth (1923) ; the 1923 curve is from measurements of 57 clams taken in our cross-sections in the fall of 1923; and the 1924 curve is from measurements of 103 clams from our cross-sections in the fall of 1924. The material in all cases comes from the intertidal zone of the same part of the beach at Oceano. The fifth ring in the 1923 data is from the total length of the clams collected in the latter part of October, 1923, before the winter ring had formed, and is, therefore, less than the actual ring diameter. Similarly the sixth ring for the 1924 data is from the total length of clams collected in the latter part of November, 1924.

TABLE 6

Growth of Clams of the 1919 Class as Shown by Material Collected in 1921, 1923 and 1924 *

Ring No.	1919 class in 1924					1919 class in 1923					1919 class in 1921					P. E. D.		
	No.	Mean length M ₁₁	P. E. M.	σ	Annual growth	No.	Mean length M ₁₁	P. E. M.	σ	Annual growth	No.	Mean length M ₁₁	P. E. M.	σ	Annual growth	M ₁₁ M ₁₁	M ₁₁ M ₁₁	M ₁₁ M ₁₁
I.....	103	2.523	± 0.037	0.558	2.523	57	2.672	± 0.044	0.493	2.672	41	2.771	± 0.056	0.532	2.771	± 0.057	± 0.067	± 0.051
II.....	103	4.387	± 0.041	0.519	2.364	57	5.103	± 0.050	0.559	2.437	41	5.214	± 0.068	0.602	2.445	± 0.065	± 0.079	± 0.084
III.....	103	7.230	± 0.046	0.602	2.343	57	7.438	± 0.057	0.640	2.329						± 0.073	.....	.....
IV.....	103	8.383	± 0.047	0.702	1.722	57	9.167	± 0.058	0.951	1.729						± 0.075	.....	.....
V.....	103	10.428	± 0.045	0.684	1.475	57	10.525	± 0.061	0.678	1.358						± 0.076	.....	.....
VI.....	103	11.600	± 0.047	0.715	1.172	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

• All measurements in centimeters.

TABLE 6

Growth of Clams of the 1919 Class as Shown by Material Collected in 1921, 1923 and 1924

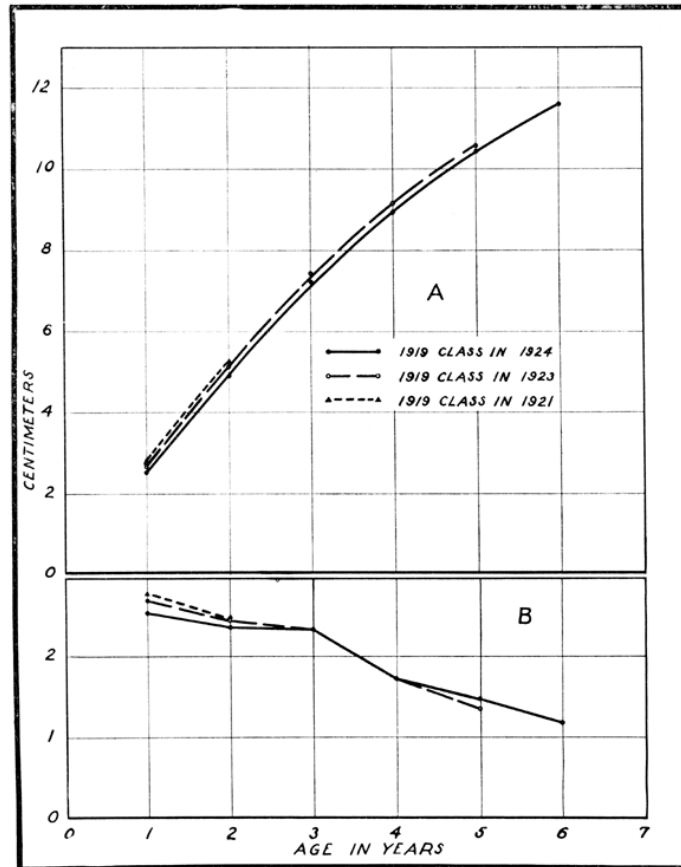


FIG. 5. Growth of clams of the 1919 class as shown by material collected in 1921, 1923 and 1924.
A—Average length of annual winter rings.
B—Annual increase in length.
Note that the vertical scale in B is twice that in A.

FIG. 5

The growth curves obtained show a distinct difference, the clams measured in 1921, before any selection for size by the fishery had taken place, are the largest age for age; the 1923 clams taken after some selection during the preceding summer come next; and the 1924 clams from a population which had experienced a year of intense selective fishing are the smallest. While the size of the samples is in each case too small to make the differences of mathematical significance, yet the consistent difference of two to four probable errors between the mean lengths makes it appear that the divergence in our samples represents a true condition in the populations from which they were collected.

The consistent decrease in the length of ring I from year to year is perhaps the most striking of the changes shown. The figures from table 6 for ring I, together with measurements made by Weymouth in 1920, are given in table 7 for the Pismo-Oceano Beach.

TABLE 7
Total Length in Different Years of Ring I of 1919 Year Class ^a

Time collected	No.	Length	P.E.M.
February-June, 1920.....	498	3.023	-----
July-November, 1920.....	500	2.947	-----
July, 1921.....	41	2.771	±0.056
October, 1923.....	57	2.672	±0.044
November, 1924.....	103	2.523	±0.037

^a Data for 1920 and 1921 from Weymouth; those for 1923 and 1924 from our cross-sections.

TABLE 7
Total Length in Different Years of Ring I of 1919 Year Class

This decrease in the size of the winter rings with increase in age will affect our determinations of growth as made from the old clams. The growth rate obtained from these clams will be less than that obtained from young specimens. Whether this decrease is entirely due to a selective mortality exercised by the fisheries or whether it is partially, at least, natural is impossible to say from the limited amount of data which we have. It is also quite possible that this decrease in average size of the rings with older clams may be, to a greater or less extent, the result of a tendency when reading the ages to include false checks as winter rings more frequently in the old clams than in the

TABLE 8
Growth of Clams from the Commercial Catch Compared to Weymouth's Norm

Ring No.	Weymouth's norm				Commercial catch, November, 1926				P.E.D. M _n M _e
	No.	Mean length M _n cm.	P.E.M. cm.	σ cm.	No.	Mean length M _e cm.	P.E.M. cm.	σ cm.	
I.....	241	2.166	±0.021	0.478	11	2.518	±0.122	0.601	±0.124
II.....	251	4.534	±0.031	0.709	11	4.900	±0.167	0.824	±0.170
III.....	259	6.547	±0.042	1.009	11	7.155	±0.215	1.057	±0.219
IV.....	257	8.448	±0.047	1.128	11	9.082	±0.247	1.216	±0.252
V.....	287	10.228	±0.045	1.130	12	11.067	±0.208	1.069	±0.213
VI.....	119	11.069	±0.065	1.055	16	12.306	±0.136	0.807	±0.151
VII.....	63	12.006	±0.071	0.834	18	12.812	±0.111	0.701	±0.132
VIII.....	83	12.945	±0.061	0.821	56	13.473	±0.070	0.784	±0.093
IX.....	9	12.978	±0.109	0.485	7	13.629	±0.197	0.772	±0.225
X.....	33	13.830	±0.098	0.824	-----	-----	-----	-----	-----
XI.....	-----	-----	-----	-----	-----	-----	-----	-----	-----
XII.....	48	14.317	±0.065	0.671	-----	-----	-----	-----	-----

TABLE 8
Growth of Clams from the Commercial Catch Compared to Weymouth's Norm

young. Such a tendency would slightly decrease the average size at any age of the old clams with a resulting decrease in calculated growth rate.

In figure 6 we have shown the data from the measurement of clams taken from the sand bars and from the area well out in the surf. The material obtained was scanty and the points on the curve are based on measurements of from 11 to 56 individuals each.

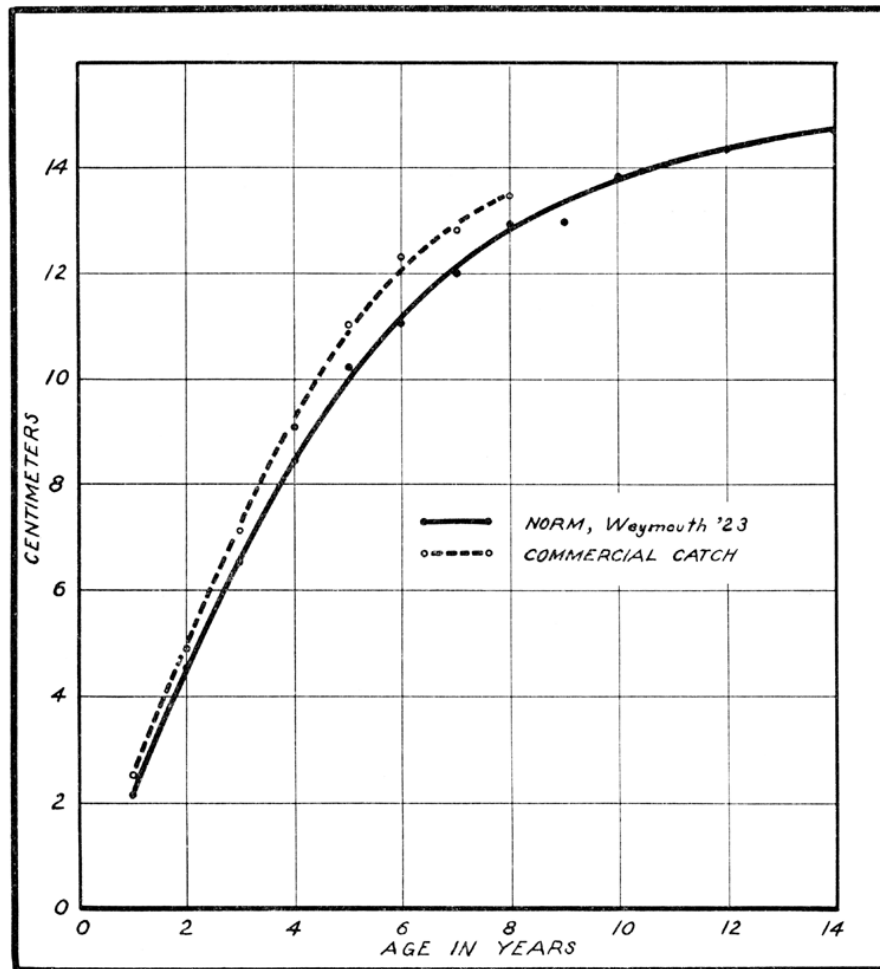


FIG. 6. Growth curve for a sample of clams from the commercial catch compared to Weymouth's norm.

FIG. 6. Growth curve for a sample of clams from the commercial catch compared to Weymouth's norm

The difference in the growth of these clams from the growth as represented by Weymouth's curve may be due to the fact that all the clams from which these determinations were made came from the areas which offer natural protection to the clam population and were therefore subject to much less intensive fishing with its accompanying selection than the clams from the intertidal zone. A greater amount of material from the sand bars and outer areas is necessary before any definite conclusions can be reached.

5.3. Rate of growth on different beaches

In 1925 and 1926 a special effort was made to collect a sufficient number of Pismo clams from the beaches at Morro and Monterey to make possible the construction of growth curves for the populations of these beaches. At present we have measurements from several hundred clams from each beach and although the data from the older clams are rather scanty, the growth curves are representative, especially for the first six or eight years. The material from Morro is from several collections made in 1924, 1925 and 1926, and comes from the commercial catch and from our own digging in the intertidal zone and sand bars. The material from Monterey Bay was collected in the spring of 1927 and is made up in a manner similar to that from Morro. Because of the varied origin of the samples, the material should be quite representative of the respective populations as a whole.

TABLE 9
Growth on Different Beaches
Ring lengths of clams collected at Turtle Bay, Pismo and Oceano, Monterey and Morro

Ring No.	Monterey				Turtle Bay			
	No.	Mean length cm.	P.E.M. cm.	σ cm.	No.	Mean length cm.	P.E.M. cm.	σ cm.
I.....	152	1.917	± 0.020	0.362	19	2.200	± 0.057	0.367
II.....	139	4.370	± 0.035	0.617	27	5.037	± 0.060	0.461
III.....	95	6.597	± 0.056	0.810	27	7.600	± 0.052	0.404
IV.....	81	8.422	± 0.058	0.770	3	9.533	± 0.097	0.249
V.....	73	9.851	± 0.054	0.684				
VI.....	65	10.859	± 0.056	0.668				
VII.....	45	11.531	± 0.058	0.580				
VIII.....	24	12.146	± 0.062	0.453				
IX.....	9	12.642	± 0.129	0.573				
X.....	9	12.989	± 0.146	0.652				
XI.....	4	13.325						
XII.....	3	14.000						
XIII.....								
XIV.....								
XV.....								
XVI.....								

Ring No.	Pismo-Oceano				Morro			
	No.	Mean length cm.	P.E.M. cm.	σ cm.	No.	Mean length cm.	P.E.M. cm.	σ cm.
I.....	241	2.166	± 0.021	0.478	136	1.515	± 0.020	0.344
II.....	251	4.534	± 0.031	0.709	109	3.705	± 0.026	0.395
III.....	259	6.547	± 0.042	1.009	65	5.509	± 0.040	0.481
IV.....	257	8.448	± 0.047	1.128	47	7.277	± 0.066	0.668
V.....	287	10.228	± 0.045	1.130	39	8.915	± 0.097	0.896
VI.....	119	11.069	± 0.065	1.055	32	10.578	± 0.102	0.855
VII.....	63	12.006	± 0.071	0.834	17	11.376	± 0.118	0.725
VIII.....	83	12.945	± 0.061	0.821	13	12.131	± 0.123	0.656
IX.....	9	12.978	± 0.109	0.485	7	12.400	± 0.138	0.543
X.....	33	13.830	± 0.098	0.824	5	12.700	± 0.123	0.410
XI.....					3	12.833		
XII.....	48	14.317	± 0.065	0.671	2	12.900		
XIII.....					2	13.100		
XIV.....	40	14.725	± 0.087	0.814	1	13.500		
XV.....					4	13.150		
XVI.....								
XVII.....					3	14.000		
XVIII.....					3	13.600		
XIX.....					3	14.600		

TABLE 9
Growth on Different Beaches
Ring lengths of clams collected at Turtle Bay, Pismo and Oceano, Monterey and Morro

The results obtained from an analysis of the data are tabulated in table 9, together with similar data for Turtle Bay, Lower California, and the Pismo-Oceano Beach. The material for the latter two beaches is from Weymouth (1923). The growth curves for the four beaches are shown in figure 7.

From these curves it appears that, for the first four years, the growth of the Turtle Bay clams is greatest and the Morro clams least, with

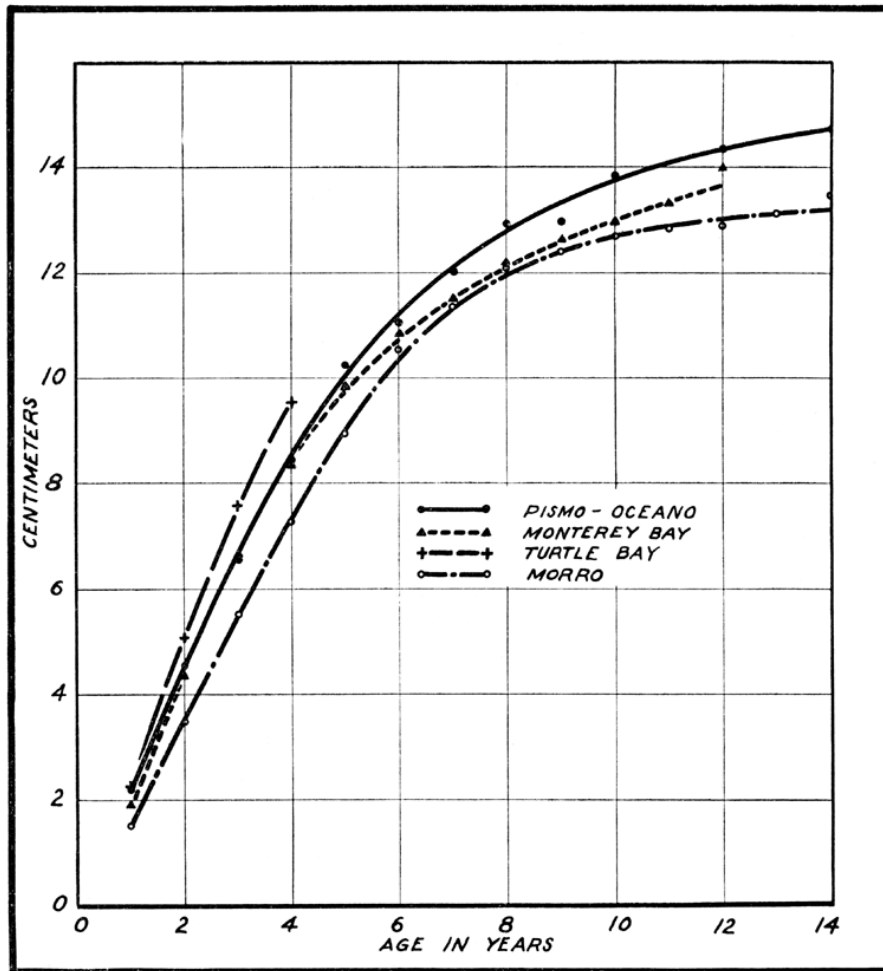


FIG. 7. Growth curves for Pismo clams from Pismo-Oceano Beach, Morro Beach, Monterey Bay and Turtle Bay.

FIG. 7. Growth curves for Pismo clams from Pismo-Oceano Beach, Morro Beach, Monterey Bay and Turtle Bay the Monterey and Pismo-Oceano clams nearly equal and intermediate between the two others. Subsequent to the fourth year the growth of the Pismo-Oceano clams is the most sustained, and the clams of this beach reach the largest size. The Morro clams show the most rapid decrease in rate of growth, while the curve for the Monterey clams falls between the other two. In comparing the curves it must be borne in mind that after the seventh or eighth year the average length

are not very reliable because of the small number of clams on which they are based.

In the study of the growth of a number of marine animals it has been found that, within the same species, the populations from the northern part of the range show a slower growth rate than those from the southern part. This is true of the plaice of the North Sea (Allen, 1916) and the halibut of the North Pacific (Thompson, 1914). In the growth of the razor clam of the Pacific coast it has been found by Weymouth and McMillin (unpublished manuscript) that the most rapid early growth is shown by the clams from the southern part of the range and the slowest early growth by those from the northern beaches. After the first years the growth of the southern clams rapidly decreases, but that of the northern clams is more sustained, with the result that a greater final size is reached by the northern than by southern forms. The populations of beaches between the northern and southern parts of the range of the razor clam show a graduated difference in growth between the two extremes.

In view of the results obtained by these investigators it is interesting to note the lack of a similar tendency in our curves for Turtle Bay, Pismo-Oceano, Morro and Monterey Bay. The most rapid early growth is found at Turtle Bay, the most southern of the beaches for which we have growth curves. The slowest early growth is found at Morro, while the curve for Monterey, near the northern limit of the range of *Tivela stultorum* falls between the two extremes and is about equal to the early growth on the Pismo-Oceano Beach. The most sustained growth during the later years is found at Oceano and Pismo, and the slowest at Morro, a locality but thirty or forty miles northwest of the Oceano Beach. The growth for Monterey again falls between the two extremes.

Judging from the material at hand it appears that in the case of *Tivela stultorum* there is no marked connection between the growth rate and latitude. It is possible that if more adequate material was collected from the beaches at Turtle Bay, Morro and Monterey that the results might be altered. The material from both Monterey and Morro, however, was collected from varied locations and year classes and should be fairly representative of the respective populations. Unfortunately it is very difficult or impossible to obtain adequate samples from additional populations intermediate between those sampled. On the beaches other than those from which we have already obtained data, the Pismo clam is either scarce or entirely absent.

6. 6. FLUCTUATIONS IN ABUNDANCE

Judged from the point of view of the State and conservation, probably the most important problem which we face in the study of the Pismo clam is the positive demonstration of the fluctuations in the abundance of this mollusk and the explanation of their cause. Once it has been made clear that the clam population has experienced decided fluctuations, and the cause of these fluctuations has been assigned to either depletion or natural variation in numbers, we can then intelligently enact measures to best conserve the supply for the future. Accordingly, it is with these questions in mind that we take up the discussion of the fluctuations in abundance of *Tivela stultorum* on the California beaches.

6.1. Source of material

The material which we have used is primarily from two distinct sources representing areas whose populations are quite different in composition. One of these is the material collected from the cross-sections made annually on the most important Pismo clam beaches. This material furnishes representative samples of the population of the intertidal zone, the area extending from the high tide mark out to the water's edge at extreme low tide. The set of small clams is, according to all available evidence, entirely confined to this area, and the clams remain there until they are washed free from the sand and into deeper water by heavy surf or are killed by either natural or human enemies.

Because of the accessibility of the intertidal zone to the clammers, there exists in such an area a very intensive fishery, with the result that a clam, after reaching legal size, has little chance to long escape the diggers. The population of this area consequently is made up in large measure by clams under the legal size limit. For example, in the material collected from the Oceano cross-sections the percentage of clams below the legal size limit was 97 per cent in 1923, 82 per cent in 1924, 96 per cent in 1925, while in 1926 they were all below the legal limit. This condition in the intertidal zone is not a natural one. In former years before man began taking such great numbers from this area there must have been many large clams found there.

The second important source of material is the commercial catch, from which samples have been taken in 1924, 1925 and 1926. In addition to these samples we have records available, in the files of the Division of Fish and Game, giving by months the total shipments of clams from the principal Pismo clam beaches. The commercial catch is taken by experienced diggers, chiefly from the sand bars, but with a varying amount coming from the lower levels of the beach where a clammer must work in water up to his waist or neck and with the surf breaking and pounding over him. Under certain conditions, such as storms, unfavorable tides, or the greater abundance of large clams in the intertidal zone, digging on the bars may be impossible or less profitable than in the intertidal zone and a greater part of the commercial catch may then come from the inshore beach instead of the sand bars. Such conditions are abnormal, however, and affect the catch for but short periods.

The clam population of the sand bars and offshore beach area, from which the commercial catch chiefly comes, is quite different in its composition from that of the intertidal zone. It is made up to a great extent of large clams and obtains its accessions through the action of the heavy surf in washing specimens from the intertidal population into deeper water. The bulk of the clam population, however, ordinarily remains in the intertidal zone until taken, and the members of the relatively small population of the sand bars and offshore areas are able to survive and reach a large size only because the difficulties and dangers involved in fishing these areas cause the fishery to be much less intense than in the intertidal zone.

The commercial catch is not truly representative of the population from which it is taken, for it is necessarily composed of individuals which have attained legal size, and, therefore, gives no representation

TABLE 10
Number of Pismo Clams of Each Year-Class Obtained from the Oceano Cross-Sections Since 1918^a

Date	Before 1918	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	Totals
Sept. 11, 1919	0	16	704									720
Nov. 23, 1920	0	4	490	1								495
July 23, 1921	0	42	418	2	0							462
Aug. 25, 1922	0	31	465	13	12	3						524
Oct. 24, 1923	2	11	317	20	6	29	1					386
Nov. 25, 1924	0	6	169	5	11	31	7	65				294
Oct. 30, 1925	0	0	5	1	2	4	3	54	5			74
Nov. 17, 1926	0	0	0	0	0	3	2	41	2	3		51
Nov. 9, 1927	0	0	0	0	0	1	0	8	6	11	19	45
Totals	2	110	2,568	42	31	71	13	158	13	14	19	3,051

^a The sections were 16 cm. wide.

TABLE 10
Number of Pismo Clams of Each Year-Class Obtained from the Oceano Cross-Sections Since 1918

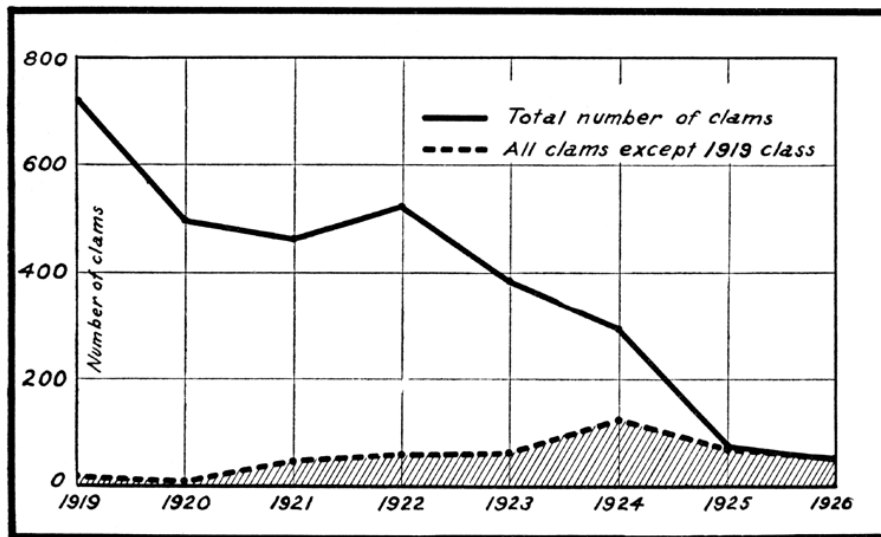


FIG. 8. Showing the influence of the dominant year class of 1919 on the abundance of clams in the intertidal zone at Oceano Beach. The area between the solid and dotted line represents the number of clams from the 1919 year class, the cross-hatched area below the dotted line represents the number of clams from all other year classes. Data from Oceano cross-sections (1919-1926).

FIG. 8. Showing the influence of the dominant year class of 1919 on the abundance of clams in the intertidal zone at Oceano Beach. The area between the solid and dotted line represents the number of clams from the 1919 year class, the cross-hatched area below the dotted line represents the number of clams from all other year classes. Data from Oceano cross-sections (1919-1926)

to the smaller clams which may be present. It does, however, give a sample of the large clams, and as the results of our own collections made in deep water and on the sand bars indicate that the population there is chiefly above legal size, the commercial catch at present can be accepted as representing the most important part of this population.

6.2. Evidence of fluctuations in abundance

The material from our annual cross-sections gives us the truest representation of the number of clams to be found in the beach, and we will first examine these data for evidence of major changes in the population of the intertidal zone. In the right-hand column of table 10 is shown the total number of clams obtained from our Oceano cross-sections for each year from 1919 to 1926. The data are also shown in graphic form in figure 8.

Consideration of these data shows that during the given period the greatest number of clams was found in the intertidal zone at Oceano in 1919 and that this number experienced a fairly steady decrease to a minimum in 1926, a drop of 93 per cent in seven years. That these figures are reliable and not subject to large errors from sampling is attested by the consistency of the results and by the material from

TABLE 11
Number of Pismo Clams of Each Year-Class Obtained from the Pismo Cross-Sections Since 1922^a

Date	Before 1918	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	Totals
Oct. 23, 1923-----	0	4	25	0	15	25	-----	-----	-----	-----	-----	69
Oct. 28, 1924-----	2	3	1	8	11	7	3	188	-----	-----	-----	223
Nov. 1, 1925-----	0	0	0	2	2	11	1	192	0	-----	-----	208
Nov. 19, 1926-----	0	0	0	0	0	0	1	27	3	46	-----	77
Nov. 10, 1927-----	0	0	0	0	0	0	0	8	5	37	15	65
Totals-----	2	7	26	10	28	43	5	415	8	83	15	642

^a The sections were 16 cm. wide.

TABLE 11
Number of Pismo Clams of Each Year-Class Obtained from the Pismo Cross-Sections Since 1922

check sections constructed parallel to and at some distance to one side of the regular sections.

The data here presented for Oceano Beach are representative only of that locality. About five miles south of the Oceano location, cross-sections made in 1925 and 1926 produced 74 and 73 per cent, respectively, as many clams as were obtained from the similar sections at Oceano. For Pismo we have data which are given in table 11, for the years 1923–1927. Sections from this beach produced the greatest number of clams in 1924, but since that time the number has shown a rapid decrease. For Morro and Monterey, our cross-section data are very scanty, but such as there are indicate that on these beaches the population of the intertidal zone is small, and that it undergoes fluctuations similar to those found at Oceano and Pismo. The results of all our Oceano cross-sections may be found tabulated in the appendix.

For indications of fluctuations in the abundance of clams beyond the intertidal zone and on the sand bars we must rely on our records of the commercial catch. In figure 12 we have shown the amount of the commercial shipments for the periods 1916–1926. These records give us a measure of the fishery over a longer period than do the results of our cross-section work, but because of numerous modifying factors they do not give us a true picture of the clam population of the areas which they represent. In the first place, our records of commercial catch include only those amounts which are shipped to distant customers by express. This includes practically all of the clams shipped to distant points by licensed diggers, but of the clams used by restaurants and hotels in the beach towns and nearby cities, we have no record. Such economic conditions as market and price must also affect the commercial catch and warp the picture which it gives of the abundance of the clam population. Consequently the fluctuation in the commercial shipments may represent fluctuations either in economic conditions or in the clam population from which the commercial catch is taken or a combination of the two.

These records from our cross-section samples and from the commercial catch indicate that in the past there have been important fluctuations in the Pismo clam population. In the intertidal zone our samples give positive evidence that great fluctuations have taken place, while fluctuations in the commercial shipments suggest the effect of changing economic conditions combined with a varying abundance of clams.

In addition to the data which we obtain from the cross-sections and commercial catch, we have the general evidence which can be obtained from the observations of old clam diggers and residents. It is common report that in former years the clams were at times so abundant that they were turned up on the beach by means of plows and hauled away by the wagon-load to be used as food for hogs and chickens. (Weymouth, 1923.) Then again in the period from 1917–1918 there is reported an exceptional abundance followed by a period of increased scarcity. Although the source of these reports can not be considered highly dependable, yet when we find them in such complete accord they do serve as a corroboration of the results which we have obtained from an examination of the commercial catch and cross-section samples.

6.3. Causes of fluctuations in abundance in the intertidal zone

The important changes in the clam population, which we have observed through the medium of the commercial catch and our cross-section samples must be due either to natural changes in the environment or to the effect of the strain imposed on the population by man. If they are natural fluctuations, then no curtailment of man's activities will eliminate them and the present scarcity can be removed only through an improvement in natural conditions. On the other hand, if the past fluctuations and the present scarcity are due to the effects of human activities, it may be that curtailment of such activities is the only means by which the abundance of the species can be increased or even prevented from entirely disappearing.

Our observations of the clam population by means of cross-sections have been carried on for eight years, and it is the material collected in this way which gives us our most detailed picture of the changes which have taken place in the population. The curves in figure 9 show the length-frequencies for the samples collected in 1923–1925, inclusive. We do not have the size-frequencies for the samples collected previous to 1923.

These length-frequency curves give us a good representation of the different year classes for the smaller sizes when the growth rate is high, but in the case of the older clams when the growth has slowed down the size groups overlap to such an extent that it is impossible to differentiate between age groups. In the case of highly dominant year classes the size group may be so large that it completely covers the smaller groups both above and below it. Such is the case in the 1923 curve. The first small mode on the left represents the 1923 class, the second the 1922 class, the third the 1921 class, and the next large mode includes all classes from 1920 up. A somewhat similar condition exists in the 1924 sample.

The feature of the length-frequency curves, which is of greatest interest, is the great mode about the 10.5 cm. length in 1923 and the 11.5 cm. length in 1924. of secondary interest is the fairly large mode

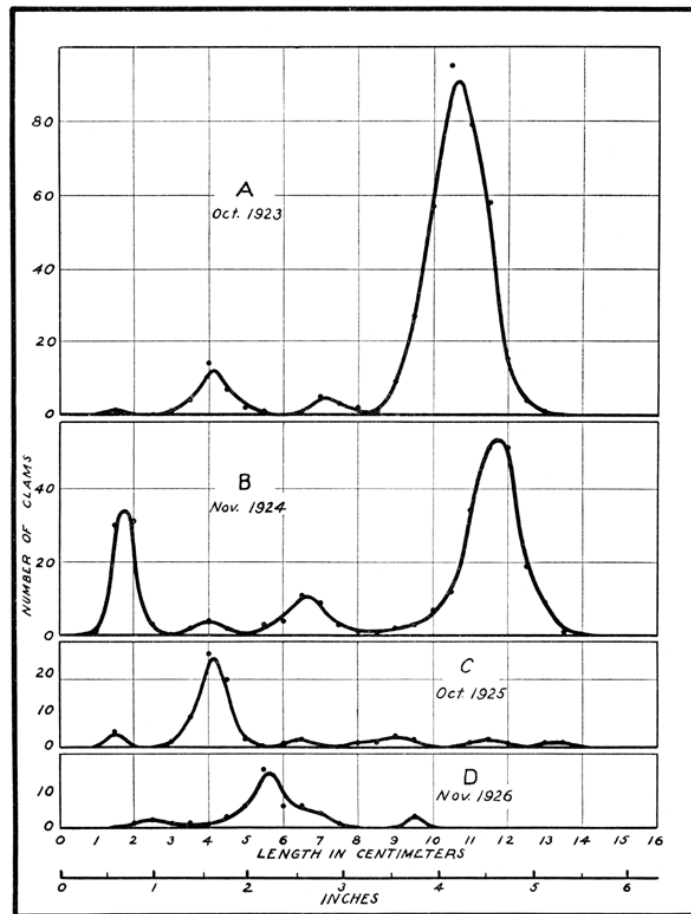


FIG. 9. Length frequency curves for cross-sections made at Oceano in 1923, 1924, 1925 and 1926. In curve A the great mode about the 11 cm. length is almost entirely formed by clams of the great 1919 class. This mode is still present in curve B, representing the cross-section made a year later, but is considerably reduced in numbers. The secondary mode about the 1.8 cm. length in curve B represents the 1924 class spawned during the preceding summer. The 1919 class practically disappears from our samples in 1925 and 1926, and the mode representing the 1924 class moves along in accord with the growth of its members.

FIG. 9. Length frequency curves for cross-sections made at Oceano in 1923, 1924, 1925 and 1926. In curve A the great mode about the 11 cm. length is almost entirely formed by clams of the great 1919 class., This mode is still present in curve B, representing the cross-section made a year later, but is considerably reduced in numbers. The secondary mode about the 1.8 cm. length in curve B represents the 1924 class spawned during the preceding summer. The 1919 class practically disappears from our samples in 1925 and 1926, and the mode representing the 1924 class moves along in accord with the growth of its members

which appears in 1924 and shows a consistent progression in size in 1925 and 1926. This mode which appears in 1924 and progresses through 1925 and 1926 is formed by the class spawned in 1924. The large mode in the 1923 and 1924 curves indicates by its progression the effect of a dominant year class which blankets the smaller age groups both above and below it. The disappearance of this mode in 1925 is related to the legal size limit, which will be discussed later.

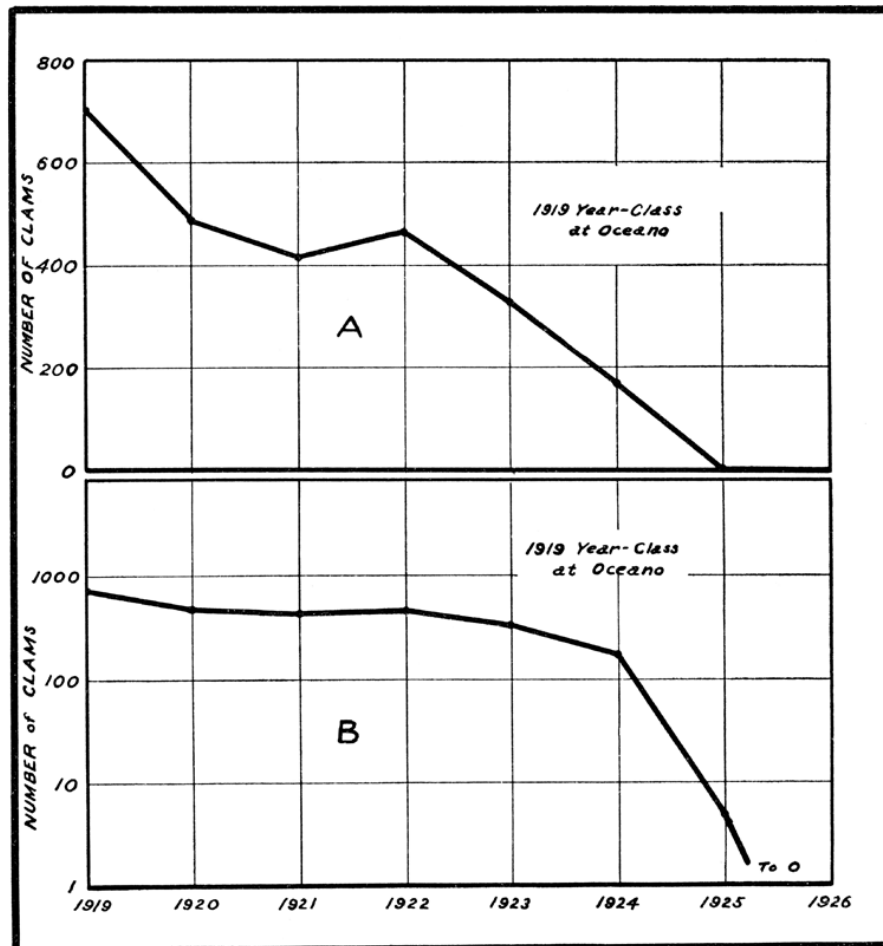


FIG. 10. A—The number of clams of the 1919 class obtained from our Oceano cross-sections in 1919–1926.
B—The numbers from A plotted to a logarithmic scale.

FIG. 10

In order to determine the composition of the large size group in the 1923 and 1924 curves and the cause of its progression in size from year to year, we have made an age analysis of the samples by means of the annual winter rings in the clam shell. These age determinations for the cross-section samples from Oceano in 1919–1927 are given in table 10.

The most interesting feature of these data are the great number of clams found in the 1919 year-class and the relative scarcity of the

members of other year groups. This class appeared in the beach in great numbers in 1919 and held a dominating position in our samples until 1925. The great mode in the 1923 length-frequency curve is made up almost entirely of this numerous class, as is the major mode in the 1924 curve. The progression of the mode from 1923 to 1924 is therefore a result of the growth in size of the members of this great class.

In order to give a graphic picture of the dominating influence of the 1919 year class in the intertidal zone, we have shown in figure 8 a curve representing the annual catch of clams from our cross-sections. The solid line represents the total number of clams taken from the cross-section each year since 1919, and the broken line the number of all clams other than those from the 1919 class. The space between the two curves consequently portrays the proportion of the samples formed by the 1919 class and the cross-hatched space below the broken line represents the proportion of all other clams.

This figure provides a visual picture of the overwhelmingly important part played by the 1919 class in the population of the intertidal zone since the summer of 1919. The appearance in that year of great numbers of clams and the subsequent fluctuations in these numbers in the following years have been almost entirely due to this one dominant year class. The only other class which appears in any appreciable numbers is that of 1924 and it significantly affects the total catch only in 1925 and 1926, after the 1919 class has nearly disappeared.

This examination of our cross-section data has demonstrated that the fluctuations in the population of the intertidal zone since the summer of 1919 have been almost entirely due to the fluctuations in the highly dominant year class of 1919. This class appeared in great numbers in the summer of 1919 and after a rapid decrease in numbers entirely disappeared from our samples in 1926.

In order to more clearly illustrate the history of the class in the intertidal zone a survival curve is shown in figure 10A, formed by plotting the number of clams of the 1919 class obtained each year from our cross-section sample. The high mortality indicated by the survival curve between 1919 and 1920, took place during the first year of the young clams' existence, when, because of their small size, they were more or less at the mercy of heavy storms and natural enemies, such as flatfish, skates and birds. The decrease in numbers shown by our cross-section samples for the following year, to a value for 1921 less than the number found in 1922, may be due to the fact that in 1921 the incoming tide interfered with the construction of the cross-section and the outer part of the clam distribution was obtained from the data by extrapolation. The value given for 1921 is, therefore, only an approximation and may be considerably in error. At any rate the numbers of this year class showed little decrease from 1920 to 1922, but following that year a rapid decline began which continued to 1926, when they entirely disappeared from our samples.

In order to show the rate at which this year class declined, a mortality curve is shown in figure 10B, made by plotting to a logarithmic scale the number of clams found each year. The increasingly rapid decline found in this curve, beginning in 1923 and continuing to 1926,

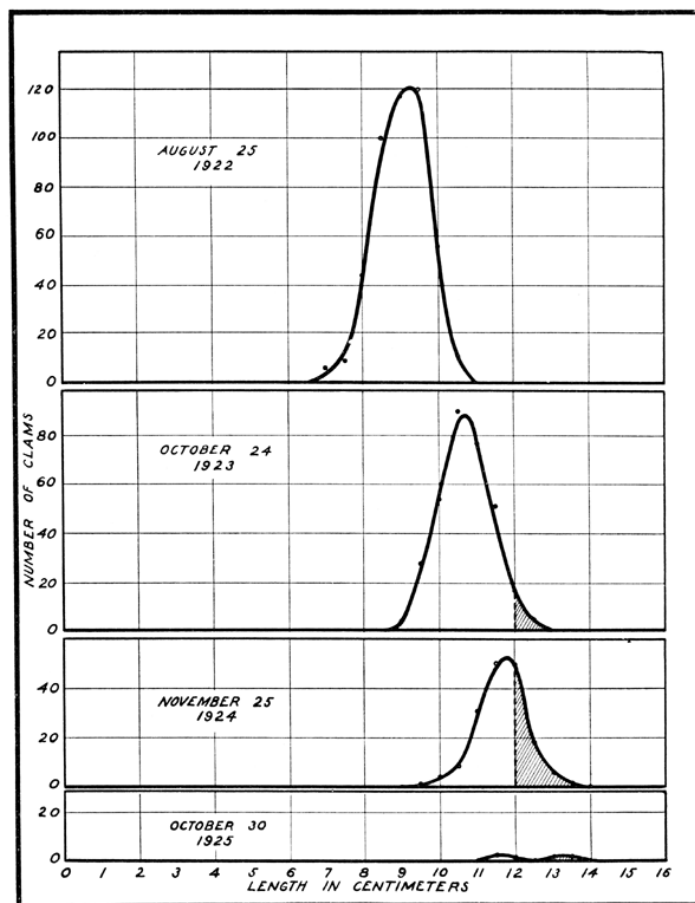


FIG. 11. Length-frequency curves for the clams of the 1919 class taken from the Oceano cross-sections in 1922, 1923, 1924 and 1925. The legal size limit was $4\frac{3}{4}$ inches (about 12 cm.). The cross-hatched area in the 1923, 1924 and 1925 curves represents the clams above legal size.

FIG. 11. Length-frequency curves for the clams of the 1919 class taken from the Oceano cross-sections in 1922, 1923, 1924 and 1925. The legal size limit was $4\frac{3}{4}$ inches (about 12 cm.). The cross-hatched area in the 1923, 1924 and 1925 curves represents the clams above legal size

suggests that in 1923 some change had begun to take place in the population or its environment which caused a rapid increase in the rate of mortality.

An analysis of the length-frequency curves in figure 11 in relation to the legal size limit suggests a probable cause for the rapid decline, beginning in 1923, in the population of the intertidal zone.

The clams used in the construction of these length-frequency curves are from our regular cross-sections constructed late in the fall of each year after most of the intensive fishing was past. During the preceding summer the clam population had been subject to an intensive fishery in which, because of the presence of a minimum legal size limit, there was a constant selection for size. As a result of the time at which the cross-sections were made and the selection of the larger clams by the fishery, the curves represent not the clam population during the summer, but the residual population in the fall after the summer fishery was over.

The presence of a minimum size limit of $4\frac{3}{4}$ inches in all probability did not absolutely limit the catch to clams above this size. There would be a tendency on the part of the diggers to take clams somewhat under the limit. This tendency would be especially pronounced on the part of the tourists, composing much the greater part of the summer diggers in the intertidal zone (see page 55), and who visit the beaches for a short period without equipment to accurately measure the clams they obtain. Consequently in considering the effect of the legal size limit we can not assume that the catch is completely restricted to the clams above $4\frac{3}{4}$ inches, but must also include a fraction of those somewhat under this size.

In view of the above considerations, we must conclude that the length-frequency curves in figure 11 do not represent the clam population which was subject to the heavy fishery during the summer. They represent, however, the part of the population remaining after the removal of a large part of such of the larger clams as were subject to the fishery. Furthermore, in considering the part of the population subject to the fishery we are not justified in including only those clams above the legal size of $4\frac{3}{4}$ inches, but must also consider a part of those falling perhaps as far as one-half to one inch below. This tendency to stray below the limit must have been particularly strong in the summer of 1923, when there were present in the intertidal zone millions of clams just under the legal size limit, with comparatively few above it.

Bearing the above conditions in mind we can now attempt the interpretation of the survival curve for the 1919 class in the intertidal zone of Oceano Beach. (See fig. 10B.) This curve shows, prior to the winter of 1922, a very slight rate of fall. Consulting the length-frequency curve for the late fall of 1922 (see fig. 11) we find that at that time even the largest of the members of the 1919 class were more than one-half inch below the legal size limit and consequently comparatively free from molestation by the clam diggers.

By the following summer and fall the clams had grown sufficiently so that a part of them had attained legal size. This is shown by the length-frequency curve for the material collected in the late fall of 1923, which shows a small fraction of the clams (about 3-4 per cent)

to be of legal size, while a considerable portion of them (41 per cent), were more than 4.25 inches in length. Corresponding to this we find that our survival curve has a suddenly increased drop between the late fall of 1922 and 1923.

During the succeeding year the clams increased sufficiently in size so that in the fall of 1924 about 25 per cent of those remaining in the intertidal zone, after the selective summer fishery, were of legal size, while 90 per cent were over 4.25 inches in diameter. Again we find that in company with this increase in the percentage of legal size clams the survival curve experiences an increased rate of fall between 1923 and 1924.

In the following year (1925) practically the entire 1919 class reached a size which subjected it to the fishery, and in the fall of the year the number left in the beach was almost negligible. A year later (1926) the clams of this class had entirely disappeared from our samples.

There is, in addition to the selective fishery which we have described, another possible cause for the rapid disappearance of the 1919 clams from the intertidal zone as they reach legal size. That is, the young clams after settling in the intertidal zone and remaining there during their early years might, with increase in size, move out into deeper water beyond the intertidal zone. This movement could possibly be a natural habit on the part of the clams or it might be the mechanical result of wave action. If the size at which this hypothetical movement took place approximately coincided with the legal size limit, we would have a decrease in the number of clams of the 1919 year class found in the intertidal zone, such as we find. (See fig. 10.)

Unfortunately we have no samples collected from the intertidal zone for a *Tivela* population untouched by man, and therefore do not know whether, under natural conditions, the older clams are found in large numbers in this area. At present, as our cross-sections have shown, the population of the intertidal zone is made up almost exclusively of clams under legal size.

It appears, however, that the lack of larger clams is more probably the result of the intensive fishery concentrated in this area than of a migration of the clams as they reach a size approximately equal to the legal size limit. The exactness of the coincidence between the legal size limit and the abrupt change in the rate of decrease in the population of the intertidal zone favors the belief that the disappearance of the 1919 class from this zone was largely due to selective fishing rather than to differential migration. This view is also supported by an analysis, which we have attempted, of the size distribution of the clams in the intertidal zone. The analysis, while not yet complete, furnishes evidence that the decline in the 1919 class during 1922–1925 was chiefly the result of selective fishing rather than migration.

If the decline in the 1919 class in the intertidal zone was due to selective fishing, as seems probable, the effect of the size limit becomes striking. It served as a veritable dead line; the clams within its protection were comparatively safe, but once they passed beyond it they were rapidly wiped out.

From this analysis of our cross-section material, it is evident that the fluctuations in the population of the intertidal zone, since our observations began, have been due principally to the effect of dominant year classes combined with selective fishing. The great number of clams appearing in 1919 is a result of the heavy set of young clams in the summer of 1919. The decrease in numbers since that time is due partly to natural mortality, but chiefly to the effect of the fishery. In 1924 another year class, larger than the average, appeared and, until 1926, made up the greater part of the beach population at Oceano and Pismo. It was, however, less than 10 per cent as numerous as the 1919 class at the same age and can be expected to have correspondingly little effect in replenishing the beach.

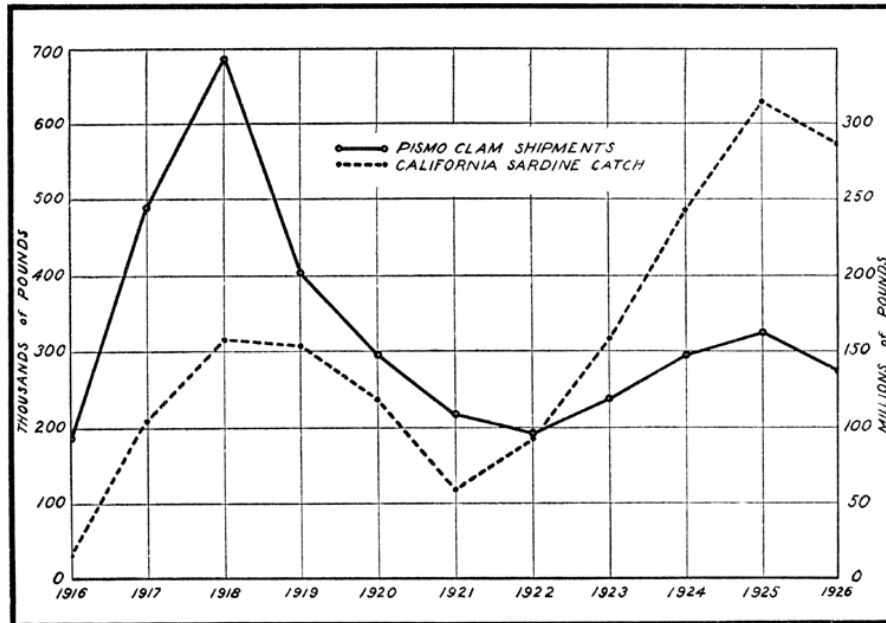


FIG. 12. Fluctuations in the California Pismo clam shipments compared to the fluctuations in the California sardine catch. The clam shipments are plotted against the vertical scale on the left and the sardine catch against the scale on the right.

FIG. 12. Fluctuations in the California Pismo clam shipments compared to the fluctuations in the California sardine catch. The clam shipments are plotted against the vertical scale on the left and the sardine catch against the scale on the right

6.4. Causes of fluctuations in abundance of the commercial catch

The analysis of the cause of the fluctuations in the commercial catch is much more involved than in the case of our cross-section samples. A varying natural abundance of clams, caused by the dominant year classes which our cross-sections so clearly show, may have been the cause of the fluctuations in the catch, or they may be due to changing economic conditions. In addition we must take into consideration two changes in bag limit which took place during the period covered by our data.

In figure 12 is shown the amount of the commercial shipments in pounds for each year from 1916–1926. This curve shows a principal peak for 1917–1919, a minor peak from 1924–1926, and minimum shipments in 1916 and 1922. It is impossible to accurately determine the relative importance of the part that varying abundance and changing

economic conditions have played in causing these fluctuations, but an analysis of our data furnishes some interesting indications.

The period from 1917–1919, during which the largest amounts of Pismo clams were shipped, corresponds to the period of the World War and the consequent high prices and good markets. In 1917 and 1918, following our entrance in the war, there came an intensive campaign for food conservation, when great encouragement was given to the use of sea foods as a substitute for meat. As a result of this and improved markets, a greater effort was made to take advantage of natural food supplies such as the Pismo clam offered. Following the war, from 1919–1922, there came a general slump in markets and we find a corresponding slump in the clam shipments.

The effect of the war period was similarly reflected in the California sardine industry, as was noted by Thompson (1921, p. 200). Quoting Thompson in part: “Almost all sardines which are taken in this country are packed, and the increase in pack is clearly shown. The first great pack was, it is obvious, in 1917. And this corresponds with the great rise in value of sardines in this country, resultant in part from the conditions we have dealt with above, and in part from war conditions considered more generally in their effect on the domestic markets. At the same time, we must remember the great encouragement given to the use of fish during 1917 and 1918 after our entry into the war.”

In order to show the similarity in the fluctuations in the sardine catch and in the Pismo clam shipments since 1916, we have plotted in figure 13 the logarithms of the annual sardine catch together with the logarithms of the annual clam shipments. The two curves

TABLE 12
Commercial Shipments of Pismo Clams Compared to the California Sardine Catch and to General Prosperity as Represented by the Index Numbers of Wholesale Prices

	Pismo clams, pounds	Sardine catch, pounds	Soft-shell clams, pounds	Index numbers	
				Bureau of Labor	Bank of Commerce
1915.....				62	
1916.....	186,654	15,648,839	566,822	75	
1917.....	489,175	104,103,331	422,857	107	
1918.....	687,322	157,652,811	356,043	121	
1919.....	402,510	153,877,179	324,824	134	141
1920.....	295,075	118,517,729	251,230	147	141
1921.....	217,618	59,332,305	197,002	95	75
1922.....	191,881	93,399,900	355,024	97	87
1923.....	237,108	158,159,356	291,444	100	98
1924.....	293,114	242,685,958	259,125	97	88
1925.....	323,185	315,294,986	284,644	103	107
1926.....	274,317	286,741,250	256,575	98	98
1927 First three months.....				94	89

TABLE 12
Commercial Shipments of Pismo Clams Compared to the California Sardine Catch and to General Prosperity as Represented by the Index Numbers of Wholesale Prices

begin with minima in 1916, followed by a rapid rise to maxima in 1918, then a drop to second minima in 1921 and 1922, a rise to second maxima in 1925 and a final drop in 1926.

In the case of the sardine the increase in the pack during 1916–1918 was due to war conditions (Thompson, 1921, pp. 195, 200), and its fall during 1920 and 1921 and subsequent rise in the following years were due to a post-war collapse of the market, followed by a recovery (Thompson, 1926, p. 23). The increase in the catch since 1921 has been due largely to improved markets as cited by Thompson and to

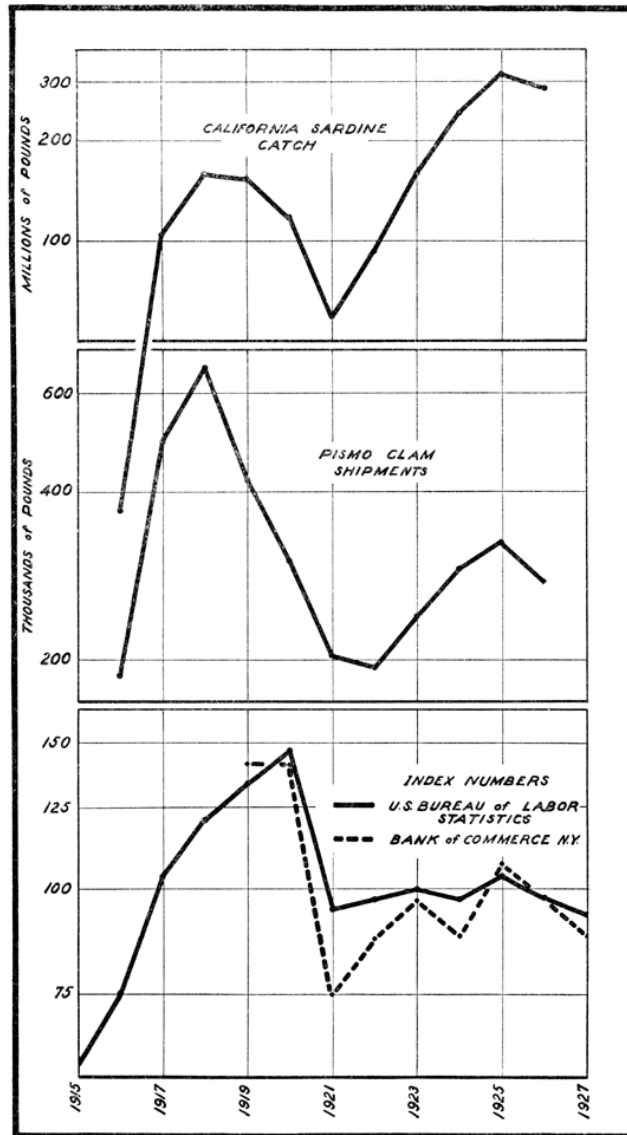


FIG. 13. Fluctuations in Pismo clam shipments and in the California sardine catch compared to fluctuations in general business conditions as represented by index numbers of prices. All curves plotted to a logarithmic scale.

FIG. 13. Fluctuations in Pismo clam shipments and in the California sardine catch compared to fluctuations in general business conditions as represented by index numbers of prices. All curves plotted to a logarithmic scale

changes in the administration of the overage law in the sardine reduction plants, combined factors which have tended to obscure the effect of any possible biological factors.

The close similarity in the fluctuations of the clam shipments to the changes in the sardine catch suggests that possibly the same factors have been responsible in this case. Economic factors during and succeeding the war period have appeared to be largely responsible for the fluctuations in the sardine catch and similar factors have, without doubt, been of great importance in causing the variations in the clam shipments.

We have been unable to obtain a record of the changes in the market for Pismo clams or of the fluctuations in price, and we therefore can not determine to what extent the changes in shipments are related to variations in the immediate market. We do, however, have a measure of the general changes in economic conditions as reflected in the prices of commodities of all kinds. This measure is found in the index numbers of wholesale prices.

In figure 13 we have plotted, for comparison with the sardine catch and clam shipments, the index numbers of the U. S. Bureau of Labor Statistics averaged for yearly periods. These index numbers are calculated from the wholesale prices of several hundred raw and finished commodities. In addition we have shown the index numbers published by the Bank of Commerce of New York: "This index has been designed with one purpose in view—to construct an indicator which will respond with the utmost promptness and sensitiveness to the varying fortunes of business. (Miller, 1927.)"

It is based on a selected list of raw materials and gives a much more sensitive indication of the change in economic conditions than do the indexes of the U. S. Bureau of Labor Statistics.

When we compare the curves representing index numbers with that for Pismo clam shipments we do find some similarity. During the war period both curves show an increase, but the clam shipments reach a peak in 1918, while the index numbers reach their highest point in 1919–1920. Following the peak in 1918 the clam shipments drop off rapidly over a period of four years to a minimum in 1922, while the index numbers fall abruptly from a maximum in 1919–1920 to a minimum in 1921. Following the low point in 1922 the clam shipments increase to a second maximum in 1925, followed by a slump in 1926. The index numbers of the Bureau of Labor Statistics show a slight increase following 1921 to a peak in 1925, while those of the Bank of Commerce show a somewhat uneven and considerably greater rise over the same period. Following this, both slump off in 1926 and 1927.

The results of this comparison indicate that there probably is some relationship between Pismo clam shipments and economic conditions, but the differences found in the fluctuations of the two values suggest that the shipments have been affected by important factors other than economic conditions. In view of the remarkable degree to which we found the population of the intertidal zone affected by dominant year classes, it is of interest to analyze the fluctuations in the commercial

catch from this viewpoint. The shipments from the Pismo-Oceano Beach have, since 1918, when our separate records began, shown the most marked fluctuations, and as our most extensive data on dominant year classes are from this area, we will use them in our analysis.

TABLE 13
Commercial Shipments of Pismo Clams from the Pismo-Oceano and Morro Beaches ^a

	January-June			July-December			Yearly Totals
	Morro	Oceano	Total	Morro	Oceano	Total	
1915.....						*60,000	
1916.....			92,404			94,250	186,654
1917.....			144,540			344,635	489,175
1918.....	130,102	251,614	381,716	169,642	135,964	305,606	687,322
1919.....	138,550	95,300	233,850	89,256	79,404	168,660	402,510
1920.....	62,941	88,185	151,126	90,838	53,111	143,949	295,075
1921.....	80,381	52,278	132,659	37,826	47,133	84,959	217,618
1922.....	37,132	50,329	87,461	39,053	65,367	104,420	191,881
1923.....	50,458	61,174	111,632	49,396	76,080	125,476	237,108
1924.....	41,501	81,896	123,397	51,331	118,386	169,717	293,114
1925.....	45,410	116,355	161,765	41,263	120,157	161,420	323,185
1926.....	35,357	102,274	137,631	34,202	102,484	136,686	274,317

^a From records of the California Fish and Game Commission.
*Estimated.

TABLE 13
Commercial Shipments of Pismo Clams from the Pismo-Oceano and Morro Beaches

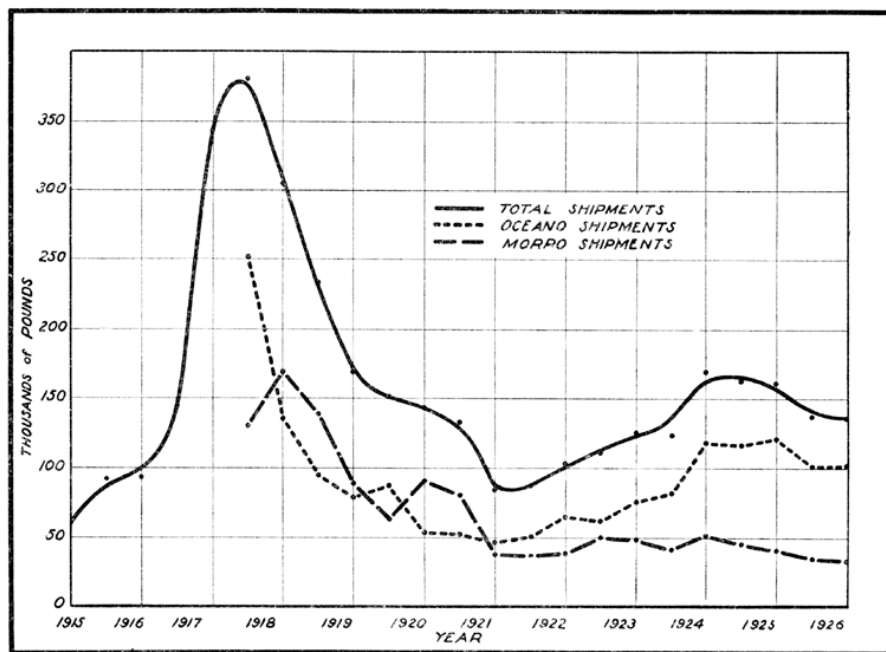


FIG. 14. Pismo clam shipments from Oceano and Morro, plotted by six-month periods.

FIG. 14. Pismo clam shipments from Oceano and Morro, plotted by six-month periods

In order to obtain a more sensitive analysis of the fluctuations in the commercial shipments we have shown in figure 14 the amount of the shipments by six-month periods. In addition we have divided them according to origin (Pismo-Oceano Beach and Morro Beach) and plotted the data separately from 1918, when the records first give the shipments separately, to 1926.

The curves showing the shipments from Morro and Pismo-Oceano independently have a maximum in 1918, their point of origin, with the greatest shipments coming from the Pismo-Oceano Beach. Following 1918 an irregular decline is found in both curves, to a minimum in 1921. In July, 1919, the bag limit was reduced from 50 to 36 per day, but this reduction had little effect on the shipments. Again in July, 1921, the limit was reduced from 36 to 15 per day, and in this case a sharp drop of about 53 per cent is shown in the Morro shipments, but of only 10 per cent in the Pismo-Oceano shipments. Following 1921 the Morro shipments experienced a slight increase in 1923 and 1924, succeeded by a slow decrease to 1926. The Pismo-Oceano shipment, however, increased more than 250 per cent to a maximum in the last half of 1925, succeeded by a fall in 1926.

During 1917, 1918 and 1919 large clams were unusually abundant in the beach and sand bars at Pismo and Oceano, as is evinced by reports at that time from clam diggers and by our age analysis of samples of clams from the commercial catch. This analysis showed that one or more dominant year classes appeared in 1912–1914 and began to reach legal size in considerable numbers in 1917 and 1918. The appearance of a dominant year class in 1913 is further affirmed by the reports of some of the clam diggers that the summer of 1913 saw a heavy set of small clams. (Weymouth, 1923, p. 91.)

This dominant year class could hardly have been entirely responsible for the sudden increase in shipments in 1917, but it must have been of importance in supporting the heavy fishing which took place during the latter part of that year and in 1918 and 1919. The extreme abruptness of the increase in 1917 points to causes other than the gradual growth of an abundant year class into legal size, yet in view of this and later developments it appears that the dominant year classes spawned in 1912 to 1914, while possibly not the principal cause of the sudden increase, were at least highly important factors in making possible the heavy fishing that followed.

After the appearance of these dominant year groups, our data show no indications of any other abundant year class until the summer of 1919, when great numbers of young were found in the beach. Corresponding to this period of poor spawning seasons we find that following the heavy shipments in 1917–1919, when the 1913 and 1914 classes were first appearing in the catch, the shipments rapidly dropped off to a minimum in the latter part of 1921.

An examination of our length-frequency curves for the great 1919 class (see fig. 11) shows that the larger members of this class were reaching legal size in 1923, and that by 1925 practically the entire group had attained legal size. These curves were made from the data collected from our cross-sections of the intertidal zone at Oceano, where the clams were exposed to the inroads of great numbers of diggers. As a result of this easy accessibility they were practically wiped out in this region, as is shown in the length-frequency curves, by the fall of 1925. On the outer beach areas and sand bars the clams are protected from all but the experienced diggers at the lowest tides. Consequently the clams in such locations are subject to the digging of comparatively few clambers and do not show the effects of the fishery as readily as does the population of the intertidal zone. As a

result in 1925 and 1926, when the clams were practically gone from the intertidal zone, they were still relatively abundant beyond this area and on the sand bars, from which the commercial catch predominantly comes.

Corresponding to this period from 1923–1925, during which the clams of the dominant 1919 class were reaching legal size in increasing numbers, the commercial shipments from Oceano show a steady increase to a maximum in 1925. The slump in shipments beginning in the latter part of 1925 is probably due to an increasing scarcity of clams following the heavy fishing in 1924 and 1925. This view is supported by the reports of the diggers and the observations of the writer. The great 1919 class had passed its greatest importance in the catch and no other numerous class had appeared to replace it.

The importance of the 1919 year class in the commercial catch from the Pismo-Oceano Beach is further shown by an age analysis of samples taken from the catch. In 1923 no samples were taken, and we, therefore, do not know what proportion of the commercial catch for that year came from the 1919 class. In 1924, however, about 87 per cent of the clams in our commercial catch samples were from the 1919 class, while in 1925 about 85 per cent came from this class, and in 1926 about 53 per cent.

The effect of the 1919 class on the commercial catch is also shown by the change in the average weight of the clams in the catch. The individual commercial shipments since 1921 comprise, in practically all cases, a bag limit of 15 clams. This number is never exceeded, as it is unlawful to ship more than one limit a day, and in only a few cases out of the many thousands examined were shipments made of less than the full limit of 15 clams. It is therefore possible, by dividing the total weight of the clams shipped by the number of shipments, to obtain the average weight of a limit of 15 clams for any period.

TABLE 14
Number of Commercial Shipments Compared to Their Average Weight ^a
OCEANO

Year	January-June			July-December			January-December		
	No. shipments	Total weight	Average weight	No. shipments	Total weight	Average weight	Total shipments	Total weight	Average weight
1920.....	1,835	88,185	48.0	1,124	53,111	47.2	2,959	141,296	47.8
1921.....	1,321	64,635	48.9	1,464	34,776	23.8	2,785	99,411	35.7
1922.....	2,079	50,329	24.2	2,893	65,367	22.8	4,942	115,696	23.4
1923.....	2,728	61,174	22.4	3,926	76,080	19.4	6,654	137,254	20.6
1924.....	4,375	81,896	18.7	5,991	118,386	19.7	10,366	200,282	19.3
1925.....	5,752	116,355	20.2	5,607	120,157	21.4	11,359	236,512	20.8
1926.....	4,564	102,274	22.4	4,435	102,484	23.1	8,999	204,758	22.8
1927.....	3,487	84,597	24.3						

MORRO									
1920.....	1,317	62,941	47.8	1,735	90,838	52.3	3,052	153,779	50.3
1921.....	1,808	90,255	49.9	1,249	27,952	22.4	3,057	118,207	38.7
1922.....	1,636	37,132	22.7	1,739	39,053	22.4	3,375	76,185	22.6
1923.....	2,175	50,458	23.2	2,094	49,396	23.6	4,269	99,854	23.4
1924.....	1,963	41,501	21.1	2,575	51,331	19.9	4,538	92,832	20.5
1925.....	2,236	45,410	20.3	1,854	41,263	22.2	4,090	86,673	21.2
1926.....	1,508	35,357	23.4	1,394	34,202	24.5	2,902	69,559	24.0
1927.....	882	22,212	25.2						

^a By six month periods, except that 1921 is divided at the end of July, when the bag limit was changed from 36 to 15.

TABLE 14
Number of Commercial Shipments Compared to Their Average Weight

In figure 15A we have plotted, by six month periods, the number of shipments from Oceano since 1921 compared to the average weight of the shipments for the same period. As can be seen, a high negative correlation is evident between the two curves, and the following condition appears to be responsible: In 1921 and 1922 the commercial catch was made up almost entirely of clams eight years old or more, each of which would weigh from one and one-quarter up to three or four pounds, with the result that a limit of 15 clams averaged about twenty-three or twenty-four pounds. In 1923 a few of the clams of the 1919 class were taken, and as the largest of them would, at that time, average

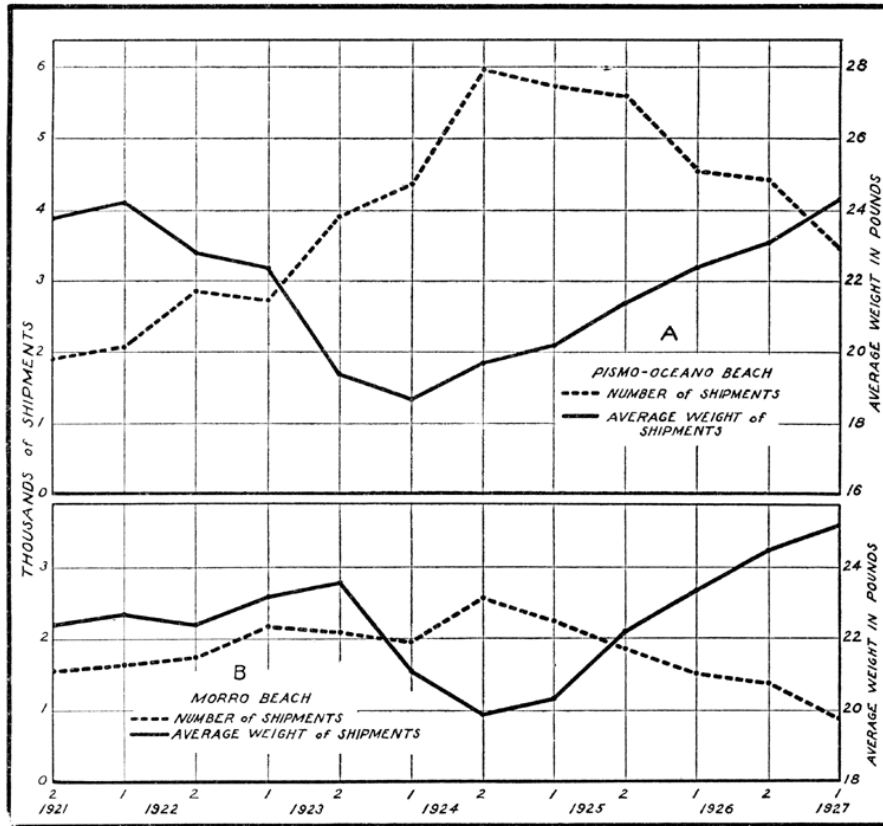


FIG. 15. A—Number of Pismo clam shipments from Oceano compared to the average weight of the shipments.
B—Similar data for Morro shipments.

FIG. 15

scarcely a pound, the average weight of a limit would be correspondingly reduced. In the following year an increasingly greater proportion of the catch was from the 1919 class, in 1924 making up nearly 90 per cent of the total. Following 1924, when the 1919 class reached its greatest importance in the catch, there is a steady increase in weight, which must be due to an increasing proportion of older clams in the catch combined with the natural growth in weight of the members of the 1919 class, which at that time were nearly all of legal size.

On Morro Beach our samples are fewer and less extensive than at Oceano, but such as we have give less indication of the highly dominant year classes which appear on the Pismo-Oceano Beach. The data from Morro (see fig. 14) therefore form an interesting comparison to the preceding results. The Morro shipments show a decrease following 1918, similar to that of the Oceano shipments, to a minimum in 1921. We have no data as to the presence of a dominant year class in the Morro catch in 1918, and can consequently make no attempt to determine the relative effect of economic conditions and abundance in causing the large shipments during this period. Following 1921 the shipments from Morro experience but a slight increase to 1924, followed by about an equal drop to 1926. Our cross-sections at Morro during this time show no evidence of the presence of the dominant 1919 year class on this beach, a condition which strengthens the theory that the 1919 class was the principal cause of the increase in Oceano shipments.

In figure 15B we have compared the average weight of individual shipments from Morro to the number of shipments. In this case no negative correlation appears until the latter part of 1924, but from that point on, the number of shipments shows a steady decrease, while the average weight increases. At Morro the fluctuations in the two variables are less pronounced than at Oceano, and as we have been able to detect no great dominant year classes on that beach it may be that the changes in catch more nearly reflect general market conditions. However, the decrease in shipments begins a year before the slump in business conditions indicated by the index numbers in figure 13, and our observations at Morro incline us to the belief that the declining shipments are caused by a growing scarcity of clams. The failure of young year classes to augment the supply of marketable clams would also cause the fishery to become more dependent on the older year classes and would cause an increase in the average weight of the shipments such as is shown both at Morro and at Oceano.

As a result of this rather general consideration of the factors affecting the commercial shipments, it appears that the probable interpretation of the facts would be as follows: The rapid increase in shipments in 1917 and 1918 was caused by an improved market due to the World War, and this increased fishery was at least in part made possible by the presence of abundant year classes spawned during 1912–1914. Following 1918 the shipments began a rapid decrease, two years before the slump in general business conditions, as reflected in the index of prices, had reached their peak. This early and rapid drop, therefore, may have been due to an increasing scarcity of clams as a result of the heavy fishing in 1917, 1918 and 1919. The decline in shipments continued until a year after general business conditions had begun to improve and was halted only when the great 1919 class began to affect the catch. The slight increase in shipments from Morro in 1923 may be a reflection of improved economic conditions as shown by the price indexes, but the large increase in Oceano shipments must be largely due to an augmented supply of clams. The fact that at Morro, where economic conditions must have been very similar to those at Oceano, but where no dominant year class was present, there was little increase in shipments following 1921, makes this interpretation appear very probable. The final drop in 1926 is reflected in all our curves and may

be due to a slump in business conditions, but our observations at both Morro and Oceano indicate that the decreased catch is due at least in part to an increasing scarcity of the stock of clams.

6.5. Evidence of a periodic recurrence in abundant year classes

The presence of dominant year classes, which the results of our cross-section work and analysis of the commercial shipments have indicated, is also shown by an age analysis of samples from the commercial catch. For this purpose we have made use of data collected by Weymouth in 1920 and presented in 1923 in his paper on the Pismo. clam, and of samples collected by us in 1926. In both cases the clams came from the commercial catch and the younger year classes are consequently not represented because of the legal size limit of $4\frac{3}{4}$ inches. As a result, only the year classes of about six years' age or greater are fully represented in our material. These data are shown in figure 16 in the form of survival curves. In both cases the material comes from Oceano Beach.

TABLE 15
Age Analysis of the Commercial Catch

Age	Commercial catch		Age	Commercial catch	
	1920	1926		1920	1926
4.....	27		18.....	3	2
5.....	54	8	19.....	1	1
6.....	52	9	20.....	3	4
7.....	74	58	21.....	7	1
8.....	58	7	22.....	0	0
9.....	29	0	23.....	4	0
10.....	18	2	24.....	1	0
11.....	15	4	25.....	4	0
12.....	10	6	26.....	2	1
13.....	8	6	27.....		
14.....	14	5	28.....		
15.....	10	4	29.....		
16.....	7	0	30.....		
17.....	8	1			
			Totals.....	409	119

TABLE 15
Age Analysis of the Commercial Catch

In the 1920 survival curve there appear three more or less prominent modes. The first one, formed by clams from five to eight years of age spawned between 1911–1915, is of doubtful significance. Most of the clams reach the legal size of $4\frac{3}{4}$ inches when about six to eight years of age, consequently the presence in the commercial catch of lesser numbers of five and six-year clams than of seven and eight-year olds must be largely the result of the size limit. The second mode in the survival curve appears at fourteen and fifteen years, but is not prominent enough, considering the numbers represented, to be more than indicative. The third mode appears at twenty and twenty-one years and while more marked than the previous one it still is not of sufficient size to remove the possibility of chance sampling errors as an explanation.

The survival curve formed by the material collected in 1926 is in many respects very similar to the 1920 curve. The peak of the first mode again comes at seven years, formed by clams spawned in 1919. In this case, however, we have evidence from our cross-section samples that definitely proves the seven-year mode to be due to the great dominance of the 1919 year class rather than to the legal size limit.

The second mode is rather broad and flat-topped and is formed by clams spawned in 1911–1915. This corresponds to the doubtful first mode of the 1920 curve, both being formed by the same year classes. The third mode in the 1926 curve appears at twenty years and is made up principally of 1906 spawn, similar to the second mode in the 1920

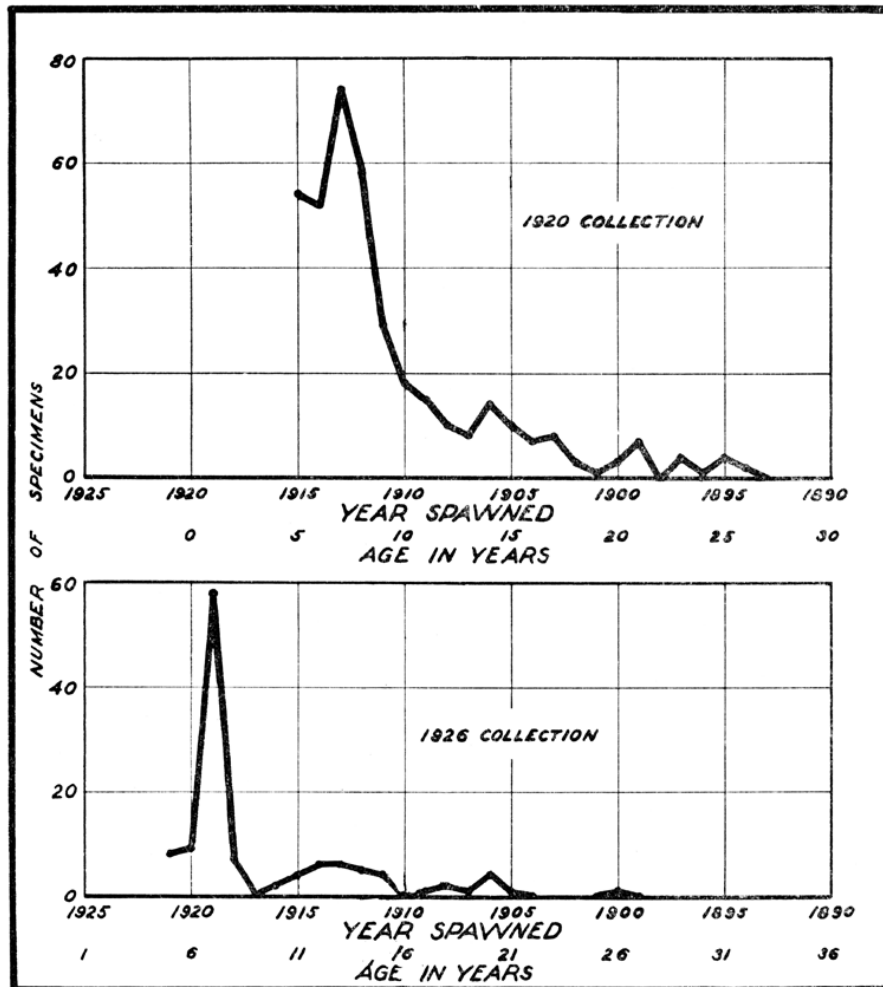


FIG. 16. Survival curve for adult *Tivela* from the commercial catch. The horizontal scales at the bottom of the figures show the year in which the clams were spawned and the age of the clams at the time the samples were collected (1920 and 1926).

FIG. 16. Survival curve for adult *Tivela* from the commercial catch. The horizontal scales at the bottom of the figures show the year in which the clams were spawned and the age of the clams at the time the samples were collected (1920 and 1926)

curve. The numbers are, however, too scanty to establish its significance.

Summing up the evidence from the survival curves we find that in the 1920 curve there appear three principal modes formed by the 1912–1915 classes, the 1906 class and the 1899 class. In the 1926 curve

we also find three modes made up of clams of the 1919 class, the 1911–1915 classes, and the 1906 class. In only one of these cases (1919 class), however, is the evidence sufficient to definitely prove that the mode is the result of a dominant year class.

Examining these data, we find that the centers of the principal modes are separated by five to seven years. Furthermore, the modes in the 1926 curve correspond to those in the 1920 curve; that is, they are made up of the same year classes. Unfortunately, we lack data for the years between 1920 and 1926, and therefore are not able to follow the progression of the modes or to determine the typical shape of the survival curve on years in which no dominant year class is entering the commercial catch. Consequently the above data can be considered at most as suggestive of the appearance at intervals of five to seven years, of one or a series of successful year classes.

These indications shown by the survival curves are strengthened by the evidence from the commercial catch and from our cross-section data. In our records of the commercial catch (see fig. 12) there are modes about 1918 and 1925. The 1925 mode, we have reason to believe, is due to the abundant 1919 year class, while the heavy catches in 1918 must have been drawn largely from the year classes of about 1911–1914.

The material from our cross-sections furnishes us with definite evidence of two dominant year classes. The first of these appeared in 1919, while the second, which is much smaller than the 1919 class, appeared in 1924.

The appearance of successful year classes at five to seven year intervals therefore is indicated by evidence from three sources. The survival curves suggest important year classes from the spawn of 1899, 1905–1906, 1911–1915 and 1919. The commercial catch points to successful spawning years about 1911–1914 and 1919, and the cross-section samples definitely show an extremely successful set in 1919 and a much better than average set in 1924.

Weymouth, in his 1923 paper, presented the 1920 survival curve shown in figure 16A, and in connection with it mentioned the possibility of an approximately seven-year rhythm in the appearance of successful year classes. The additional evidence we now have from the 1926 survival curve, from the commercial catch, and from our cross-section samples, supports this interpretation, but is not extensive or reliable enough to establish it. Additional evidence from future observations will be required before the presence of such a cycle can be accepted as an established phenomenon.

These results which we have obtained apply only to the Pismo-Oceano Beach from which the material we have presented was collected. Our material from Morro and Monterey is much less comprehensive, but such as there is does not show the presence of dominant year classes and fluctuating abundance to as great an extent as our Pismo-Oceano data. It is, however, possible that if adequate material were examined a greater similarity would appear.

6.6. The question of depletion

In a population affected to such a great extent by natural fluctuations, it is difficult to determine to what degree its numbers have suffered from depletion at the hands of man. Is the present scarcity of clams a temporary condition due to natural fluctuations or is it a

permanent condition caused by the heavy drain of the fishery in recent years? That is the question which we must answer if we hope to determine the extent to which overfishing has affected our beaches.

In the intertidal zone the numerous 1919 year class has practically disappeared, and the only other class to appear in any numbers, that of 1924, is less than one-tenth as numerous as was that of 1919. As a result there are fewer clams found in the intertidal zone at present than at any other time in the eight years since 1919, when this work was begun. It is true that some of the clams from the dominant class of 1919 have found their way into deeper water, but all of our evidence indicates that this group is but a small part of the original number.

The changes in the population of the deeper beach areas and sand bars are more difficult to follow, but as represented by the commercial catch, this population appears to have held its own at Oceano since 1920. It must, however, be borne in mind that this was due largely to the contributions from the 1919 class.

On the Pismo-Oceano Beach eight years have now elapsed since the last heavy set in 1919. The only season during that time in which the spawning has been at all successful was in 1924, and in that year it fell far short of the numbers found in 1919. Since 1924, due to the natural causes of mortality and probably even more to the work of thoughtless or unprincipled frequenters of the beach, the numbers of the 1924 class have been greatly reduced. At the rate they are diminishing there will be few remaining by the time the legal size is reached in 1929 and 1930.

From present conditions it appears that unless there is a heavy set of young clams in the near future, which seems doubtful from a consideration of the past, or unless the present spawning stock is protected until another heavy set takes place, the future of the Pismo clam on the Pismo-Oceano Beach is not promising. If the heavy drain on the adults continues, with few young clams appearing to replace them, the spawning stock is bound to be seriously affected, and we know from examples such as we find at Long Beach and Anaheim Landing, that it is quite possible to deplete the spawning stock to the point where it is far from adequate to produce a numerous set of small clams, even in favorable years. On these beaches the clams were formerly found in great numbers, but in recent years the adults have been very scarce and there has been no important set of small clams in many years.

Even were we to assume that depletion was not taking place we would still be forced to admit that our present methods of regulating this natural food supply are very inadequate. Our evidence from the past indicates the occasional appearance of dominant year classes separated by periods of unsuccessful or only fairly successful spawning years. About four to seven years after the appearance of such a numerous year class the members reach legal size and in from one to three years more are practically wiped out from the areas of greatest abundance by the intensive fishery which, under present regulations, is able to increase enormously immediately following any large increase in the abundance of clams. Then ensues a period of scarcity until another abundant year class replaces them.

Thus our records show that large clams were abundant on the Pismo-Oceano Beach in 1917, 1918, and 1919. This period was followed by several years of increasing scarcity in 1920, 1921, and 1922, until the members of the numerous 1919 class began to attain legal size in 1923. Then followed several years of great abundance until 1925, when, due to the enormous drain of the fishery, the great 1919 class had almost completely disappeared from the intertidal zone. Members of this class are still found in some abundance on the sand bars and outer beach areas, where they can be reached only at extreme low tides by diggers who are willing to venture out into the surf, or to pick their way to the sand bars.

Now, providing that another numerous year class soon appears to replace that of 1919, we would still be faced with a period of five to eight years of great scarcity. It is true that there are protective measures in force at present, but it is most plainly evident that they must be indeed insufficient for present conditions if an abundant class such as the 1919 group can, under their protection, support the fishery for but two or three years.

6.7. Causes of present scarcity

If we expect to develop an intelligent program for the future conservation of the Pismo clam, it is necessary that we have an understanding of the agencies which have been responsible for the present conditions. We have no accurate record of the magnitude of any of these factors, with the exception of commercial shipments, but a general conception of their importance can be obtained by an examination of the effect they have had on the clam population. Among these agencies are the clams' natural enemies which were present long before man appeared on the scene, and secondly, man, who at present is probably the dominating factor.

6.7.1. *Natural causes of mortality.*

The natural mortality of *Tivela* during the larval stage is unknown, but must be enormous. The great number of eggs produced by each individual indicates a low chance for survival. We are not, however, concerned so much at present with the mortality during the larval stages as with that which takes place after the young have settled in the beach. It is the decrease in the numbers during this stage which has become so marked during the time of our observations.

Among the natural enemies of the young and adult are birds, rays, starfish, and various marine snails. Quoting Weymouth (1923, p. 93) in this respect: "Gulls may often be seen feeding on the injured or very small individuals where clams have been dug, and they have been observed to drop small clams from the air in order to break the shells. There is no evidence that the gulls can obtain undisturbed clams; those eaten had been turned out by the clambers or by wave action. * * * Scoters and other water birds have often been seen feeding in the surf where young clams are found, and some of the fishermen claim to have found many small clams in the crops of "surf ducks." Various fish are known to feed on clams, for instance, the ray upon the softshell in San Francisco Bay, but no evidence has been found that fish feed upon Pismo clams. Starfish are known to be destructive to oysters and other bivalves, but very few have been encountered on this sandy beach. In one case coming under the writer's notice, the starfish was attacking a razor clam. Various marine snails destroy clams by drilling through the shell, usually near

the umbo, and eating out the soft parts. The shell of the adult *Tivela* is so hard and thick as to render it proof against this form of attack, and though shells have been found which the snails have attempted to drill, none have been encountered in which they have been successful. The very young are, however, less protected, and perforated shells have been found, though they are far less common than in several other species. * * * In fact, after the Pismo clam has reached a length of an inch or more it seems better fitted to resist its natural enemies than the majority of clams." "It will be seen that though there is a heavy larval mortality, the natural enemies of the young and adult are neither numerous nor formidable."

In addition to the enemies of the clams which have been mentioned, there are certain physical causes of mortality such as frosts and storms. There is one case on record of the destruction of Pismo clams by frost, the damage being due to the chilling of the young in the sand at low tide, which enabled the incoming surf to wash them out and up the beach, where they became the prey of birds or were stranded. Destruction by storms is carried on to some extent throughout the entire year. The clams are occasionally washed up and stranded on the beach, where they will eventually die, and there have been cases reported of clams found so deeply buried by the shifting sand that they were apparently unable to dig out. During the winter of 1925–1926 unusually severe storms occurred along the California coast, during which the beach level at Oceano was in places lowered four feet or more by the erosion of the sand. This shifting in their habitat, however, apparently had little effect on the clams in the intertidal zone, for cross-sections made in the fall of 1925 and the spring of 1926 show that the population in this region suffered little loss during the intervening winter months. Occurrences such as we have mentioned are not common and their effect does not ordinarily appear to be unduly severe.

It is possible to obtain a general impression of the influence of these natural causes of mortality from an examination of the survival curves for some of the large year classes. The curve for the 1919 class (see fig. 10B) shows that between the fall of 1919 and that of 1922 the number of clams of this class in the intertidal zone decreased by about 34 per cent. The decrease during the first year amounted to 30 per cent, and during the next two years to about 5 per cent. (The drop in 1921 is probably due to incomplete sampling. See page 35.) During this period from 1919 to 1922 the clams were subject to the natural causes of mortality and in addition experienced a certain drain from the actions of some of the diggers in taking undersized clams. (Weymouth, 1923, p. 94.) Yet the mortality from the combined causes amounted to only about 5 per cent from 1920–1922, the period following the relatively high mortality suffered by the small clams during the first year and before the clams had reached legal size. In other words, the effect of natural enemies on the 1919 class after the clams had survived their first year on the beach and before they had approached legal size, must have been of the order of 5 per cent or less of the original number.

When, however, we consider the mortality curve for the years following 1922 we find an increasingly rapid rate of decline. During this time the clams were of sufficient size to be practically immune to birds and fish, and our records make no mention of particularly destructive storms or frosts. Consequently it appears highly probable that natural

causes of mortality were not the primary factor in the rapid depletion of the 1919 class during this period.

6.7.2. *Effect of man.*

Man has made his presence felt on the Pismo clam population indirectly, through damaging the habitat of the clam by such agencies as the oil discharged near the beach by steamers and tankers, and directly by the numerous diggers present on the beaches in recent years.

An instance of the destruction of Pismo clams by oil was cited by Weymouth (1919), and since that time there have been cases reported in which the clams were so weakened by the presence of oil on the beach that they were unable to maintain their position in the sand and were consequently washed out on the beach. It is likely that the effect of the oil is felt much more by the small clams than by the large ones, and during the egg and larval period its presence may be an important factor. Oil is sometimes present in the sand in the form of tar-like masses, or the lighter oils may be churned by the surf into an emulsion which is swept over the beach by the advancing waves. But few cases have been reported of the destruction of large clams from this cause, and in the visits to the beach made by the author in 1924, 1925, and 1926 no cases were observed. Judging from our observations the effect of oil appears to be a minor factor and can be ignored in considering the principal causes of the depletion of the 1919 class during 1923–1925.

The numerous clambers working on the Pismo-Oceano Beach in recent years may be divided into two major groups—commercial diggers and amateur diggers. The commercial digger obtains his limit nearly every day throughout the year and either ships his clams to outside markets or disposes of them locally to restaurants or tourists. We have a record of all clams shipped to outside markets, but there is no record of the amount used locally, and we must depend on rough estimates for our idea of its magnitude.

The records of the Division of Fish and Game show that the total weight of the clams shipped from the Pismo-Oceano Beach during the three years, 1923–1925, was slightly under 575,000 pounds and was made up of about 425,000 clams. The estimates of various observers place the amount of clams sold to restaurants and tourists at from 50 to 100 per cent of the amount shipped.

Our cross-sections show that at Oceano, during the same period from 1923–1925 the intertidal zone of a single mile of beach experienced a depletion of about 4,900,000 clams. When it is considered that the productive area of this beach is from seven to nine miles in length, it is evident that the number of clams taken from the entire beach must have been several times the amount given above.

If the entire commercial catch, including the clams used locally and those shipped to outside markets, came entirely from the intertidal zone during this period (and we know a large part came from the sand bars), even then the amount taken in this way could have played but a minor role in the depletion of the beach which we have observed. We must, therefore, find the commercial digger not guilty of being the chief factor in the present condition of the beach.

The second great group of diggers who take their toll from the Pismo clam population is the amateur group. They dig clams for their own

use and for friends or sometimes just for the sport that this diversion affords. The part played by these diggers in the depletion of the population of the intertidal zone is difficult to analyze because of the lack of any statistics on the amateur catch.

In order to obtain any conception of the magnitude of this phase of the fishery we must depend on the observations of reliable eye witnesses. From our own observations on the beach and those of deputies of the Division of Fish and Game, we know that at any low tide during the summer months of recent years several hundred automobiles might have been seen parked along the hard, smooth Pismo-Oceano Beach, while their occupants were engaged in obtaining their limit of clams. On week-ends and holidays this number was increased many times by campers and tourists from all parts of the state. Mr. Edwards, the deputy at Oceano during the summer of 1925, stated that on several occasions during that time he had counted or estimated about 1500 automobiles parked on the beach while their occupants were digging clams. His figures include only those machines present at one time and do not include the diggers who must have been on the beach at other hours of the day or at the low night tides. These estimates were corroborated by residents near the beach and by our own observations.

It is impossible to make an accurate determination of the number of clams taken by such a group of diggers, but a general idea of the amount may be arrived at by some rough calculations. If we make the conservative assumption that each of the automobiles mentioned above, carried two diggers, then at a time such as observed by Edwards there would be 3000 clammers on the beach from this source alone. In 1923, 1924, and during the early summer in 1925, great numbers of large clams were present in the intertidal zone, where they could be obtained by the clammers, dry shod, at low tide. For this reason even the most inexperienced diggers were easily able to obtain a limit of clams at any low tide during this period. Therefore, assuming that each digger obtained his limit, the 3000 clammers would carry off a total of about 45,000 clams, an amount in one day equal to about one one-hundredth of the approximate loss during 1923–1925 from a mile of the Oceano Beach. When it is considered that such groups must have been present many times during the summers of 1923, 1924, and 1925, and that great numbers of clams were taken by smaller parties at other times, it becomes evident that the motorists and campers must have been a much more important factor in the depletion of the intertidal zone population during 1923–1925 than the commercial diggers, and must indeed have been largely responsible for this depletion.

These estimates are for the Pismo-Oceano Beach only. At Morro the clams have, in recent years, been much less numerous in the intertidal zone where they are more easily accessible than at Oceano, and as Morro Beach lies off the main coast highway it has been less frequented by tourists and campers. For this reason the commercial catch rather than the amateur catch is probably the most important factor at Morro.

6.8. Present conditions

Consideration of the results of our study of the Pismo clam's abundance does not, under present conditions, offer much encouragement for the future. Our cross-section samples have shown us that at

Oceano, where the clams have been most abundant in the past, the population of the intertidal zone is at present made up largely of members of the 1924 class, and that this population is less numerous than at any other time since our records began in 1919. At Pismo the beach population in the fall of 1926 was composed chiefly of members of the 1924 and 1926 classes, and this population was the smallest since 1923. On the sand bars and lower beach areas at Oceano the adult population, as far as we can judge by our records and observations, is more numerous than in 1921 and 1922, but less than in 1925 and 1926. It must, however, be remembered that this increase over 1921 and 1922 has been due to the additions from the 1919 class and that there are at present few young clams growing up to replace the large individuals captured by the diggers. Our work with the distribution of clams on the beach has indicated that the great proportion of young clams are found in the intertidal zone and that the ones found in deep water and on the sand bars are stragglers from the main distribution which have been washed out by the surf. Consequently, if the intertidal zone is kept stripped of clams, there will be no stock of young to replenish the adult population in deeper waters as it is depleted by the fishery, and in time the spawning stock will be reduced to the point where it will be unable to furnish a set of young sufficient to materially repopulate the beach.

Eight years have elapsed since the appearance of the 1919 class on the Pismo-Oceano Beach and no successful spawning season has appeared, with the exception of the small set in 1924, which has fallen far short of replacing the 1919 clams. If the five to seven-year cycle in the recurrence of successful spawning seasons, which has been indicated in the past, continues in the future, then we can hardly expect to have another successful set of young clams for four or five years.

With the beach in the present depopulated condition, it appears that our principal duty at present is to give the remaining population of young and adult clams every protection possible in order to preserve a spawning stock until favorable conditions once more occur. The first step in this direction has been taken in a new law prohibiting the shipping of Pismo clams and increasing the minimum legal size from $4\frac{3}{4}$ inches diameter to 5 inches. Under present conditions prohibiting the shipment of clams will materially benefit the situation, for most of the commercial catch comes from the sand bars, where at present the principal remaining spawning stock is found. It will not, however, affect the commercial catch of clams used locally by restaurants and hotels, which must be approximately as great as the amount formerly shipped, and which likewise comes from the present spawning reserves.

Provided the spawning stock does survive in sufficient numbers until another heavy set of young is produced, then, when these reach sufficient size to be subject to the fishery, we will at best be confronted with a repetition of the 1923–1925 period. The number of people who now are able to come to the beaches during the summer is so great that with the present bag limit of fifteen a day, they are able to deplete in two or three years even such a numerous year class as was that spawned in 1919. Then follows a period of scarcity or, if the strain is too great, practical extermination. With the increasing automobile traffic this condition is, under present regulations, bound to become worse each year.

The only solution to this problem appears to be in limiting the strain on the clam population in some way so that the numbers of an abundant year class will be able to support the fishery over a longer period of years and thus tide over a period of scarcity. This might be done by radically reducing the bag limit, or in some way reducing the number of diggers. A reduction in bag limit would at present be but little felt by the amateur diggers, for with the present scarcity of clams it is seldom that anyone not well acquainted with the beach and willing to work the more difficult areas is able to obtain more than a fraction of a bag limit.

Another factor of great importance is the strict enforcement of the present size limit of five-inch diameter, which would allow the clams to at least reach sufficient size to be of importance as breeders for one or two years. If we desire to maintain a fairly continuous and abundant supply of clams it is essential that radical measures for their conservation be taken in the immediate future.

7. 7. SUMMARY

The following is a brief summary of the principal results obtained in the present study of *Tivela stultorum*.

1. The Pismo clam begins spawning in its third or fourth summer (at the end of the second or third year).
2. The number of eggs produced is most closely related to the weight of the clam; the number of eggs and weight increasing at about the same rate.
3. The growth rate is not noticeably affected by the crowded conditions produced in the beach by dominant year classes.
4. The selection for size which takes place in the fishery significantly affects the rate of growth as determined from the annual rings in the shell.
5. There is a considerable difference in the rate of growth of clams from different beaches; in our material the clams from Turtle Bay show the greatest early growth and those from Morro the least.
6. The clam population in the Pismo-Oceano Beach has, in the past, undergone great fluctuations in abundance. These fluctuations have been due principally to dominant year classes and the effects of the fishery.
7. The census in the fall of 1926, of the number of clams in the intertidal zone of the Pismo-Oceano Beach, shows the greatest scarcity since our records began in 1919.
8. Strict protection of undersized clams, and regulations which will decrease the strain on the breeding stock, are essential if the Pismo clam fishery is to be maintained.

8. 8. BIBLIOGRAPHY

- Allen, E. J. 1917. The age of fishes and the rate at which they grow. *Journal, Marine Biological Association*, Vol. XI, 1916–1918, pp. 399–424.
- Belding, D. L. 1912. A report upon the quahaug and oyster fisheries of Massachusetts. Commonwealth of Massachusetts. Boston.
- Garstang, Walter. 1909. The distribution of the plaice in the North Sea, Skagerak and Kattegat, according to size, age and frequency. *Rapports et Proces-Verbaux, Conseil Permanent International pour l'Exploration de la Mer*, Vol. XI, pp. 65–133.

1926. Plaice in the North Sea. Changes in size and catch. London Times, April 21, 1926, p. 15; April 26, 1926, p. 20.
- Gilbert, C. H., and Rich, W. H. 1927. Investigations concerning the red salmon runs to the Karluk River, Alaska. Bulletin, U. S. Bureau of Fisheries, Vol. XLIII, Pt. 2, Document No. 1021.
- Heath, H. 1916. California clams. California Fish and Game, Vol II, No. 4, pp. 175–178.
1913. Investigation of the clams of California. California Fish and Game Commission, Fish Bulletin No. 1, pp. 27–28.
- Herrington, W. C. 1926. Depletion of the Pismo clam in California. California Fish and Game, Vol. XII, No. 3, pp. 117–124.
- Kelley, T. L. 1924. Statistical Methods. New York.
- McMillin, H. C. 1924. The life-history and growth of the razor clam. State of Washington, Department of Fisheries.
- Miller, E. M., and Cavanaugh, F. J. 1927. Price index of the National Bank of Commerce in New York. Journal, American Statistical Association, Vol. XXII, No. 158, pp. 171–183.
- Thompson, W. F. 1915. A preliminary report on the life-history of the halibut. Report, British Columbia Commissioner of Fisheries, 1914, pp. 76–99.
1919. The scientific investigation of marine fisheries, as related to the work of the Fish and Game Commission in Southern California. California Fish and Game Commission Fish Bulletin No. 2.
1921. The sardine of California. California Fish and Game, Vol. VII, No. 4, pp. 193–194.
1926. The California sardine and the study of the available supply. California Fish and Game Commission, Fish Bulletin No. 11, pp. 5–66.
- U. S. Bureau of Labor Statistics. 1921. Index numbers of wholesale prices in the United States and foreign countries. Bulletin, U. S. Bureau of Labor Statistics, No. 284.
- Weymouth, F. W. 1919. A case of the destruction of Pismo clams by oil. California Fish and Game, Vol. V, No. 4, pp. 174–175.
1920. The edible clams, mussels and scallops of California. California Fish and Game Commission, Fish Bulletin No. 4.
1921. The abundance of young Pismo clams. California Fish and Game, Vol. VII, No. 2, pp. 103–106.
1923. The life-history and growth of the Pismo clam. California Fish and Game Commission, Fish Bulletin No. 7.
- Weymouth, F. W., McMillin, H. C. and Holmes, H. B. 1925. Growth and age at maturity of the Pacific razor clam, *Siliqua patula* (Dixon). Bulletin, U. S. Bureau of Fisheries, Vol. XLI, Document No. 984.
- Wright, F. S. 1926. Report on the cockle beds and cockle industry of England and Wales. England, Ministry of Agriculture and Fisheries, Fishery Investigations, Ser. 2, Vol. IX, No. 5.

9. APPENDIX

— 59 —

9. APPENDIX

TABLE 1A

Length-Frequencies of Clams of the 1919 Class From the Oceano Cross-Sections in 1922, 1923, 1924 and 1925*

1919 Class in											
Length cm.	1922			Length cm.	1923			1924		1925	
	f	Grouped f	Weighted f		f	Grouped f	Weighted f	f	Grouped f	f	Grouped f
6.9	1			9.0	1	3	4				
7.0	0	2	6		1	0					
7.1	0				2						
7.2	1				3	5					
7.3	1				4	3					
7.4	1				5	2					
7.5	0	3	9		6	3	20		1		
7.6	0				7	7		1			
7.7	1				8	3		0			
7.8	4				9	9		0			
7.9	2			10.0	9	39	54		4		
8.0	2	15	44		1	7		1			
8.1	5				11			2			
8.2	2				13			1			
8.3	7				12	4		1			
8.4	4				15		65	2	8		
8.5	4	34	99		6	14		2			
8.6	7				7	11		3			
8.7	9				8	12		4			
8.8	5				9	13		8			
8.9	7			11.0	9	55	76		31		
9.0	9	40	117		1	9		9			
9.1	7				2	12		6			
9.2	12				3	12		14			
9.3	12				4	13		9			
9.4	10				5	7	37	51			
9.5	7	42	123		6	3		10			
9.6	5				7	2		9			
9.7	8				8	2		12			
9.8	3				9	4		16			
9.9	6			12.0	2	12	17	18	50		1
10.0	7	19	56		1	4		7			
10.1	0				2	0		7		1	
10.2	3				3	2		5			
10.3	1				4	1		3			
10.4	1				5	0	4	5	18		0
10.5	1	4	11		6	1		3			
10.6	1				7			4			
10.7					8			1			
10.8					9			1			
10.9				13.0	1			2	6	1	1
11.0					1			1			
11.1					2						
11.2					6					1	
11.3					7			1	1		1
Totals	159	159	465		235	235	325	169	169	5	5

* The frequencies for 1922 were made from measurements of the fourth ring of 159 clams of the 1919 class collected in 1923 and 1924 and are weighted to bring them up to the number of 1919 clams obtained from the cross-sections in 1922. In 1923 a maximum of 20 clams of the 1919 class was saved from each segment. When more than this number were found in a segment, 20 were picked at random and saved. We have therefore weighted the frequencies of the clams thus saved to bring them to the total from the section.

TABLE 1A

Length-Frequencies of Clams of the 1919 Class From the Oceano Cross-Sections in 1922, 1923, 1924 and 1925

TABLE 2A
Ring Lengths in Centimeters

Length Ring I			Ring II			Ring III		
Length	1919 class collected in		Length	1919 class collected in		Length	1919 class collected in	
	1923	1924		1923	1924		1923	1924
1.0			3.2		1	5.0		
1			3.5		1	1		
2			6		3	2	1	
3	1		7		1	3	1	1
4	1		8	1	3	4	0	0
1.5		3	9	1	1	5.5	0	0
6	2	2	4.0	2	2	6	1	0
7	1	1	1	0	6	7	1	0
8	0	4	2	0	3	8	0	1
9	1	5	3	1	2	9	0	0
2.0	2	7	4	1	0	6.0	0	0
1	2	3	4.5	2	7	1	1	3
2	4	6	6	1	5	2	1	0
3	4	6	7	2	3	3	3	4
4	4	3	8	8	4	4	1	0
2.5	5	4	9	4	5	5.5	0	3
6	1	12	5.0	6	10	6	1	5
7	5	6	1	2	6	7	0	4
8	5	6	2	4	7	8	0	6
9	3	5	3	2	5	9	3	2
3.0	2	5	4	3	5	7.0	3	4
1	3	6	5.5	3	5	1	3	5
2	6	7	6	5	4	2	3	7
3	3	3	7	3	6	3	3	3
4	2	3	8	0	3	4	2	8
3.5	1	2	9	1	3	7.5	5	8
6	0	1	6.0	2	0	6	2	8
7	1		1	2	1	7	7	5
8			2	0		8	4	1
9			3	1		9	3	0
4.0			4			8.0	2	5
			6.5			1	2	7
						2	1	3
						3	1	1
						4	3	1
						8.5	1	2
						6	0	0
						7	1	2
						8		
						9		
						9.0		
Totals	57	103	11	57	103	11	57	103

TABLE 2A
Ring Lengths in Centimeters

TABLE 2A—Continued
Ring Lengths in Centimeters

Ring IV			Ring V			Ring VI		
Length	1919 class collected in		Length	1919 class collected in		Length	1919 class collected in	
	1923	1924		1923	1924		1923	1924
6.9		1	8.7		1	9.5		
7.0		0	8.8		1	9.6		
7.1		0	8.9		0	9.7		
7.2		1	9.0		1	9.8		1
7.3		1	9.1		0	9.9		0
7.4		1	9.2		1	10.0		0
7.5		0	9.3		2	10.1		2
7.6		0	9.4		0	10.2		2
7.7	1	0	9.5		3	10.3		0
7.8	1	3	9.6		3	10.4		1
7.9	1	1	9.7		2	10.5		2
8.0	1	1	9.8		1	10.6		3
8.1	0	5	9.9		1	10.7		0
8.2	2	0	10.0		1	10.8		3
8.3	1	6	10.1		4	10.9		2
8.4	2	5	10.2		6	11.0		6
8.5	1	3	10.3		3	11.1		3
8.6	2	6	10.4		0	11.2		5
8.7	5	4	10.5		3	11.3		9
8.8	1	4	10.6		3	11.4		6
8.9	3	4	10.7		1	11.5		6
9.0	1	8	10.8		6	11.6		3
9.1	0	7	10.9		5	11.7		3
9.2	7	5	11.0		1	11.8		6
9.3	5	7	11.1		1	11.9		5
9.4	3	7	11.2		3	12.0		5
9.5	2	5	11.3		1	12.1		7
9.6	3	2	11.4		2	12.2		7
9.7	5	3	11.5		2	12.3		3
9.8	2	1	11.6		3	12.4		2
9.9	3	3	11.7		0	12.5		2
10.0	2	5	11.8		0	12.6		5
10.1	0	0	11.9		0	12.7		3
10.2	1	2	12.0		1	12.8		0
10.3	0	1	12.1		0	12.9		0
10.4	1	0	12.2		0	13.0		1
10.5	0	1	12.3		0	13.1		1
10.6	1		12.4		1	13.2		
10.7			12.5			13.3		
10.8			12.6			13.4		
10.9			12.7			13.5		
11.0			12.8			13.6		
11.1			12.9			13.7		
11.2			13.0			13.8		1
11.3						13.9		1
11.4						14.0		1
Totals	57	103	11	57	103	12		16

TABLE 2A
Ring Lengths in Centimeters

TABLE 2A—Continued
Ring Lengths in Centimeters

Offshore clams				1919 class in 1921			1918 class		
Length	Ring VII	VIII	IX	Length	Ring I	II	Length	Ring II	III
11.5	1			1.4	1		1.4		
6		1		6	1		6		
7				8	1		8		
8				2.0	0		2.0		
9	1			2	6		2		
12.0				4	3		4		
1	1			6	5		6		
2	1			8	3		8		
3		5		3.0	10		3.0		
4	1	2		2	6		2		
12.5	2	0		4	2	1	4		
6		3	1	6	2	1	6		
7	1	0		8	1	0	8		
8	2	2	1	4.0		0	4.0		
9	1	1		2		1	2		
13.0	2	2		4		2	4		
1		1		6		3	6		
2	1	3		8		4	8		
3	2	4		5.0		1	5.0		
4		3	1	2		6	2		
13.5		1		4		9	4		
6		5	1	6		7	6		
7		4		8		2	8		
8		4		6.0		0	6.0		
9	1	2	1	2		2	2		
14.0		0	1	4		2	4		
1		0		6			6		1
2		4					8		0
3		1					7.0		3
4		2					2		1
14.5		2					4		2
6	1	0					6		3
7		0					8		5
8		2					8.0		2
9		0					2		5
15.0		1					4		1
1		0	1				6		0
2		0					8		1
3		0					9.0		0
4		1					2		1
15.5									
6									
7									
Totals	18	56	7		41	41		169	23

TABLE 2A
Ring Lengths in Centimeters

TABLE 3A
Comparison of Ring Measurements of *Tivelo* From Morro, Monterey and Turtle Bay

Ring I				Ring II			Ring III			
Length cm.	Morro	Mon- terey Bay	Turtle Bay	Morro	Mon- terey Bay	Turtle Bay	Length cm.	Morro	Mon- terey Bay	Turtle Bay
0.8	1						4.0			
9	3						1			
1.0	5	1					2			
1	9	0					3	1		
2	19	1					4	0		
3	8	3					5	0		
4	17	10	1				6	0		
5	11	10					7	2		
6	19	14	1				8	1		
7	14	10					9	2		
8	10	21	1				5.0	5	1	
9	5	18					1	2	1	
2.0	7	16	6				2	9	1	
1	2	8					3	5	2	
2	1	8	1				4	2	3	
3	2	9					5	9	1	
4	1	9	4				6	6	3	
5	2	7					7	1	3	
6		4	4				8	2	4	
7		2					9	5	3	
8		0	1	2			6.0	5	3	
9		1		1			1	4	9	
3.0				2			2	0	2	
1				3	2		3	2	2	
2				8	2		4	0	5	
3				7	5		5	0	5	
4				9	6		6	1	4	
5				6	1		7	0	7	
6				12	4		8	0	6	2
7				5	3		9	0	1	
8				13	10		7.0	1	0	1
9				9	9		1		1	
4.0				9	4	1	2		3	3
1				7	4		3		1	
2				8	5	2	4		3	4
3				3	8		5		6	
4				2	6	0	6		2	8
5				3	10	7	7		4	
6					12	2	8		4	0
7					5		9		1	
8					9	3	8.0		1	7
9					6		1		2	1
5.0					10	6	2		0	
1					3		3		0	
2					5	8	4		1	1
3					4		5			
4					4	2	6			
5					1					
6						0				
7										
8					1	2				
9										
6.0						1				
Totals....	136	152	19	109	139	27		65	95	27

TABLE 3A
Comparison of Ring Measurements of *Tivelo* From Morro, Monterey and Turtle Bay

TABLE 3A—Continued
Comparison of Ring Measurements of *Tivela* From Morro, Monterey and Turtle Bay

Ring IV				Ring V			Ring VI			Ring VII	
Length cm.	Morro	Mon- terey Bay	Turtle Bay	Length cm.	Morro	Mon- terey Bay	Length cm.	Morro	Mon- terey Bay	Morro	Mon- terey Bay
5.5	1			6.6	1		9.0	1			
							1	1			
									3		
								0	0		
								1	0		
								1	0		
6.2	2			7.5	2			1	1		
3	3			6	0			8	0		1
4	1	1		7	1			9	0	1	1
5	1			8	1		10.0	0	1		
6	2			9	1			0	2		
7	2			8.0	1			3	2		
8	1			1	4			2	5	0	
9	0	1		2	0	1		4	0	1	2
7.0	2	0		3	0	0		5	1	7	0
1	3	0		4	3	1		6	0	1	1
2	1	1		5	3	1		7	2	4	1
3	3	1		6	0	0		8	3	2	0
4	4	0		7	0	0		9	1	6	0
5	4	5		8	2	1	11.0	1	4	2	1
6	2	7		9	1	4		1	1	2	0
7	3	3		9.0	1	3		2	4	0	4
8	5	3		1	3	1		3	1	2	0
9	1	2		2	5	1		4	1	5	1
8.0	1	5		3	0	4		5	2	3	1
1	1	1		4	0	1		6	2	2	0
2	1	5		5	3	7		7	0	2	3
3	1	7		6	2	5		8	1	2	4
4	1	1		7	1	1		9	0	1	0
5		5		8	2	6	12.0	0	1	1	4
6		2		9	0	1		1	1	0	1
7	1	4		10.0	1	9		2		1	1
8		0		1	1	2		3		1	0
9		2		2	0	3		4		0	1
9.0		5		3	0	0		5		0	0
1		4		4	3	7		6		0	0
2		6	1	5		4		7	1	1	1
3		3		6		1		8			
4		3	0	7		4		9			
5		3		8		0	13.0				
6		0	1	9		2		1			
7		0	1	11.0		0		2			
8		0	1	1		1		3			
9		0		2		1		4			
10.0		0		3							
1		0		4							
2		1		5							
3		0		6							
4		0		7							
5		1									
6											
Totals ..	47	81	3		39	73		32	65	17	45

TABLE 3A
Comparison of Ring Measurements of *Tivela* From Morro, Monterey and Turtle Bay

TABLE 3A—Continued
Comparison of Ring Measurements of *Tivela* From Morro, Monterey and Turtle Bay

Length cm.	Ring VIII		Ring IX		Ring X		Ring XI		Ring XII		Morro					
	Morro.....	Monterey.....	Morro.....	Monterey.....	Morro.....	Monterey.....	Morro.....	Monterey.....	Morro.....	Monterey.....	Ring No.					
											XIII.....	XIV.....	XV.....	XVI.....	XVII.....	XVIII.....
11.0.....	1															
1.....	0															
2.....	1															
3.....	1															
4.....	0															
5.....	2			1												
6.....	0															
7.....	0		2			1										
8.....	5															
9.....	1							1								
10.....	1															
12.0.....	0			1												
1.....	0			3		2										
2.....	1			0												
3.....	1			3		1										
4.....	0			3		1										
5.....	0			2		1		1								
6.....	2			1		2		1								
7.....	0			1		0		1								
8.....	0			1		0		1								
9.....	1			0		1		1								
13.0.....	2			0		2		0								
1.....	0			1		0		1								
2.....	1			0		0		0			2					
3.....				1		0		0								
4.....				0		1		1								
5.....				1		1		1								
6.....				1		1		1								
7.....																
8.....																
9.....																
14.0.....								1								
1.....						1										1
2.....															1	1
3.....											1					
4.....																
5.....																
6.....																
7.....								1								
8.....																
9.....																
15.0.....										1						
15.5.....																
Totals.....	13	24	7	9	5	9	3	4	2	3	2	1	4	3	3	3

TABLE 3A
Comparison of Ring Measurements of *Tivela* From Morro, Monterey and Turtle Bay

TABLE 4A
Length Frequency Table
Clams from the Standard Oceano Cross-Sections, 1923-1926

Total length, cm.	Sec. C, 1923 cont'd	Sec. E, 1924 cont'd	Sec. A, 1925 cont'd	Sec. C, 1926 cont'd	Sec. E, 1926 cont'd	Sec. A, 1926 cont'd	Sec. C, 1926 cont'd
1.0	1	0	0	0	0	0	0
1.1	0	0	0	0	0	0	0
1.2	0	0	0	0	0	0	0
1.3	0	0	0	0	0	0	0
1.4	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0
1.6	0	0	0	0	0	0	0
1.7	0	0	0	0	0	0	0
1.8	0	0	0	0	0	0	0
1.9	0	0	0	0	0	0	0
2.0	0	0	0	0	0	0	0
2.1	0	0	0	0	0	0	0
2.2	0	0	0	0	0	0	0
2.3	0	0	0	0	0	0	0
2.4	0	0	0	0	0	0	0
2.5	0	0	0	0	0	0	0
2.6	0	0	0	0	0	0	0
2.7	0	0	0	0	0	0	0
2.8	0	0	0	0	0	0	0
2.9	0	0	0	0	0	0	0
3.0	0	0	0	0	0	0	0
3.1	0	0	0	0	0	0	0
3.2	0	0	0	0	0	0	0
3.3	0	0	0	0	0	0	0
3.4	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0
3.6	0	0	0	0	0	0	0
3.7	0	0	0	0	0	0	0
3.8	0	0	0	0	0	0	0
3.9	0	0	0	0	0	0	0
4.0	0	0	0	0	0	0	0
4.1	0	0	0	0	0	0	0
4.2	0	0	0	0	0	0	0
4.3	0	0	0	0	0	0	0
4.4	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0
4.6	0	0	0	0	0	0	0
4.7	0	0	0	0	0	0	0
4.8	0	0	0	0	0	0	0
4.9	0	0	0	0	0	0	0
5.0	0	0	0	0	0	0	0
5.1	0	0	0	0	0	0	0
5.2	0	0	0	0	0	0	0
5.3	0	0	0	0	0	0	0
5.4	0	0	0	0	0	0	0
5.5	0	0	0	0	0	0	0
5.6	0	0	0	0	0	0	0
5.7	0	0	0	0	0	0	0
5.8	0	0	0	0	0	0	0
Totals	386	294	74	57	51		

TABLE 4A
Length Frequency Table
Clams from the Standard Oceano Cross-Sections, 1923-1926

TABLE 5A
Variations in First Season's Growth
Total length of Ring I

Length cm.	1914	1918	1919	1924	1925	1926
0.6		1				
7						
8		0				
9						
1.0	1	1		1		
1				2	2	2
2	2	0		1	5	0
3				2	2	2
4	2	2	3	3	3	0
1.5				6	4	1
6	2	8	9	8	2	5
7				20	3	3
8	6	18	10	19	0	2
9				18	0	5
2.0	11	55	27	25	1	3
1				15		5
2	12	103	37	15		6
3				6		5
4	3	120	69	0		5
2.5				2		0
6	3	141	104			1
7						
8	1	91	136			
9						
3.0	2	60	198			
1						
2	1	30	196			
3						
4	0	13	138			
3.5						
6	0	9	82			
7						
8	0	6	15			
9						
4.0	1	2	9			
1						
2			6			
3						
Totals	47	660	1,039	143	22	45

TABLE 5A
Variations in First Season's Growth
Total length of Ring I

TABLE 6A

Year Class of 1924

Total length of Ring II of clams collected in 1926

Length cm.	f	Length cm.	f	Length cm.	f
2.5		3.5	1	4.5	6
6		6	2	6	3
7		7	2	7	6
8	1	8	3	8	6
9	0	9	5	9	3
3.0	0	4.0	3	5.0	1
1	1	1	10	1	1
2	0	2	7	2	1
3	0	3	9	3	1
4	3	4	3	4	
				5	
				Total	78

TABLE 6A
Year Class of 1924
Total length of Ring II of clams collected in 1926

CALIFORNIA DIVISION OF FISH AND GAME 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 Quinnet 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.

* No. 10. The Life History of *Leuresthes tenuis*, an Atherine Fish with Tidecontrolled Spawning Habits. By Frances N. Clark. October, 1925; 51 pp., 6 graphs, 7 pls.

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. Reports 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.

* Out of print.

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 tshawytscha*) 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.

These bulletins are offered in exchange for the publications of other bodies engaged in marine research. Address: California State Fisheries Laboratory, Terminal Island, California.