GROWTH AND AGE AT MATURITY OF THE PACIFIC RAZOR CLAM, SILIQUA PATULA (DIXON)

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INTRODUCTION

In the spring of 1923 the senior author was engaged by the Bureau of Fisheries to undertake the investigation of the razor-clam fishery of Alaska. The following summer, accompanied by Mr. Holmes, he spent 8 weeks in the field, visiting the Cordova beds and those near Chisik Island, Cook Inlet. In March, 1924, Mr. McMillin, who had been working on a similar problem for the State of Washington, entered the service of the bureau, and during the following summer accompanied the senior author for 10 weeks in the field, examining the beds at Cordova and those in the vicinity of Kukak Bay; the Washington beds were visited on the return trip.

The data collected was worked up at Stanford University by Mr. Holmes in the fall of 1923 and by Mr. McMillin during the fall and winter of 1924–25, under the supervision of the senior author. All general conclusions are the results of discussion and agreement of the three authors.

The study of growth and maturity forms the main part of this paper. These matters are not only of scientific interest but are of importance on account of the bearing which they have on the measures of conservation that have been put into effect or may be recommended for the future. On this account the paper will be of more than usual interest to the men engaged in the clam industry of Alaska, and it has seemed desirable to include a discussion of certain matters which would not ordinarily be included in a strictly scientific paper, but which experience has shown will be of interest to the nonscientific reader and will lead him to a better understanding of the more technical portions.

We wish to acknowledge the advice and helpful criticism of Dr. Willis H. Rich during the progress of the work.

THE RAZOR CLAM

The razor clam, *Siliqua patula* (Dixon), occurs in commercial quantities from near the mouth of the Columbia River to the Aleutian Islands. Canning has been carried on at Warrenton, Oreg., along the whole coast of Washington, on Vancouver and Graham Islands in Canada, and at Cordova, in Cook Inlet, and Shelikof Straits, Alaska. This range possibly may be extended by the opening of canneries in southwestern Alaska along the Alaska Peninsula. It is essential to determine whether the variations encountered in this 2,800 miles of coast are of specific value.

The razor clam (*Siliqua patula*) was first described by Dixon in 1788 from specimens found near Coal Harbor, Cook Inlet, Alaska. Conrad found shells near the mouth of the Columbia River in 1838, and described them as a separate species—*Siliqua* (*Solen*) *nuttallii.* Later this was changed in rank to a variety of the original *Siliqua patula.* Other species and varieties exist, which, however, need not be considered here. A description of the two mentioned above, taken from Dall (1899, p. 109), is as follows:

3. *Siliqua patula* Dixon, 1788, Okhotsk Sea; the southern border of Bering Sea, and the Gulf of Alaska to Sitka.

Described from Cook Inlet, Alaska. * * * Large, with the submedian beaks and straight rib. The following are discriminable varieties, but apparently connected by gradations with the typical *S. patula.*

4. *Siliqua* (*patula* var.) *alta* Broderip and Sowerby, 1829; Bering Sea and Strait. * * *.

5. *Siliqua* (*patula* var.) *nuttallii* Conrad, 1838, Lituya Bay, Alaska, south to Oregon, and California as far as Monterey.

* * *. The shell is very straight, brilliantly polished, narrower than the typical *S. patula* and with a much more oblique rib. * * *

A full copy of the original description is given by Oldroyd (1924, p. 58) without comment. The distinction given rests on the direction of the rib, which is said to be " straight " in " *patula* " and " more oblique " in " var. *nuttallii*," and on the proportional width of the shell, which is alleged to be broader in "*patula*" than in " var. *nuttallii*."

It is not difficult to separate Alaskan and Washington shells by their general appearance, but these differences are, we think, not of specific rank. The clams from the northern waters grow more slowly; the annual rings of growth on the shell, plainly visible upon even superficial examination, are thus more numerous and closely placed. While the number and placing of the rings may distinguish shells from various localities, these, as we shall show, are the result of environment and not specific differences. It is also found that clams on different sections of one beach grow at different rates. Specimens from places only a few feet apart but separated by some obstruction, such as the Grays Harbor jetty, may show decidedly different shell markings, and the growth curve constructed from shell measurements reflects the distinction.

The weight of shells from different beds also varies according to the rate of growth. As shown in Figure 13, the number of years necessary for clams to

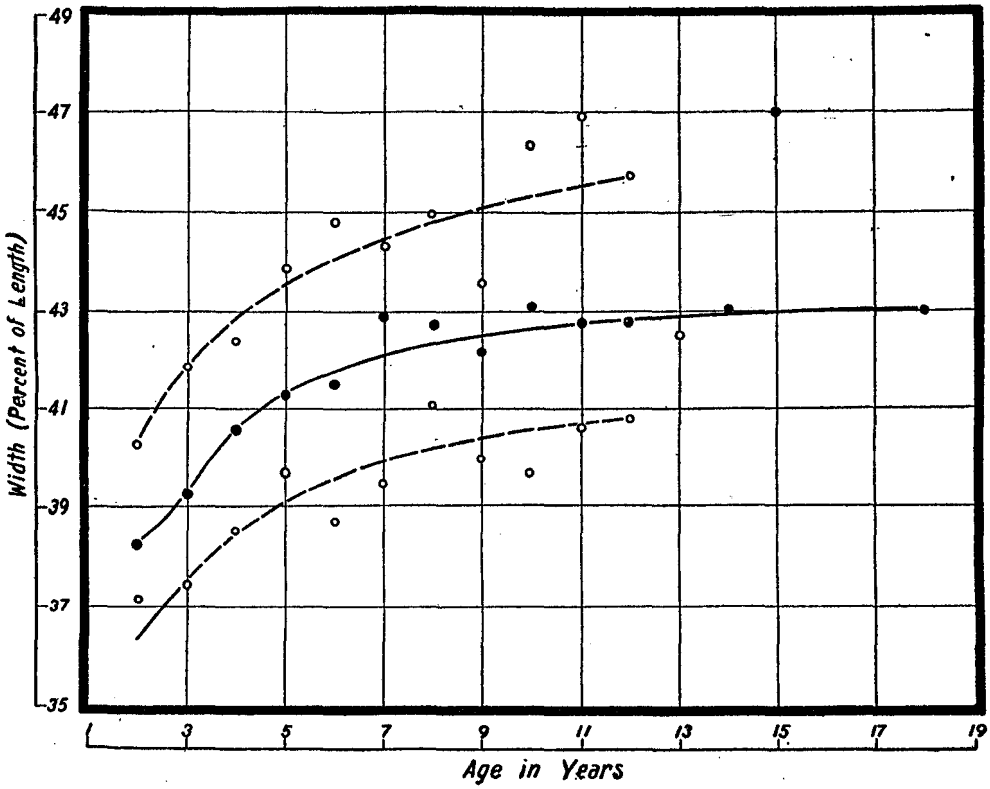

FIG. 1.—Showing increase in relative width with age. The solid line shows the median width at each age and the broken lines the 10th and 90th percentiles, between which are included 80 per cent of the widths. (Compilation of data derived from all sources.)

reach a certain size varies with the beds. Each year a new layer is added to the inner surface of the shell. In clams that have not reached their full size a thickened portion of the new layer extends beyond the margin, thereby increasing the size. The additions on some old clams increase only the thickness of the shell. Thus there is a relationship between the age of the shell and its thickness, and in comparisons both age and size must be considered.

The direction of the rib is another point of alleged difference between the two varieties. It is charactized as "straight" in "*patula*" and "oblique" in "var. *nuttallii*." The rib is somewhat more oblique in young shells than in old ones, and as Alaskan shells, on the whole, are older than those from the Columbia River district, it seems probable that "var. *nuttallii*" was described from younger shells than were used by Dixon for the original description. The direction of the rib varies between shells, but so far as can be determined there is no variation that is peculiar to or confined to one bed.

In the growth of the clam both length and width increase, but not in constant ratio. There is a variation between individuals of the same age and an increase in average width with age. The average relation of length to width (in percentages) at each age is plotted in Figure 1. The variation at each age is apparent; for example, at 3 years of age the width of eight out of every ten shells lay between 37.5 and 42 per cent of the length. If sufficient records are used to give a reliable average, it is seen that with increasing age the average width rises from about 38 to 43 per cent of the length. This change of relative width appears to be more closely correlated with age than with size. In comparing specimens of the same age from various localities we have been unable to find constant differences of significant size as compared with individual variation.

From what has been said it is clear that, in the description quoted above, the influences of age and relative size have not been considered, and that clams from the ranges of these two varieties do not differ significantly in the characters of direction of rib or of width of shell nor, so far as can be determined, in other features apart from those directly dependent upon environment. It will be noticed that "var. *alta*" is not included in this discussion. It is unsuited to canning and therefore is not considered in this paper. A thorough study of the shell and the soft parts shows it to be a separate species, distinct from *S. patula.*

The writers feel, after visiting beds on all parts of the coast and examining many thousands of shells, that the above views are sound. Excluding valid species, such as "var. *alta*" and *S. lucida*, which do not form a part of the commercial catch, we are dealing with a single form. Therefore, comparisons of its reaction to features of environment on different parts of the coast are valid. A more detailed consideration of these and other points of biological interest will be given in a later paper.

ANATOMY

Everyone who handles clams has noticed some of the more conspicuous parts and, since the mollusk is so different in structure from ourselves and other mammals, has wondered what the various organs are and how they work. The following brief sketch is intended to answer some of the most common of these questions and to give a glimpse of the plan of organization of a type of animal strange to most of us. A number of features of the anatomy of the razor clam merit more attention than is given here and may be treated later.

The clam, like other members of one group of mollusks, is protected by two similar shells or *valves* (hence the term *bivalves*), which are formed on the right and left sides of the animal, the back or dorsal side being that where the valves are joined together. This shell, which is so striking a feature of these animals, is a product of the *mantle*, a soft structure also characteristic of this group.

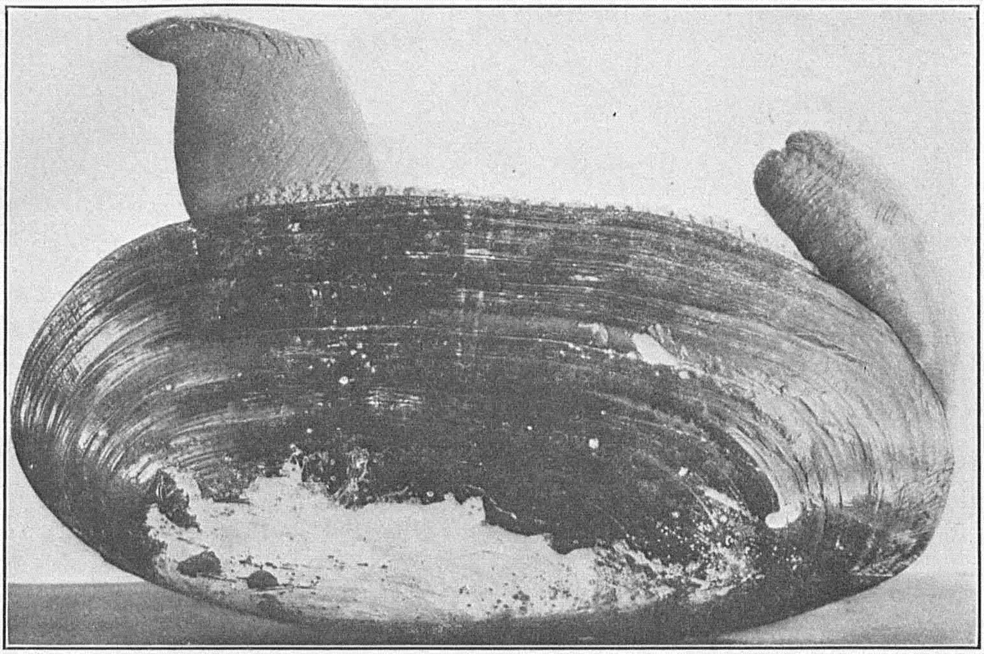

FIG. 2.—Razor clam, *Siliqua patula* (Dixon), side view

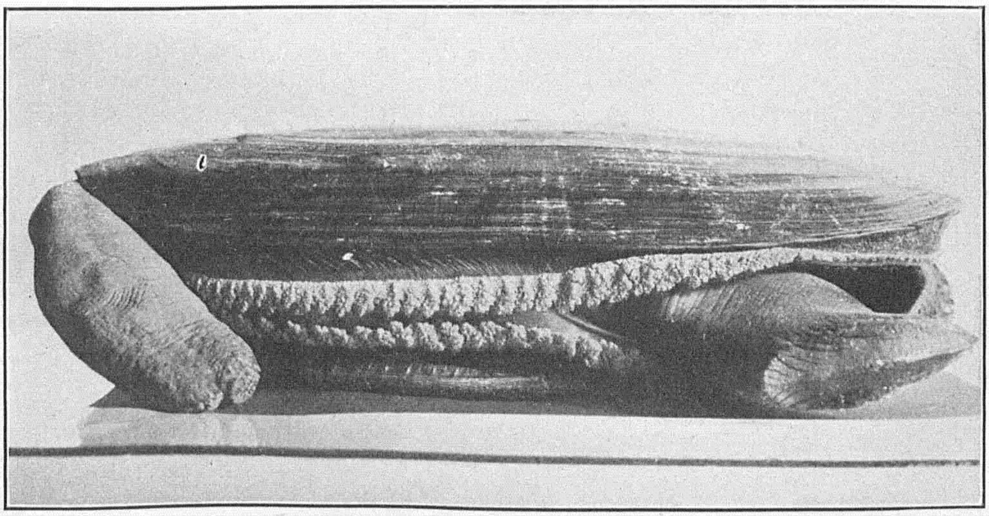

FIG. 3.—Razor clam, *Siliqua patula* (Dixon), ventral view

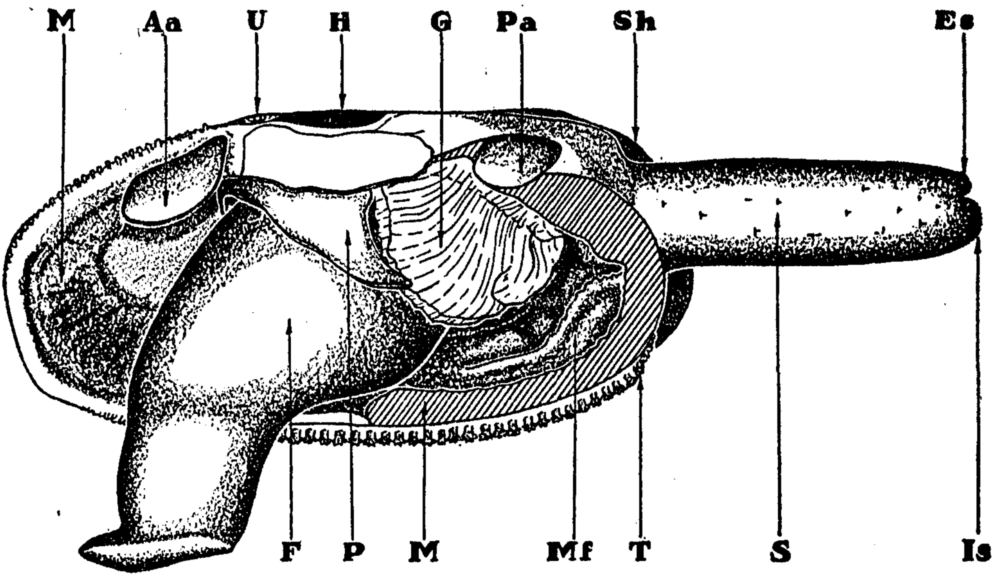

FIG. 4.—Razor clam. View of left side, with shell and mantle removed. *Aa*, anterior adductor. *Es*, exhalent siphon. *F*, foot. *Is*, inhalent siphon. *G*, gill. *H*, hinge. *M*, mantle. *Mf*, mantle fold. *P*, palp. *Pa*, posterior adductor. *S*, siphon. *Sh*, shell. *T*, papillæ. *U*, umbo

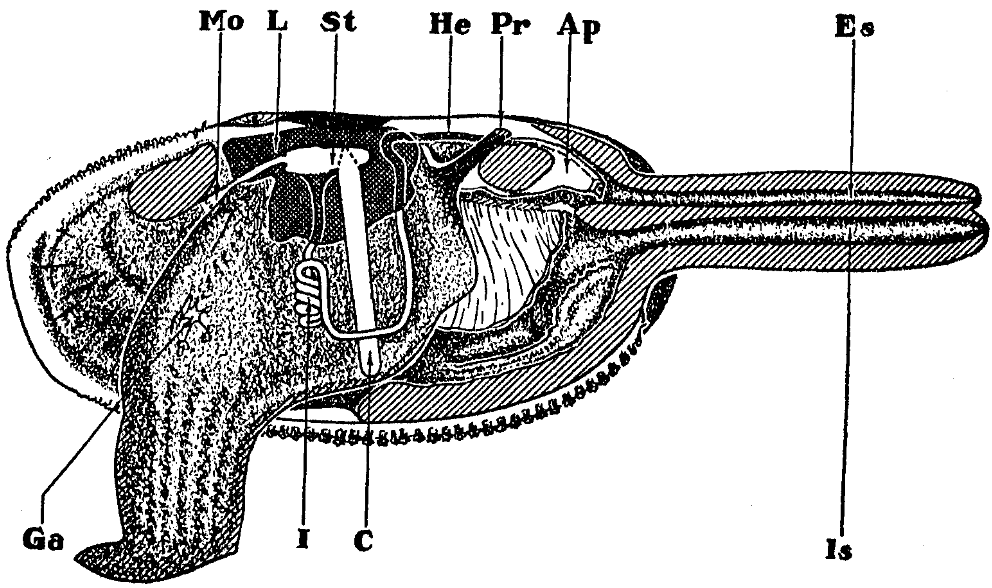

FIG. 5.—Same as Figure 4, but with left gills and palps removed, and siphon, foot, and visceral mass also removed. *Ap*, anal papilla. *C*, crystalline style. *Es*, exhalent siphon. *Ga*, pedal ganglion. *He*, heart. *I*, intestine. *Is*, inhalent siphon. *L*, liver. *Mo*, mouth. *Pr*, posterior rectractor. *St*, stomach

The *mantle* covers the animal as the flyleaves cover the body of a book, and by its activity secretes the valves of the shells, which thus come to occupy the position of the covers of the book. If we think of a book with limp leather covers, which bend over to meet each other around the edges and imagine the flyleaves doing the same thing, the picture is a very complete one.

Shells found on the beach or in the cannery shell piles lie flat, as an open book on a table. They are held in this position by the black hinge at the back. In life the valves are closed, to protect the animal, by the contraction of two large muscles, one toward each end of the shell. The muscles are called the *anterior* and *posterior adductors*, the latter being that nearer the siphon.

In the simplest form of mantle the edges are free except on the back, where the hinge is located, corresponding to the arrangement in a book, and the sea water may enter the cavity inclosed by the mantle at almost any place; this is the condition, for instance, in the oyster. In the razor clam, however, the edges of the mantle are fused, not only along the back, where the valves are joined together, but for about one-half of the remainder, chiefly at the posterior end. Three openings are left. The largest of these extends from the back around the anterior end and about halfway along the lower margin. Through this large slit the foot can be extended, and the hole is guarded by finely branched papillæ extending like ruffles along the margin (see figs. 4 and 5). When these are brought together, the sand is prevented from entering. At the posterior end the mantle is developed into a long double tube surrounding the two other openings of the mantle cavity. These form the siphon or "neck", which, contrary to the implication of the common name, is not at the anterior or head end but at the posterior or hinder end. We thus have, when the clam is feeding quietly in the sand, a fairly large cavity, in which hangs the main body of the clam, closed except for the double tube reaching up through the sand to the water above.

The mantle is lined with cells, most of which are covered with cilia—fine, microscopic, hairlike projections, but, unlike hair, always in vigorous motion. They lash sharply in one direction and return slowly, thus driving along any water that touches the mantle, like a myriad of tiny oars. The cilia on the mantle and gills all beat according to a plan which causes a current to flow out of the tube nearer the back, which is thus called the *exhalent siphon*, and in at the other, or *inhalent siphon*.

The water that passes through the mantle cavity supplies the clam with food and oxygen. The food consists of a great many microscopic plants and animals that live in the sea water. They are passed by the cilia across the gills (commonly called "livers" by those engaged in the industry) and the palps to the mouth, which lies just above and anterior to the foot near the anterior adductor. As the water passes through the gills it comes in close contact with the blood. An interchange takes place, similar to that in our own lungs in which oxygen is taken up by the blood and carbon dioxide given off. The waste products from the intestine are carried out by the water as it leaves the body through the exhalent siphon.

DIGESTIVE SYSTEM

The mouth of the razor clam has the shape of a flattened funnel and leads directly into a slender œsophagus. The œsophagus opens into the stomach, which lies directly under the hinge and in this clam is comparatively large; it is surrounded by a dark "liver," which secretes digestive juices into it through wide open ducts. The posterior part of the stomach is lined with cartilaginous tissue, from the bottom of which a long diverticulum extends downward to the lower margin of the foot. This is filled with a clear, gelatinous rod called the "crystalline style," containing a starch-digesting enzyme similar to that of the saliva.

The intestine leads downward from the middle of the stomach and is coiled below the liver, from whence it follows the posterior margin of the foot upward through the end of the liver. Here it turns abruptly backward, passes through the heart, over the posterior adductor, and ends in a fleshy papilla at the base of the exhalent siphon. There are two dark-colored kidneys, one on either side near the heart cavity.

NERVOUS SYSTEM

The nervous system of the razor clam is very simple, consisting of three pairs of ganglia. The *cerebral ganglia* lie on either side of the mouth near the lower surface of the anterior adductor muscle. The *visceral ganglia* occupy a somewhat similar position on the posterior adductor muscle; they are more closely united than are the cerebral. The *pedal ganglia* are closely fused and are embedded in the muscles of the foot. These pairs of ganglia are connected by nerves. There are no special sense organs except a pair of minute statocysts, or balancing organs, lying on either side of the pedal ganglia.

LOCOMOTION

One of the most interesting things about the razor clam is its unusual ability to move through the sand. The foot is quite different in shape from that found in the soft-shell and butter clams, being elongated and nearly cylindrical instead of flattened. It is a very effective burrowing organ, and, unlike many others, the razor clam retains throughout life a high power of active movement. In burrowing, the foot is extended from the shell; the tip, which is pointed, is thrust through the sand, and, when fully extended, the tip expands, forming an effective anchor. The foot is then retracted, drawing the body toward this anchored portion. Repetition of this action gives the clam a rapid movement.

The mechanism for the retraction of the foot is easily demonstrated. The bulk of the elongated foot consists of longitudinal fibers. These are connected with the shell by two specialized retractor muscles (anterior and posterior), one of which lies near each of the large adductor muscles which close the shell. The combined contraction of these shortens the foot with considerable force.

The method by which the foot is extended is less well understood. Clams taken out of the sand very often discharge a large amount of fluid from the tip of the foot, apparently through a rupture of the body wall. It is generally assumed that the contraction of the circular fibers of the foot and visceral mass forces this fluid to extend the foot by hydraulic pressure.

SPAWNING

In most mollusks the sexes are separate; in a few, however, both eggs and sperm are produced by the same individual. In the razor clam, as in most forms, all observations have shown each individual to have germ cells of one kind only. The reproductive material is cast into the water at spawning time, and there fertilization and further development take place.

Only by examination of the gonads is it possible to tell the sex of the clam. There are no superficial characters that betray the sex. If the contents of the gonads are spread on a glass slide or on a scalpel, a marked difference between sexes is apparent. The ova have a granular appearance, in contrast to the viscous homogeneous mass in which the sperm is found. The sexes of the entirely immature clams can be determined only by microscopic examination of tissue, which was not carried out in this case while in the field. A large number of clams in more advanced stages of maturity were examined and the sex recorded. This was done for two reasons—to determine the stage of maturity and to make sure that both sexes were equally represented. As far as has been determined both sexes pass through similar stages in an equal period of time, and from the standpoint of maturity and growth they do not differ, hence, in the following calculations the sexes have been combined.

TIME OF SPAWNING

Data were obtained from the 1923 and 1924 spawning seasons on the Washington coast (McMillin, 1923). These two spawnings differed somewhat and may represent two extremes. As described in the above reference, the 1923 spawning took place on May 30, 31, and June 1. It was practically simultaneous, and the major portion was completed in a very short time. As a result of this spawning a heavy set of young was produced, the average per square foot on the whole beach numbering more than 1,400. The spawning of 1924 was different, apparently because the temperature during May was variable and the average remained low. Spawning started on a rise of temperature on June 12, the rate of discharge of eggs was reduced by lowered temperature on June 14, and after that spawning continued slowly for two weeks. Although the action was slow, all observations showed the clams to be acting in unison, and at any one time all seemed to be in the same condition. The result of this year's spawning was negligible, no specimens representing this class having since been found.

In 1923 the spawning on the Oregon coast was not followed. On the North Beach section of Washington, extending from Willapa Harbor to the Columbia River, spawning started on May 19. On the section beween Willapa and Grays Harbors it started on May 24, and on the Copalis section, as already described, on May 30. In each of these sectors the whole population of the beach spawned at the same time. No data were collected for the Queets and Kalalock beds of

FIG. 6.—Small clams, Copalis beach

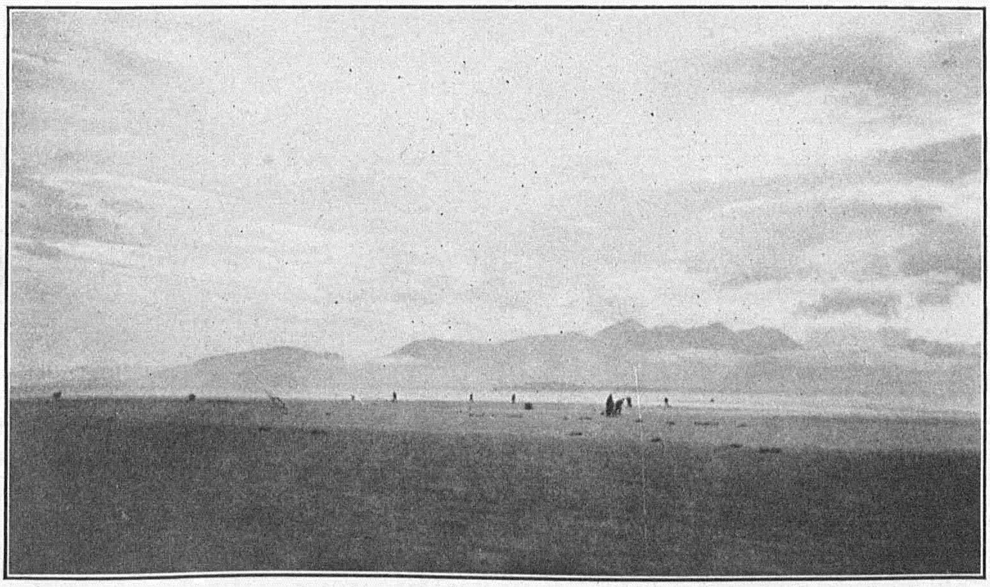

FIG. 7.—Digging on the "river spit," Swickshak beach

northwestern Washington. There is no available information on spawning on the Vancouver Island and Graham Island beds in Canada.

While visiting the canneries and beaches of Alaska, as many observations as possible were made on the condition of the clams at various times. During the season several cannery men preserved specimens in formalin at stated intervals. These specimens were collected and examined further to determine the amount of reproductive material in the gonads during each part of the season. In this way it is possible to fix approximately the spawning season for each section from which specimens were obtained.

Spawning records for the vicinity of Cordova are very incomplete. The observations made on preserved material and the examination of clams on the beds indicate that spawning started soon after July 1, 1924. On July 13 but 2 per cent of the clams showed they had recently spawned out, 10 per cent had full gonads of such consistency as to indicate no active spawning, and the remainder (88 per cent) showed various degrees of incomplete spawning. On August 15, when over 400 specimens were examined, but 2 per cent carried any appreciable amount of spawn, 28 per cent showed the presence of a small amount of reproductive material, and 70 per cent were completely spawned out.

The two records cited above were taken over a month apart. They give a fair example of what is found to exist generally in Alaska. There is no short common spawning season, as is found on the Washington beaches, but rather a gradual changing over in the condition of the clams, from those in midsummer with large, full gonads to the thin, spent ones in early fall. The process takes over a month, although it is probable that any particular individual may cast its entire spawn more quickly.

Similar conditions are found to exist elsewhere in Alaska. Near Chisik Island in Cook Inlet observations were made during the summer of 1923. The clams appeared fullest, or "fat," in late July. Evidently spawning started between July 25 and 30. After August 1 it proceeded more rapidly and continued as long as specimens were obtained. On September 25 a few showed the presence of a very small amount of reproductive material, but it is doubtful if any spawn was being cast.

The figures from Swickshak Beach for 1923 and 1924 show that the clams develop reproductive material rapidly in early May. By July 1 they are quite full, and they start spawning between July 20 and 25, but proceed most rapidly after August 1. They appear to spawn out somewhat more rapidly than on either the Cook Inlet or Cordova beaches. Before September 1 spawning was completed.

RELATION OF WATER TEMPERATURE TO SPAWNING

From the excellent work of Dr. Thurlow C. Nelson (1921) it is apparent that the water temperature is closely correlated to the spawning of the oyster. A critical temperature of 21° C. (70° F.) has been found, below which oysters will not spawn. Above 21° C. spawning will take place more rapidly as the temperature increases. It is further stated that due to continued cold weather, where the water has failed to reach the critical temperature for any length of time, the eggs will not be cast, but rather be resorbed by the oyster.

From the meager data available it appears that temperature influences the spawning of the razor clam very much as it does the oyster. During the winter the gonads are very small; they consist of a series of tubules lying among the muscle bundles of the foot and about the intestine. After the first rise in temperature in the spring the gonads increase in size. They gradually distend the visceral mass until they form about 30 per cent of the total body weight and cause a decided gape in the shell. The eggs and sperm are contained in follicles within the tubules. Shortly before spawning it appears that the follicle walls are ruptured or disappear, and the reproductive products are then free within the tubules.

While more data would be desirable, available records indicate that the temperature of the water over the beds is closely related to the act of spawning. It is known that a high temperature is accompanied by rapid spawning of the clam, and a drop in temperature arrests progress. During the season of 1923 the

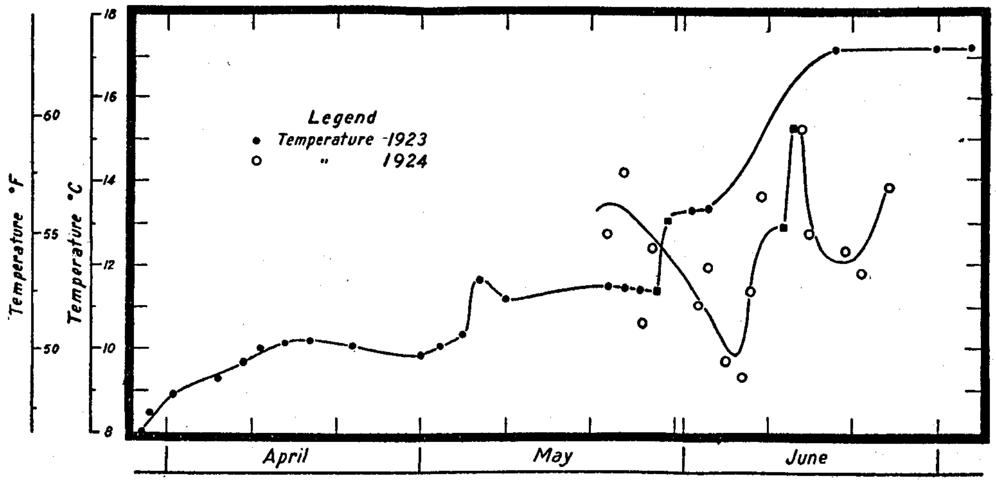

FIG. 8.—Showing water temperatures at Copalis during the seasons of 1923 and 1924. The rise of temperature that immediately preceded spawning in both cases is indicated between the square dots (■—■)

temperature of the water over the beds at Copalis rose steadily from 8° C. on March 27 to 11.5° C. on May 20. During this time there has been a constant increase in the size of the gonads but no active spawning. Between the taking of the temperature at 6 a. m. on May 29 and a similar time the following day there was a rise in temperature from 11.4 to 13.1° C. (See fig. 8.) Spawning started quickly and with great vigor. There was no appreciable drop in temperature, and spawning was nearly complete in two days. Some eggs remained in the gonads, but they were few in number compared with the great mass that had been cast.

The following year (1924) spawning started 14 days later. The temperature of the inshore water, as well as that at the Columbia River Lightship off the mouth of the Columbia River, was more variable than that of the previous year. Again spawning started immediately following a rise in temperature, which in this case was from 12.8 to 15.3° C. Two days later the temperature dropped sharply to 12.6° C., accompanied by a greatly reduced rate of spawning. Less spawn was cast in 10 days during this period of low temperature than during the 2 days of the preceding year. From all indications spawning may have been suspended entirely during part of the time. No attempt was made to correlate the rate of spawning with the number of larvæ in the water, which Nelson has shown to be possible with the oyster. The condition of the clams was determined by opening a large number and making direct observations on the contents of the gonads.

Temperatures taken in Alaska near the spawning time were very similar to those on the Washington beds. The open beach near Cordova had a temperature of 13.9° C. on July 16, which was shortly after the onset of spawning. The protected waters of Orca Inlet and adjoining bays from which claims were taken varied in temperature from 12.8 to 14.5° C. The temperature records from Swickshak Beach showed an average of 13.5° C. at spawning time.

These figures suggest a critical temperature of about 13° C. (55.5° F.) for the razor clam, as compared with 21.0° C. (70° F.) for the oyster. The summer temperature of the Alaskan waters is quite high in all cases, except where influenced by glaciers or glacier-fed rivers. The variation from day to day in the Ketchikan records is less striking than on the Washington coast. For instance, the variation at Ketchikan for the month of July was from 13.5 to 16.0° C., and for August, 13.0 to 17.0° C. In contrast to this, similar figures for the Washington coast were as follows: July, 10.6 to 17.2° C.; August, 11.1 to 17.2° C. On two occasions during the summer of 1923 the temperature of the shore water at Copalis dropped more than 6° (centigrade) over night. This cold water was accompanied by a fog which was largely confined to the beach. Crab fishermen outside the harbor declared it was clear a short distance offshore, and personal observation showed the fog to extend not more than half a mile inland.

A few hours after the cold water was noticeable on the beach a peculiar collection of material was cast up by the surf. It contained a great many sponges, snails and snail shells, worm tubes, cast crab shells of several varieties, and a great mass of other detritus, which ordinarily rest lightly on the bottom. This indicated the presence of a current of comparatively high velocity moving landward over the bottom, which caused an upwelling of cold water along the shore. It was evidently of small extent, as it affected not over 20 miles of coast line.

It was suggested by McEwen, in a personal communication, that this upwelling was not similar to one described by him (McEwen, 1912) from the California coast but, rather, it was caused by some local condition of the air currents. While the Ketchikan temperature record does not show the sharp transient drops that might be expected from such an upwelling, this would not prove that upwellings do not occur in this region. Their effect would be most marked on the outer coast; as, for example, on the west side of Prince of Wales Island the circulation of the tide among the many islands of the Alexander Archipelago would tend to obscure fluctuations of the inland waters about Ketchikan.

As has been shown by J. Nelson (1917), oysters acclimated by living for many years in the Gulf of St. Lawrence have a reduced critical temperature of 20° C. (68° F.). It has been further shown by T. C. Nelson (1921) that oysters moved from New England to New Jersey spawn two weeks earlier than do the native oysters. Those moved north from Virginia spawn later than the native strain.

The critical temperature for the razor clam of Alaska is probably not lower than for those on the Washington beach, as the slight difference in summer temperature probably insures an opportunity for spawning along the whole coast under similar conditions. The temperature of the inshore waters, from Pismo, Calif. (the southern limit of *Siliqua patula*), to the end of the Alaskan Peninsula, is quite uniform during the summer.

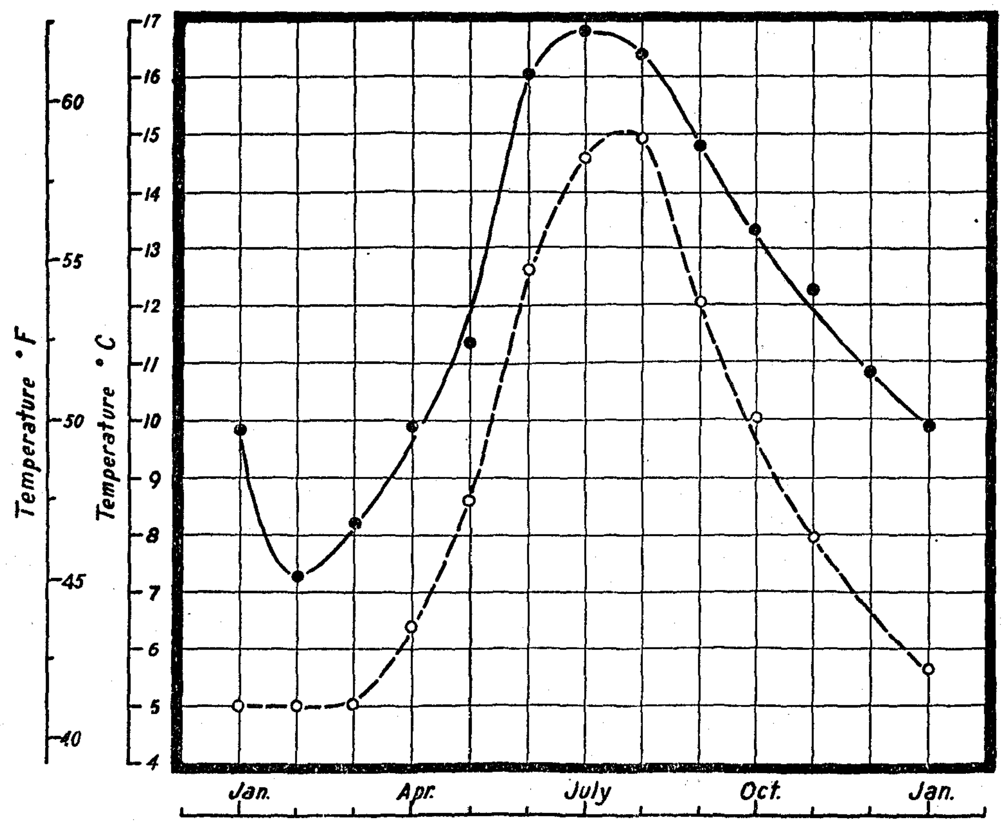

FIG. 9.—Showing the mean (average) monthly temperatures for Washington beach and Ketchikan (Ketchikan temperatures furnished by U. S. Coast and Geodetic Survey). ● — ●, Washington beach; o — o, Ketchikan

The temperature record for Ketchikan is the only complete set for Alaskan waters. Comparison of these with records taken over the clam beds indicate that they are representative of conditions that exist generally over the whole region. The more southern waters reach what might be called a normal temperature earlier than do those farther north, and they also cool later in the year. For instance, the Washington temperature was above 13° C. for twice as long as was the temperature at Ketchikan during the 1923 season. (See fig. 9.) The mean temperature for each month showed a difference in the maxima of 1.8° C., while the actual difference was illustrated by the reading on August 5, which was Washington, 17.2° C., and Ketchikan, 17° C.

LARVAL DEVELOPMENT AND GROWTH OF YOUNG

The spawning season of 1923 presented an excellent opportunity for the study of larvæ on the Washington coast. Spawning took place in a very short time, and the razor clam larva was the predominant form taken in plankton tows made during the time when they were swimming. Three weeks after spawning the larval stage appeared in the tows. At that age the shell is transparent and can be seen only when shattered by slight pressure. One month after spawning a great number of what proved to be half-grown larvæ were found in the surf at high tide. In tows taken in 4 feet of water at the same time many similar larvæ and some larger ones were found. More were taken at high tide than at low tide. This may have been due to the flood tide raising the larvæ out of the surface layer of the sand and carrying them in the surf during the remainder of the flood and part of the ebb of the tide. As the larvæ increased in size more were found in the sand, and at the same time the numbers in the tows decreased. All clams were considered as larvæ until they had opaque shells covered with a brown periostracum, and the shape had become markedly elliptical.

There is no evidence of extensive migration of adult clams. In fact, observations point to a very limited range for any individual. The distribution occurs mainly during the larval stages. As the period during which the young are in the swimming stage amounts to about eight weeks, the excellent set resulting from one spawning would indicate that the larvæ are largely confined to the sand. If the eggs and larvæ were free for this length of time they would probably be so widely scattered that the original beds would not be heavily stocked. The eggs sink quite rapidly and are not easily raised by surf action. They are probably discharged at the surface of the sand. If they sink as soon as they have left the body of the mother and resist the action of the surf, which would tend to scatter them, they would be fertilized in great numbers in the surface layer of the sand. As they also spend a large part of their larval life in the sand, it is not surprising that the resulting set in one place is enormous. However, the young clams do swim and the eggs are doubtless moved about, but apparently not to the extent that might be expected from an eight weeks' larval period.

LENGTH OF LARVAL LIFE AS COMPARED WITH OTHER MOLLUSKS

The length of the larval life of the razor clam seems quite long when compared with that of other mollusks. It has been found by Nelson (1921) that the eastern oyster (*Ostrea elongata*) has a free-swimming stage lasting from 14 to 18 days. This was determined by direct observation under known conditions of salinity and temperature.

According to Kellogg (1910) the soft clam (*Mya arenaria*) swims as a larva for from three to six days. The general observations from which this indeterminate period was inferred are not very satisfactory. A number of difficulties are encountered. Attempts to rear them artificially were unsatisfactory, and because of the extended breeding season and the numerous similar young of other mollusks the direct observations of the larvæ were not decisive.

Belding (1910 and 1912) concluded that the quahog (*Venus mercenaria*) remained a free-swimming larva from a week to 12 days, while the pecten (*Pecten irridans*) passed through the corresponding stage in about a week. It was concluded by Field (1922) that the common mussel (*Mytilus edulis*) remained in the free-swimming stage about two months when living under natural conditions. He compared the specimens taken in nature with those raised in an aquarium and arrived at quite definite conclusions.

This length of time agrees more closely with the larval period of the razor clam. The larvæ differ in one respect, however, as the mussel is actually swimming during the greater part, if not all, of the period, while the razor clam is more inclined to remain in one place. The mussels are scattered over a great area and are dispersed by this method. The habitat of the razor clam is more limited, and the larvæ do not scatter to a like degree.

TIME OF SETTING AND GROWTH OF YOUNG

Eight weeks after spawning large clam larvæ visible to the unaided eye were found in a quiet lagoon. None of this age was taken with the plankton net in the surf, although repeated attempts to do so were made at several places. It is probable that the majority had already passed through this stage. The larval shell was now dense enough to hinder observation of the organs, and the posterior end had a marked tendency toward the elongation which is so marked in the adult clam. Prominent gills were present, but no velum was seen.

While under observation the live specimens would extend the characteristic long foot from the shell. Five days later small clams in the adult stage were found in the surface of the sand. They averaged 0.25 centimeter in length and were the forerunners of a very heavy set. Distribution was slightly uneven, although they were everywhere abundant, averaging approximately 1,450 per square foot. At this size they were found in the surface layer of the sand, and if a small hole was dug in the wet sand it quickly filled with water in which there were a number of small clams. If the water in this depression were given a circular motion with the hand, a number of small clams, as well as sand from the edge, were dislodged. The clams tended to be whirled to the center, but as they are very active, even when being carried quite rapidly over the surface of the sand, they will catch their foot in the sand and disappear from sight.

At intervals large numbers of small clams were taken by screening the sand. These were measured and the median size determined. (See fig. 10.) During the month of August the small clams increased in average size from 0.25 to 0.88 centimeter. The following month they grew to 1.39 centimeters in average length. A marked decrease in the rate of growth was found in October, during which month an increase of only 0.24 centimeter was shown. At this time the average length was 1.63 centimeters, and no further growth was observed.

MORTALITY OF YOUNG

The preceding paragraphs give some idea of the great number of small clams that may settle in the sand in late summer as the result of a successful spawning year. The set is not equally heavy in consecutive years. Some years the young are very numerous, while at other times it is difficult to collect specimens enough for an examination. The abundant set of 1923 gave an excellent opportunity to study the mortality as well as the growth of these small clams during the first season.

On August 1 the young clams, now only 0.25 centimeter in average length (about 1/8 inch), were found on the beach in great numbers. From four counts the

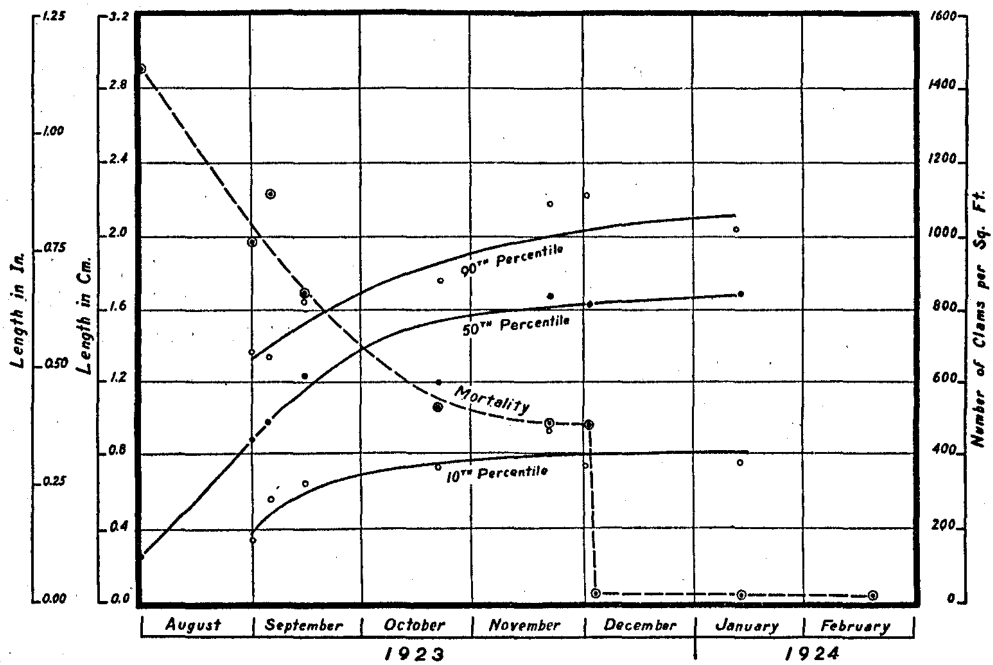

FIG. 10.—Showing the growth and mortality of small clams on the Copalis beach of Washington in 1923. Solid lines, read from scale on the left, indicate growth, showing rapid increase in size during August, soon after settling in the sand, and no increase during the winter. The broken line, referred to scale on the right, shows the decrease in numbers of small clams per square foot. The sudden drop in early December was due to a storm

average number per square foot was found to be 1,451. In determining the distribution the clams were taken only from the top layer of the sand about 2 inches in thickness. The shifting of the sand may account for some errors, as Thompson (1919) has shown that the action of the surf on exposed sand beaches continually changes the topography of the beach. This was illustrated by the counts of September 1 and 9, in which 986 clams per square foot were found on the first date, while 1,122 were found on the same area nine days later.

As indicated by the figures just given, there was a steady decrease in the number of clams per unit area. By late fall they had been reduced to a third of the original number. On December 4 there was an average of 494 per square foot. On that date a heavy storm strikingly changed the topography of the beach. An extraordinarily heavy surf dragged the sand from the high beach out into deep water. Certain sections of the beach were lowered 4 or 5 feet. While it is natural to assume that a great number of the small clams perished, undoubtedly many were carried out into deep water where their survival is uncertain.

A census of the beach immediately after the storm showed very few clams. Some places were entirely barren, but an examination of the entire beach gave an average of 18 per square foot. During the winter there was a lighter mortality, leaving about 16 per square foot when examined the following February. Of these survivers very few, if any, were left the following summer. Thus we see that the number of small clams resulting from one spawning is no criterion of the extent to which that year class will affect the commercial catch. The records given above show the total loss of a very heavy set; therefore, a successful spawning does not necessarily indicate that the population of the beds will be increased by it.

The fate of clams removed to the area below low tide is questionable. Small clams are not found in water deeper than 12 feet, and probably only stragglers among the mature clams are found far from the intertidal zone. In the instance cited above a great many may have been removed to the area exposed at the lowest tides only or bordering these areas. They would then supplement the number already there, and might even spread out and return to the higher levels, where they might be taken by the diggers.

The State of California is attempting by a yearly census to find the abundance of the annual set and to follow the survival of the young of the Pismo clam from year to year. This is done by taking all clams from a trench crossing the entire beach. The process is repeated at several places in order to obtain a reliable average. The clams are then sorted as to age, and the number of each class for each meter of trench is recorded. The result of the last census is given by Herrington in a paper which will appear in an early number of the California Fish and Game Bulletin (1925). A similar system of annual surveys of the Washington beach, supplemented with the examination of the cannery shell piles, would give an index of the beach population. The census of the set each year, with an analysis of its subsequent effect upon the commercial catch, would make it possible to determine the result of fishing, protective measures, and to foretell with some degree of accuracy the amount of the commercial catch.

GROWTH OF THE ADULT

RING METHOD OF AGE DETERMINATION

The size at various ages is a matter of very great practical importance in various questions, such as the determination of age at sexual maturity and the efficiency of protective legislation. Since the absence of direct observation which can fix the age has made is necessary to use extensively the indirect determination by "annual rings," a short statement of this method will be desirable.

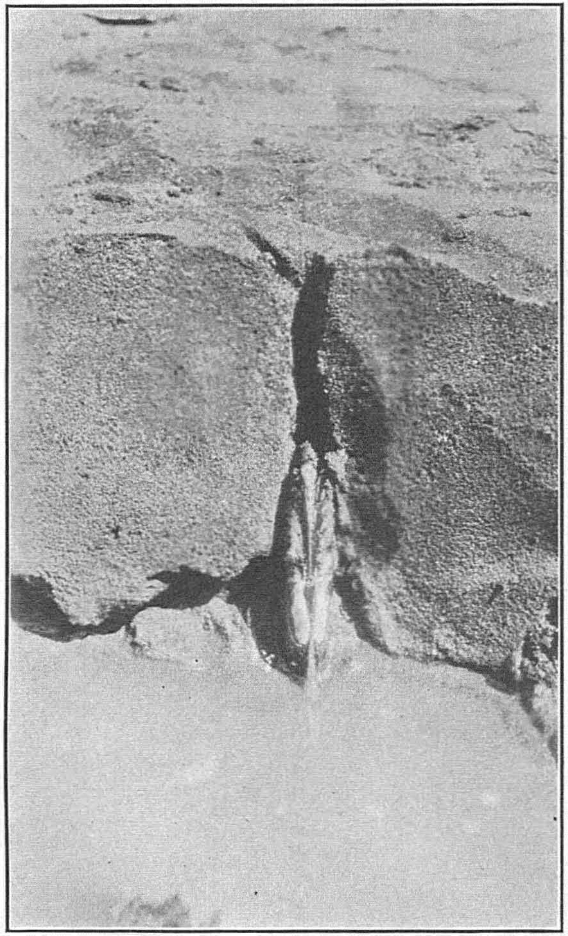

FIG. 11.—Clam in a burrow, ventral view

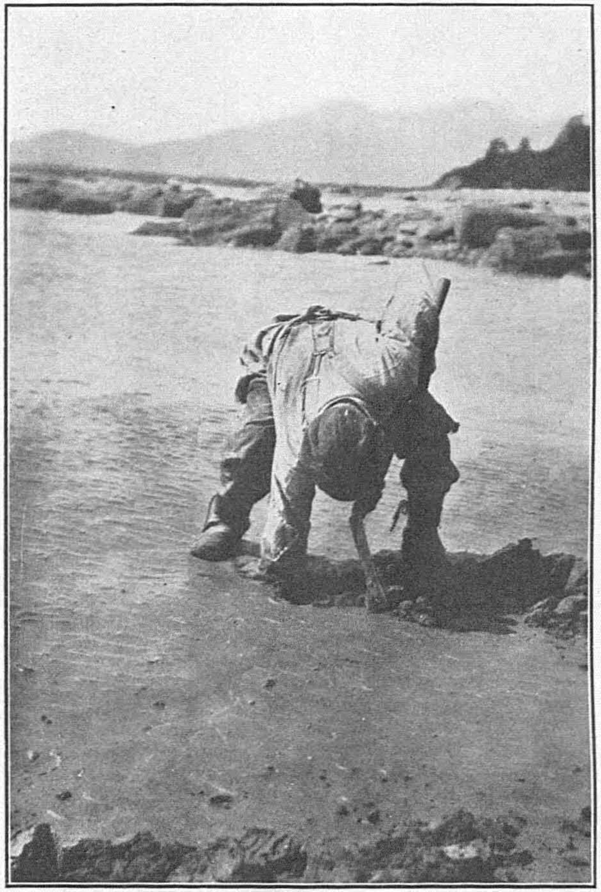

FIG. 12.—Native digger, Snug Harbor

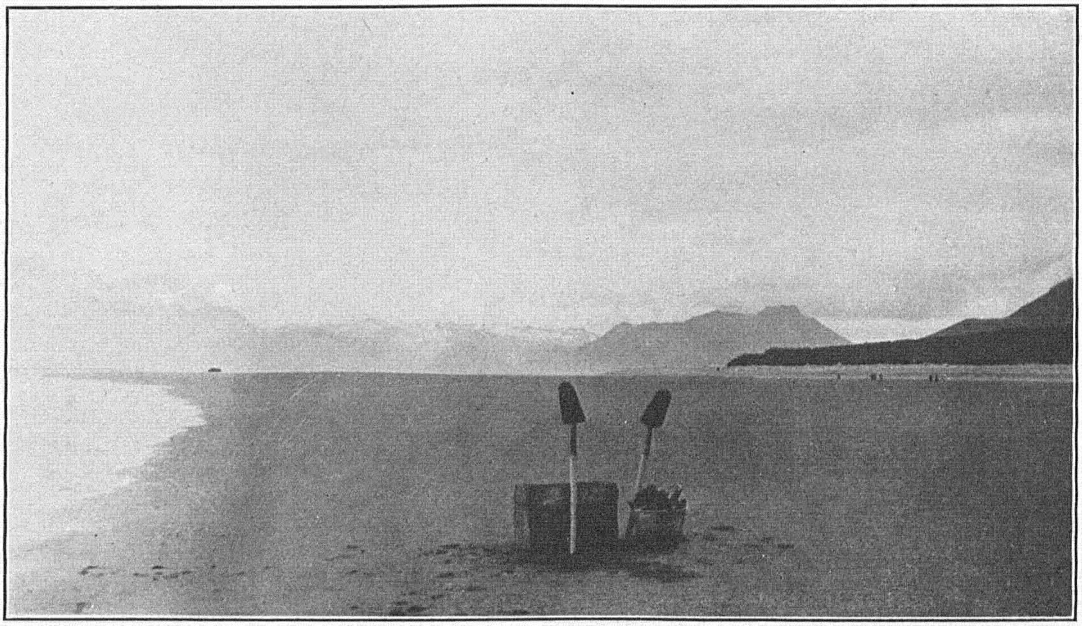

Fig. 13.—Clam digger's equipment, Swickshak beach

The method is that which has long been unquestioningly applied to trees, which, in their structure, show evidences of the number of seasons through which they have passed. The annual nature of the "rings" visible in the shell of the clam has been clearly proved by the senior author (Weymouth, 1923) in the case of the Pismo clam. The same method has already been applied to the razor clam (McMillin, 1923). In brief, it rests upon the fact that the clam does not grow at a uniform rate, growth being rapid in summer and slow or absent in winter. This is illustrated by the results obtained by following the young of the Pismo clam through two years (Weymouth, 1923) and the small razor clams through one year.

Figure 10 (reproduced from McMillin, 1923) shows the absence of growth during the winter. The possible reasons for this, chief among which appears to be temperature, are discussed in detail in the papers referred to and need not be considered further here. For our purpose it is sufficient to note that the rings are formed during the season of slow growth. This is confirmed by many observations on the razor clam, in that the relation of the rings to the growing margin of the shell in clams small enough to show appreciable annual growth is always what might be expected for a winter formation of the ring. They lie close to the margin in the spring, farther away in the summer, and farthest in the fall.

This is further supported by the study of size frequencies. During the winter all clams were taken from a certain area of beach and their total lengths recorded. By tabulating these in size classes a frequency table was obtained from which a curve was constructed (McMillin, 1923; fig. 8). This curve showed modes the location of which corresponded to the lengths of the annual rings for the second and third years. After the third year the overlapping in size of the different year classes obliterates the modes of each class.

The annual ring is a structural feature of the shell and not a superficial mark. In the broken shell a layer marking the surface of the shell at the time the ring was formed can be seen extending from the ring on the present surface through the entire shell. A white line remains on the underside of the periostracum when it is peeled off. This is found to mark the location of the annual ring. Some feature of the growth about the time of the formation of the ring causes the periostracum to become fused with the calcified portion of the shell, thus giving emphasis to its location. From these facts it is clear that a ring of definite character is formed once and only once each year and is therefore a definite indication of age.

The difficulties in applying this method are of three kinds. (1) Injury to the edge of the shell in summer may retard the growth and cause a check that might be confused with the annual ring. (2) A first and sometimes a second ring is difficult to determine on clams 12 or more years of age, as these early rings are formed on very thin shells and may be removed by erosion. (3) The crowding of the annual rings near the edge of the shell, due to the very small increment of growth, makes the location of the last rings in old shells indefinite. From the above causes some records may be in error, but the number and magnitude of these are not large, and because of the great number of observations the general results can not be appreciably affected.

GROWTH IN DIFFERENT LOCALITIES

Many shells of various localities have been examined and the total length of each ring determined, thus giving a great mass of records of lengths at known ages. All measurements were made with one caliper by one or two persons. The caliper was graduated in millimeters, and by the use of a vernier scale could be read to tenths of millimeters. While all measurements were made and recorded in tenths of millimeters, the last place was not used in calculations. A few measurements were made in the field, but the majority were made in the laboratory. There is

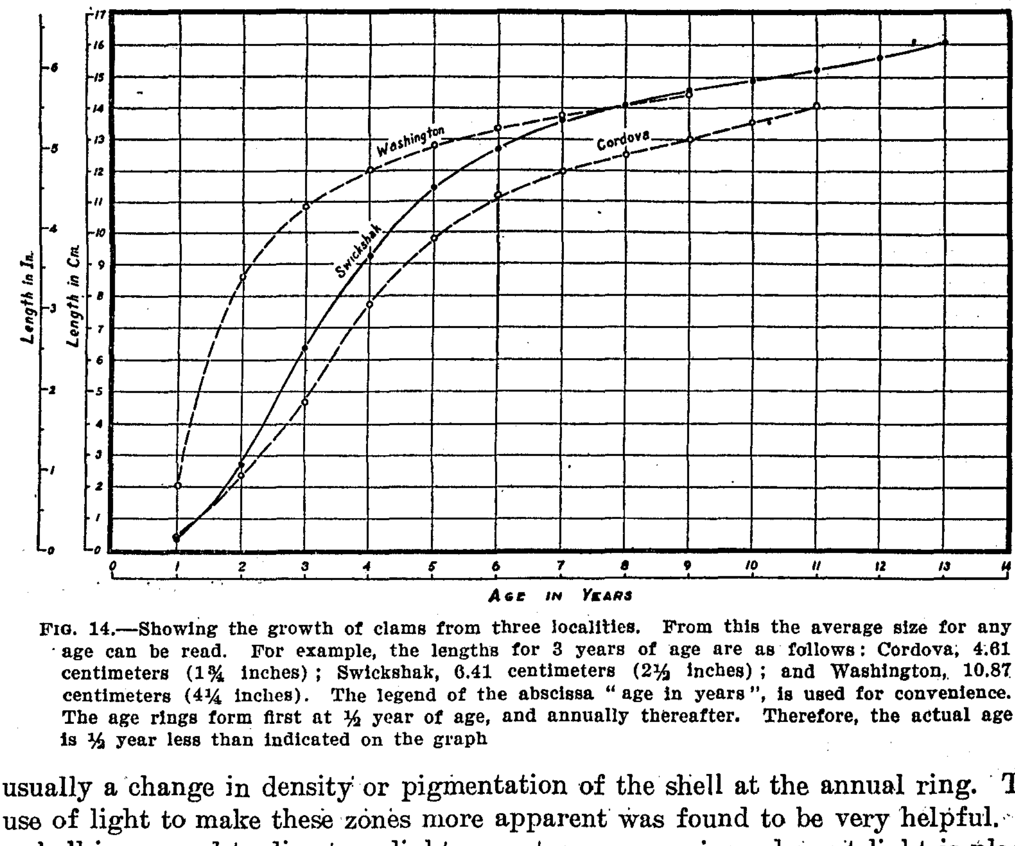

FIG. 14.—Showing the growth of clams from three localities. From this the average size for any age can be read. For example, the lengths for 3 years of age are as follows: Cordova, 4.61 centimeters (1¾ inches); Swickshak, 6.41 centimeters (2½ inches); and Washington, 10.87 centimeters (4¼ inches). The legend of the abscissa "age in years", is used for convenience. The age rings form first at ½ year of age, and annually thereafter. Therefore, the actual age is ½ year less than indicated on the graph

usually a change in density or pigmentation of the shell at the annual ring. The use of light to make these zones more apparent was found to be very helpful. If a shell is exposed to direct sunlight or a strong arc or incandescent light is placed under it, the annual rings show up in such a way that they can be measured without difficulty.

From measurements made in this manner growth curves for clams from various beaches have been constructed. Three curves presented here (fig. 14) were made from clams taken from beds at Copalis, Wash., and Cordova and Swickshak, Alaska. The data are given in tables 1 to 4, inclusive.

TABLE 1.—*Copalis: Adult razor clams, total length at time of formation of each ring, based on ring measurements*

Length, in centimeters, mid-value of class	Ring number									Length, in centimeters, mid-value of class	Ring number								
	1	2	3	4	5	6	7	8	9		1	2	3	4	5	6	7	8	9
0.60	18									8.00		23							
0.80	17									8.20		28							
1.00	11									8.40		21							
1.20	22									8.60		31							
1.40	31									8.80		28							
1.60	44									9.00		32							
1.80	53									9.20		32	1						
2.00	55									9.40		33	4						
2.20	58									9.60		31	8						
2.40	53									9.80		37	9						
2.60	33									10.00		12	22						
2.80	19									10.20		7	23	1					
3.00	16									10.40		2	49	1					
3.20	9									10.60			50	5					
3.40	13									10.80			53	3					
3.60	7									11.00			46	8					
3.80	5									11.20			45	10					
4.00	3									11.40			34	22	3				
4.20	1									11.60			34	52	2				
4.40		1								11.80			29	49	4	1			
4.60		1								12.00			10	63	22				
4.80		11								12.20			4	54	16	2			
5.00		1								12.40			2	45	37	5	1		
5.20		4								12.60			1	40	41	6	2		
5.40		2								12.80				21	74	15	4		
5.60		5								13.00				4	46	34	1	3	
5.80		10								13.20				3	30	37	10	1	
6.00		8								13.40				5	25	48	20	1	1
6.20		9								13.60				2	14	34	25	3	
6.40		11								13.80					6	31	32	12	2
6.60		5								14.00					7	20	27	15	1
6.80		10								14.20					2	4	19	12	2
7.00		10								14.40					1	8	15	12	3
7.20		11								14.60						4	9	6	2
7.40		15								14.80						1	6	7	1
7.60		22								15.00							1	2	4
7.80		14								15.20								1	2

TABLE 2.—*Cordova: Adult razor clams, total length at time of formation of each ring, based on ring measurements*

Length, in centimeters, mid-value of class	Ring number										
	1	2	3	4	5	6	7	8	9	10	11
0.10	28										
0.30	75										
0.50	35										
0.70	17										
0.90	2	3									
1.10		10									
1.30		15									
1.50		24									
1.70		37									
1.90		48									
2.10		52									
2.30		55									
2.50		66									
2.70		41	1								
2.90		29	4								
3.10		25	3								
3.30		14	6								
3.50		1	5								
3.70		1	15								
3.90		1	29								
4.10		1	33								
4.30			36								
4.50			33								
4.70			34								
4.90			38	2							
5.10			39	2							
5.30			38	1							
5.50			30	5							
5.70			22	7							
5.90			25	15							
6.10			14	12							
6.30			11	13							
6.50			10	20							
6.70			4	25							
6.90			2	21	1						
7.10				26	4						
7.30				32	5						
7.50			1	34	2						
7.70				32	8						

Length, in centimeters, mid-value of class	Ring number										
	1	2	3	4	5	6	7	8	9	10	11
7.90				35	13	1					
8.10				31	15						
8.30				29	10	1					
8.50				17	12	1					
8.70				21	15	5					
8.90				11	20	3					
9.10				14	22	7					
9.30				7	25	5	1				
9.50				4	27	13					
9.70				3	33	11	1				
9.90				1	35	10	3				
10.10				1	32	15	4				
10.30					36	9	4	1			
10.50					22	20	3				
10.70					28	19	10	3			
10.90					11	22	12	2			
11.10					11	22	14		1		
11.30					9	28	15	3			
11.50					5	14	14	8	1		
11.70					3	20	9	10	3		
11.90						18	27	3	1		
12.10						16	27	16	5	1	
12.30						15	15	12	1	4	
12.50						18	22	14	5	2	
12.70						17	16	12	7	1	3
12.90						13	18	8	9	4	2
13.10						9	8	14	8	3	1
13.30						8	2	9	5	8	3
13.50						11	1	3	5	4	2
13.70						3	1	6	5	5	4
13.90						2	1	2	4	5	2
14.10									2	6	6
14.30									1	2	3
14.50									1	3	1
14.70										1	5
14.90										1	3
15.10											1
15.30											1

TABLE 3.—*Swickshak: Adult razor clams, total length at time of formation of each ring, based on ring measurements*

Length, in centimeters, mid-value of class	Ring number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.10	62													
0.30	11													
0.50	32													
0.70	21													
0.90	11	1												
1.10	1	1												
1.30		9												
1.50		12												
1.70		17												
1.90		31												
2.10		55												
2.30		65												
2.50		68												
2.70		96	1											
2.90		65	1											
3.10		74												
3.30		42	4											
3.50		34												
3.70		31	4											
3.90		11	9											
4.10		7	8											
4.30		4	7											
4.50		4	12											
4.70		1	25											
4.90		1	11											
5.10			17											
5.30			31											
5.50			27											
5.70			28											
5.90			52											
6.10			35											
6.30			32											
6.50			46											
6.70			34											
6.90			39											
7.10			37	5										
7.30			46	2										
7.50			24	5										
7.70			20	8										
7.90			25	3										
8.10			13	20										
8.30			9	15										
8.50			10	12										
8.70			5	18										
8.90			1	23										
9.10				18	1									
9.30				17	4									
9.50				13	2									
9.70				15	1									
9.90				13	4									
10.10				8	12									
10.30				11	8									
10.50				9	15									
10.70				12	20									
10.90				8	22									
11.10				8	16	5								
11.30				8	15	2								
11.50				3	23	8								
11.70					20	7								
11.90					15	11	3							
12.10					16	20	3							
12.30					14	19	4							
12.50					8	18	9	3						
12.70					7	30	14	5						
12.90					10	26	18	4						
13.10					1	24	14	10		1				
13.30					2	23	21	10	10	1				
13.50					2	10	23	16	9	3				
13.70						7	27	23	8	10	3			
13.90					1	5	24	25	16	9	5	2		
14.10						6	22	21	14	5	5	1		
14.30						5	14	18	16	13	6	4		
14.50						1	9	18	24	21	7	4	1	
14.70							6	22	13	17	12	5		1
14.90							2	8	13	16	16	4		
15.10						1	4	8	18	11	13	12		
15.30								4	12	17	13	3	1	1
15.50							1	4	12	11	6	6	2	1
15.70								4	7	13	10	6	1	
15.90								1	2	10	11	7	1	
16.10									3	2	8	8	2	1
16.30										4	6	4		1
16.50										2	4	6	2	
16.70											1	2		1
16.90											1	3	1	

TABLE 4.—*Growth in different localities*

Years	Copalis	Cordova	Swickshak
1	2.04	0.43	0.38
2	8.61	2.38	2.70
3	10.87	4.68	6.41
4	12.04	7.73	9.28
5	12.81	9.84	11.47
6	13.40	11.40	12.74
7	13.84	12.03	13.70
8	14.18	12.57	14.19
9	14.50	13.08	14.63
10		13.60	14.94
11		14.15	15.25
12			15.61
13			16.12
14			15.96

The Washington curve shows the fastest growth, followed by Swickshak and Cordova, in the order named. The first point on each curve represents the average size of the young clams from the respective beds during the first winter. The Washington clams reach an average size of 2 centimeters, in contrast to ½ centimeter for Alaska. This is due to the later spawning in Alaska and the earlier suspension of growth, due to the shorter season, which is about one-half as long as for the southern beds. The young clams of Alaska are very difficult to find during their first year. Plankton tows taken at Cordova on August 17, 1924, showed a large number of half-grown larvæ, which could hardly have settled soon

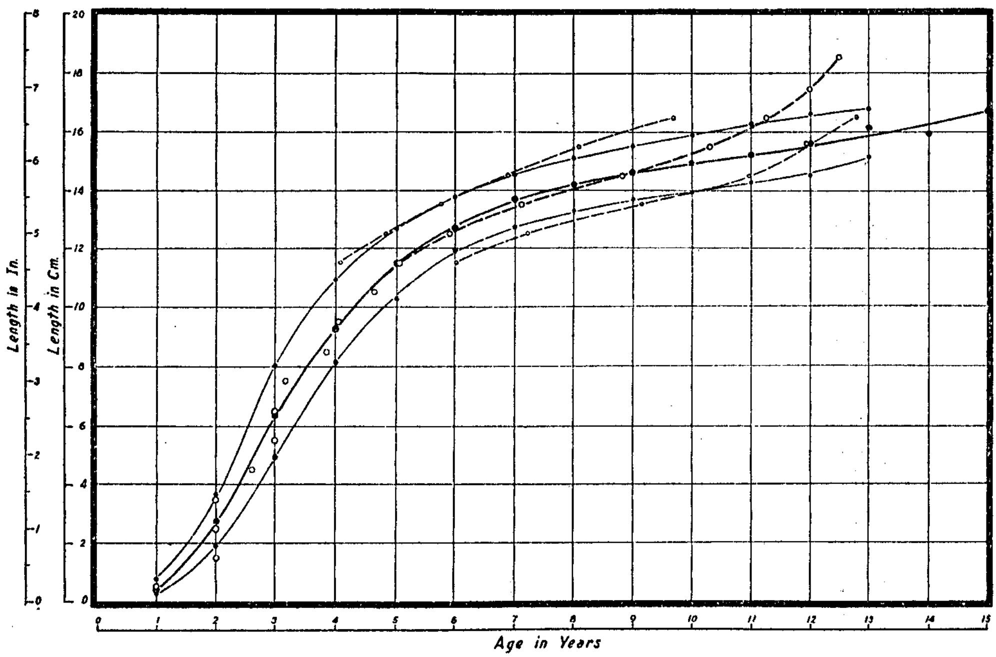

FIG. 15.—Swickshak clams. Graph showing the average length of each age (solid line) and the average age of each length (broken line). The latter is irregular in the first three years, due to the necessity of using one year as an interval of time. Center line shows the median or age, and the lines above and below show the 90th and 10th percentiles, respectively

enough to make appreciable growth before the water temperature dropped below the point where growth is possible.

While there is not a great difference in the final size of clams from various beds, there is a marked variation in the rate of growth during the first few years. As has already been stated, clams from the Washington beds reach maturity at about 10 centimeters in two years, while those from Swickshak and Cordova do not reach a similar size before three and four years, respectively. The legal size of 11.44 centimeters (4½ inches) is reached at the following ages: Washington, 3.5 years; Swickshak, 5 years; and Cordova, 6.3 years. The growing season in Alaska, as already mentioned, is roughly one-half as long as in Washington.

However, more definite data may show a closer correlation between the rate of growth and the length of growing season of the different beds, which in turn may be confined to clams below a certain size. The maximum for the Washington clams is about 12 years, while those from Alaska may reach an age of 17 or 18 years, but the large number of specimens necessary for an average to extend the growth curves to those ages are not available.

The ordinary growth curves, samples of which have been presented in Figure 14, are constructed from a table in which the average (median used) length of each age is calculated. With the same data used to calculate the values for the Swickshak growth curve the process was reversed, and the average age of each length class was determined (fig. 15 and Table 5) and a growth curve constructed from these figures (Weymouth, McMillin, and Rich, 1925). As the annual interval is very much larger than is convenient to use, the points at the lower end of the curve are irregular. The range was too small to calculate the tenth and ninetieth percentiles until the fifth year. Up to the age of five years the two curves might well be considered as coinciding; then the second "regression" (the average age for each length) tends to fall below the first, but later it rises and crosses it at about nine years, after which there is a distinct separation of the two curves. This shows that the correlation between age and size is less as the clams increase in age. In younger specimens size is a fair indication of age. A 2-year-old and a 4-year-old clam are greatly different in length, but the difference between a 9-year-old and an 18-year-old clam may amount to very little, with the possibility of the younger being the larger.

TABLE 5.—*Swickshak beach*

Length on age				Age on length			
Age in years	Percentiles 10	Percentiles 50	Percentiles 90	Length in centimeters	Percentiles 10	Percentiles 50	Percentiles 90
1	0.24	0.38	0.76	1.5		1.00	
2	1.94	2.70	3.52	2.5		2.00	
3	4.70	6.41	7.81	3.5		2.00	
4	8.13	9.28	10.94	4.5		2.00	
5	10.30	11.49	12.68	5.5		2.60	
6	11.92	12.74	13.76	6.5		3.00	
7	12.74	13.70	14.51	7.5		3.00	
8	13.27	14.19	15.11	8.5		3.16	
9	13.57	14.63	15.60	9.5		3.87	
10	13.94	14.94	15.93	10.5		4.05	
11	14.29	15.25	16.28	11.5		4.67	
12	14.53	15.61	16.61	12.5	4.09	5.03	6.04
13	15.19	16.12	16.78	13.5	4.85	5.94	7.25
14		15.96		14.5	5.77	7.12	9.15
				15.5	6.91	8.83	10.97
				16.5	8.08	10.03	11.94
				17.5	10.03	11.25	12.78

MATURITY

AGE AT MATURITY

During the summer of 1924 a large amount of fresh material was examined to determine the age and size at maturity. In some localities the specimens were taken from boxes on the cannery floors soon after they arrived from the beds; at other times they were dug especially for this purpose and examined on the beach. As the length of the clams used for this study varied from 7 to 12 centimeters (2½ to 4½ inches) the shells were very thin. The mantle was split along the mid-ventral line, and the shell broken back to expose the interior. When the mantle is

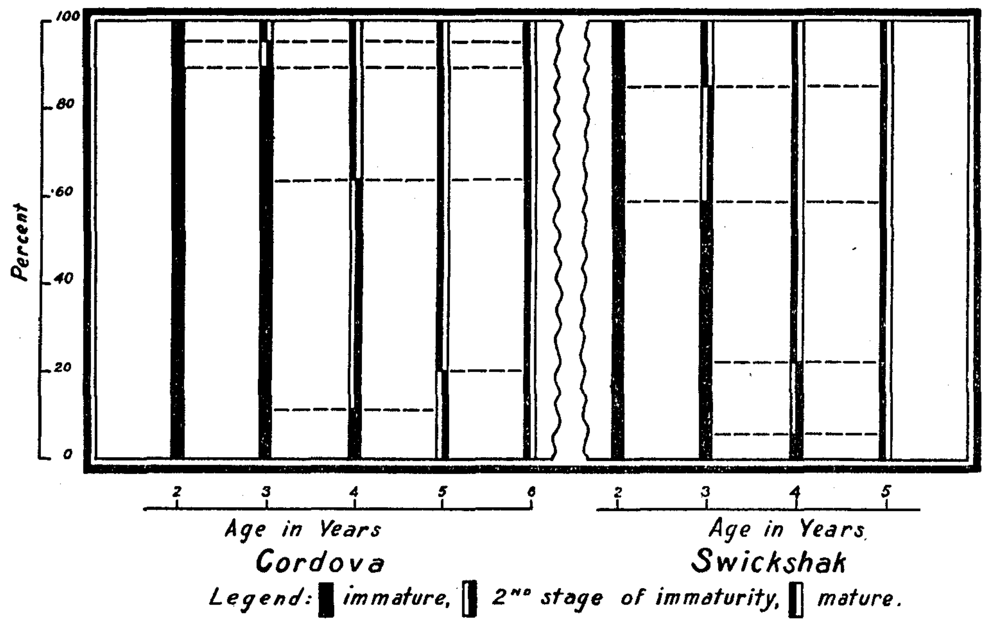

FIG. 16.—Showing the coming into maturity of small clams from Swickshak and Cordova, with reference to age. All are immature at 2 years of age and change gradually, to become completely mature at 5 and 6 years of age, respectively. Some pass through an intermediate stage the year prior to full maturity

opened, the larger part of the body is seen to be composed of the foot, or "digger," which contains the gonads and in mature specimens before spawning is distended with a great mass of reproductive material. In immature clams the posterior part of the foot appears translucent, and through its walls the outline of the digestive tract can be seen. After a number of examinations a marked difference, apart from size, can be noticed between clams that have spawned out and those that have never formed reproductive material. The mature clams never regain the translucent appearance and some become very dark soon after spawning.

In localities where maturity comes on at from 3 to 5 or even 6 years of age, there is a gradual changing over from the immature to the mature state. This makes a class between the obviously immature and the mature that can be distinguished accurately. For the sake of simplicity this intermediate stage has been called the "second stage of immaturity." It was first thought that the second stage of immaturity, as here explained, was a transient phase preceding complete maturity by a few weeks. Careful study, however, showed that this intermediate stage persists after the mature clams have spawned. Small egg strings or sperm-bearing masses are present in unchanged condition in late summer. Female clams have small elongate eggs, which do not change during the season. For these reasons it appears that those individuals passing through this stage remain in the same condition for the year prior to maturity. It is not known whether the reproductive products are held over the following winter or are resorbed.

Assuming that the stage of maturity is accurately determined in all cases (282 clams examined), the facts seem complicated. For the sake of clearness Figure 16 has been prepared from the data given in Tables 6 and 7. From it the process of coming into maturity is shown from the standpoint of age of the specimens. At Cordova all of the specimens examined in their second year were immature. In the next class a few (5.3 per cent) had become completely mature, and the same number had developed only partially—that is, had reached the second stage of immaturity. The following year class showed a few still immature and the mature ones of the former year still present, with their number increased by the addition of those in the second stage of immaturity of the former year. It is also shown that about 80 per cent of the fourth-year class passed out of the immature state, going into the two advanced divisions in the proportion of about 3 to 5, the smaller number becoming mature and the remainder advancing to the second stage of immaturity. No immature clams were found in the fifth-year class; 80 per cent were mature and 20 per cent were in the second stage of immaturity. This last figure is larger than the number of immature of the preceding year, but does not necessarily show that some individuals remained in the second stage of immaturity more than one year.

TABLE 6.—*Swickshak beach: Size of clams in different stages of maturity*

Length in centimeters	Age								
	3			4			5		
	Im_1	Im_2	M	Im_1	Im_2	M	Im_1	Im_2	M
7.5	22								
8.0	17								
8.5	36	7							
9.0	28	19		1		2			
9.5	12	21	5	3	3				
10.0	3	8	15	2	7	11			
10.5		1	5		3	15			1
11.0			1		2	18			2
11.5			2			14			1
12.0						8			3
Medians	8.78	9.55	10.30	9.83	10.32	11.16			11.75
Medians (total)	9.25			10.91			11.75		

TABLE 7.—*Cordova: Size of clams in different stages of maturity*

Length in centimeters	Age 3			Age 4			Age 5		Age 6
	Im₁	Im₂	M	Im₁	Im₂	M	Im₂	M	M
7.0	3								
7.5	8			1					
8.0	17			5			1		
8.5	23	1		5	2				
9.0	12	1	1	6	27				
9.5	3	1		1	45	6	3	2	1
10.0		1	2		14	33		3	1
10.5			1			18		1	
11.0						6		4	
Medians	8.60	9.50	10.75	8.80	9.67	10.39	9.67	10.50	
Medians (total)	8.70			9.87			10.06		

It must be remembered that each year class here used had a separate origin. The annual variation that exists may account for the apparently large number of 5-year clams that were not fully mature. In the vicinity of Cordova clams are taken from several beds, upon which the rate of growth is not equal, and the

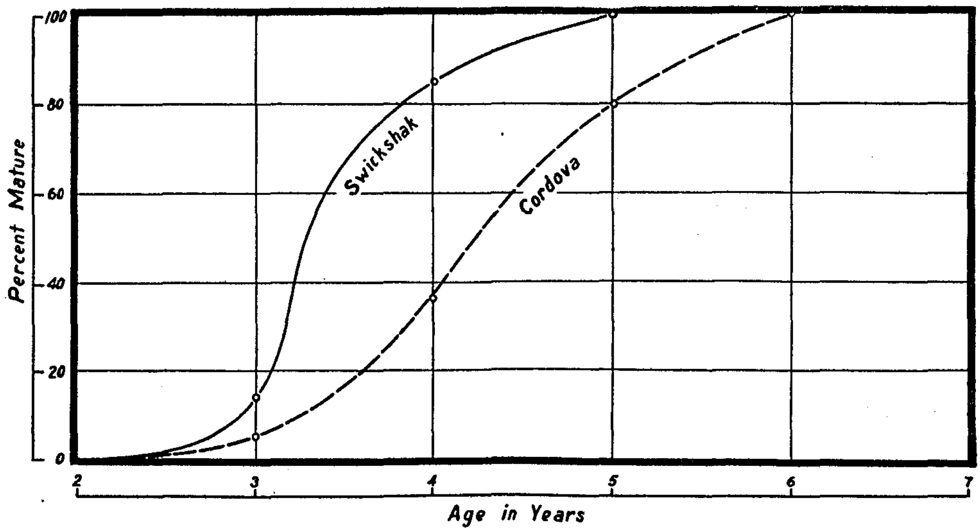

FIG. 17.—Showing the percentage of all clams mature at each age. For example, at Cordova of all clams 4 years of age 36.5 per cent were mature, while at Swickshak 85 per cent were mature at the same age

selection of some of the material used may have caused this discrepancy. All clams more than 5 years old are completely mature and spawn every year.

Figures obtained from 308 clams taken on Swickshak Beach gave more regular results. All 2-year-old clams were immature, but the following year over 40 per cent had passed out of this stage, 15 per cent becoming completely mature. In the fourth-year class 7 per cent were immature, while those in the second stage of immaturity numbered about 17 per cent. A great majority in the fourth year (over 75 per cent) and all specimens that were older were completely mature.

On the Washington beach no such gradual changing over is found. After the clams pass through their second winter they begin to develop reproductive material, and at 2 years of age spawning takes place. Doubtless there are some that do not spawn at this age, but none such have been found. The amount of the spawn cast is not large, but it does not differ in appearance from the products of the larger clams.

Thus it is seen that on some beds maturity comes on over a period of years. In such cases the age at which 50 per cent of the clams are mature (fig. 17) is taken as the age of maturity, and as thus determined is found to be 3.2 years at

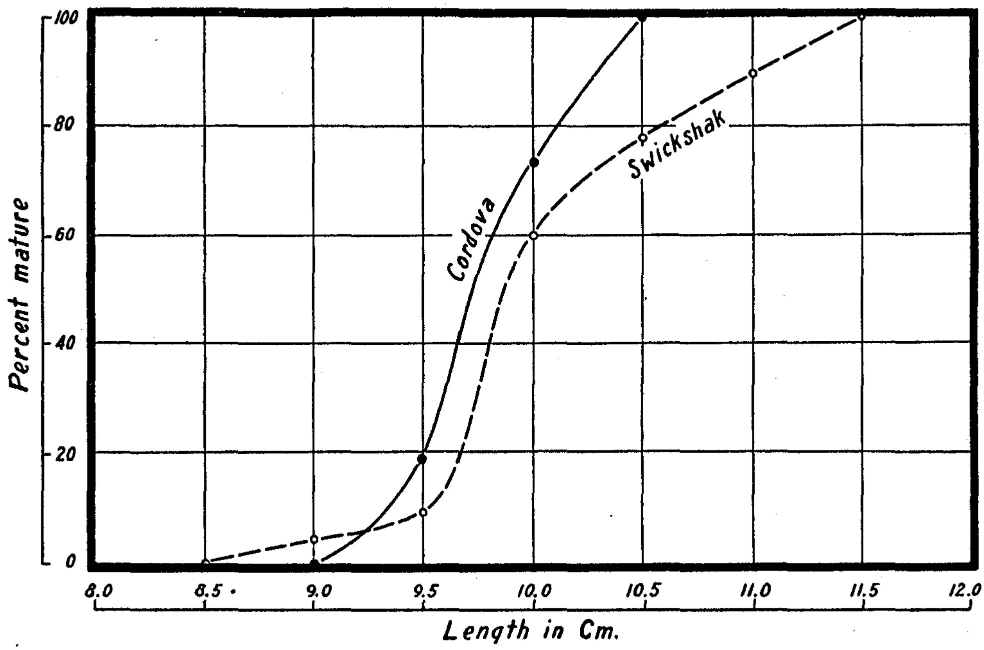

FIG. 18.—Showing the percentage mature at each interval of length

Swickshak, 4.2 years at Cordova, and 2 years at Washington. To summarize, about one-third of the clams at Cordova and one-half of those at Swickshak and all on the Washington beach become mature without passing through an intermediate stage. Since the clams at Cordova are slower in growth than those at Swickshak or Washington, it appears probable that more of them would pass through the second stage of immaturity, and this is found to be the case. The bearing of size upon maturity will be taken up in the following section of this report.

SIZE AT MATURITY

The relation of size to maturity has been treated in the same manner as age (fig. 18). The percentage of each stage of maturity in each class interval of length was calculated and plotted. At Cordova no mature clams of less than 9 centimeters were found, and all clams more than 10½ centimeters were mature. The size at which 50 per cent were mature (9.75 centimeters) was taken as the size at maturity. At Swickshak clams are first mature at 8½ centimeters, and all above 11½ centimeters are mature, maturity (50 per cent) being at 9.91 centimeters. All clams from the Washington beach spawn when they are 2 years old.

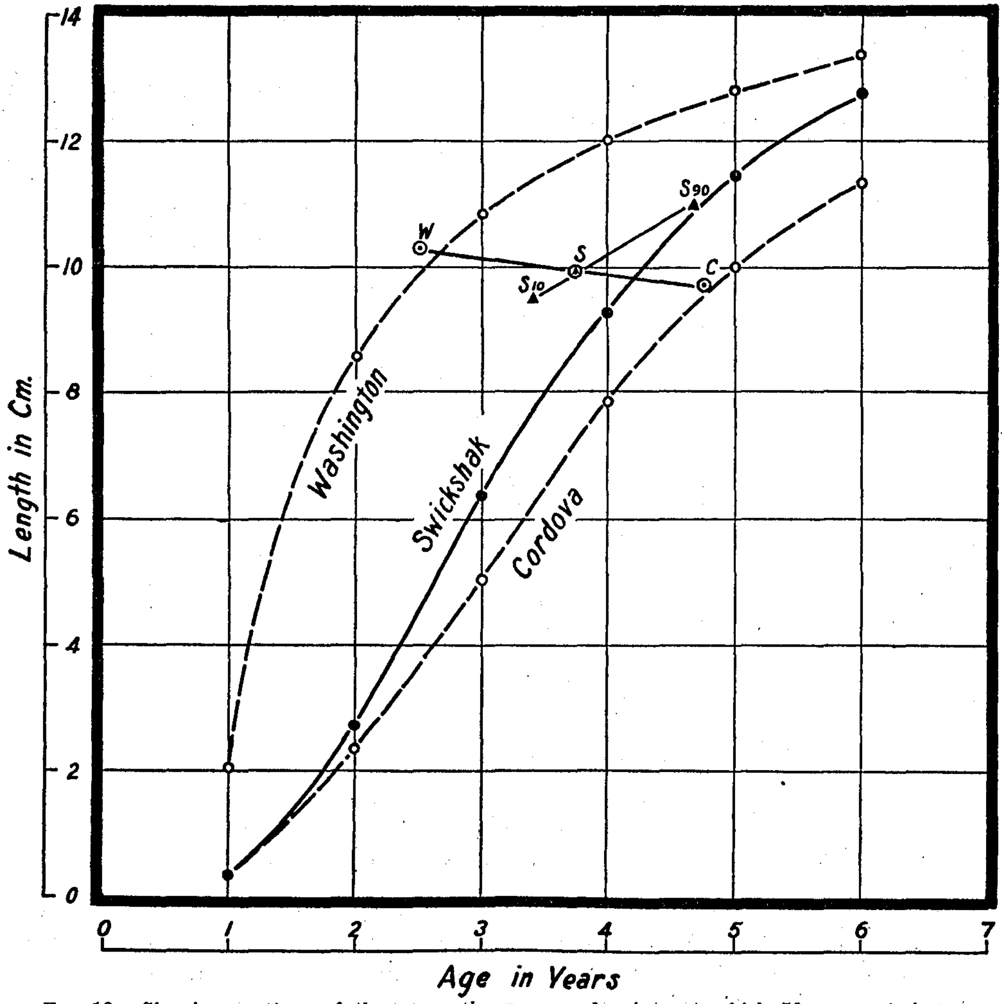

FIG. 19.—Showing portions of three growth curves and points at which 50 per cent, by age, and 50 per cent, by size, are mature on each bed (points *W*, *S*, and *C*). For the Swickshak material, S_{10}, *S*, and S_{90} represent the points at which 10, 50, and 90 per cent, respectively, by both age and size, become mature

Since all mature at the same age, the median length of these at spawning time has been taken as the size at maturity.

Thus in order of size the lengths at maturity on the different beaches are as follows: Cordova, 9.75 centimeters; Swickshak, 9.91 centimeters; Washington, 10.30 centimeters. At the rate at which the Washington clams were growing at this age (1.54 centimeters in three months) this difference amounts to one month's growth.

It must be remembered, in comparing these lengths with possible size limits, that at the above lengths but 50 per cent are mature. A recommended size limit is intended to provide opportunity for all individuals to spawn at least once.

RELATION OF AGE AND LENGTH TO MATURITY

The comparison of the results of the last two sections throws an interesting light on the process of maturing on the various beds of the Pacific coast. From a study of Table 8 and Figure 19 we see that there is a wide difference in age at maturity, but there is a close agreement in size. While the differences in size are small in comparison with those of age, an examination of the data shows them to be orderly and significant. Clams from beds where growth is slow, while older at maturity, are also smaller. The Washington clams, which show the most rapid growth, are the youngest but are largest at maturity; conversely, those at Cordova which show the slowest growth are the oldest but the smallest.

QUANTITATIVE MEASURES

A quantitative measure of the respective influences of age and length may be obtained by analysis of the figures given in Table 8. Between the youngest and the oldest there is a difference of 2.2 years, or, compared with the average of the three ages (3.1 years), a variation of 71 per cent. In contrast with this we have a variation of 0.55 centimeter in length, which, compared with the average length (10 centimeters), gives but 5.5 per cent. Therefore, in the process of maturing an increase in size of 1 per cent accompanies the same sexual development as an increase in age of 13 per cent.

TABLE 8.—*Age and length at maturity*

Locality	Maturity	
	Age	Length
Washington	2.0	10.30
Swickshak	3.2	9.91
Cordova	4.2	9.75

The data of Table 8, plotted in Figure 19 as line *W–S–C*, show the influence of both age and length on maturity. If age alone determined maturity, this line would be perpendicular and clams from all beds, while varying in size, would mature at one average age. If size alone determined maturity, the line would be horizontal. The age would vary, but the size would remain constant. From this line another ratio may be obtained by comparing the average relation of age to length and this same relation in respect to maturity. For example, from Figure 14 (p. 218), on the Swickshak curve near the size of maturity (3 to 4 years of age), one year's growth is equal to 2.89 centimeters, or, using this proportion, 0.346 of a year equal 1 centimeter in length. Like figures obtained from Washington and Cordova are given in Table 9. From the maturity line (fig. 19, line *W–S–C*) it is found that a variation of 2.25 years corresponds to a variation of 0.55 centimeter, which gives the following values: 4.10 years equal 1 centimeter; 1 year equals 0.244 centimeter.

TABLE 9.—*Relation of rate of increase of age and length at maturity*

Locality	Value of 1 year in centimeters	Value of 1 centimeter in years
Washington	2.26	0.442
Swickshak	2.89	.346
Cordova	2.17	.460
Average	2.44	.416

The figures given immediately above are comparable with the averages of Table 9. In growth, therefore, one year corresponds to 2.44 centimeters, but in maturity one year corresponds to 0.244 centimeter. The influence of a year in growth is thus ten times as great as in the process of maturing; or, from the standpoint of size, 1 centimeter corresponds to 0.416 year in age, but in maturity 1 centimeter corresponds to 4.10 years. The influence of a centimeter in growth is thus one-tenth as great as in the process of maturing. The ratio (1 to 10) thus obtained compares very favorably with that above (1 to 13), when the differences in methods are taken into account.

MATURITY IN OTHER FORMS

The relation of age and length to maturity given for the razor clam does not hold in all forms. The work of Thompson (1914) on the halibut shows that these vertebrates mature at nearly the same average age in different localities, while the average size varies quite widely. However, there is a difference in average age at maturity which, although slight, may be accounted for by the difference in average size. For example, fish from Hecate Straits mature at an average of 12 years of age and 40.7 inches in length, while those from Kodiak Island Banks mature at an average of 12.3 years and 35.4 inches. Thus, there is a variation in age of 0.3 year in 12, or 2.5 per cent, and in size of 5.3 inches in 35.4, or 15 per cent. The conclusion is, then, that a difference of 15 per cent in size at maturity between these two banks is accompanied by a difference of 2.5 per cent in age, which shows in this form that age and length influence maturity in the ratio of 6 to 1, age being the more important.

We offer no explanation for the maturing of halibut according to age and of clams according to size. Figures for other species are not available. The work of Baldwin (1921) and Crampton (1908) give data on the size and age of boys and girls at maturity, which further analysis may show to be similar to one of the above cases.

Fig. 20.—Rising tide, Snug Harbor beach

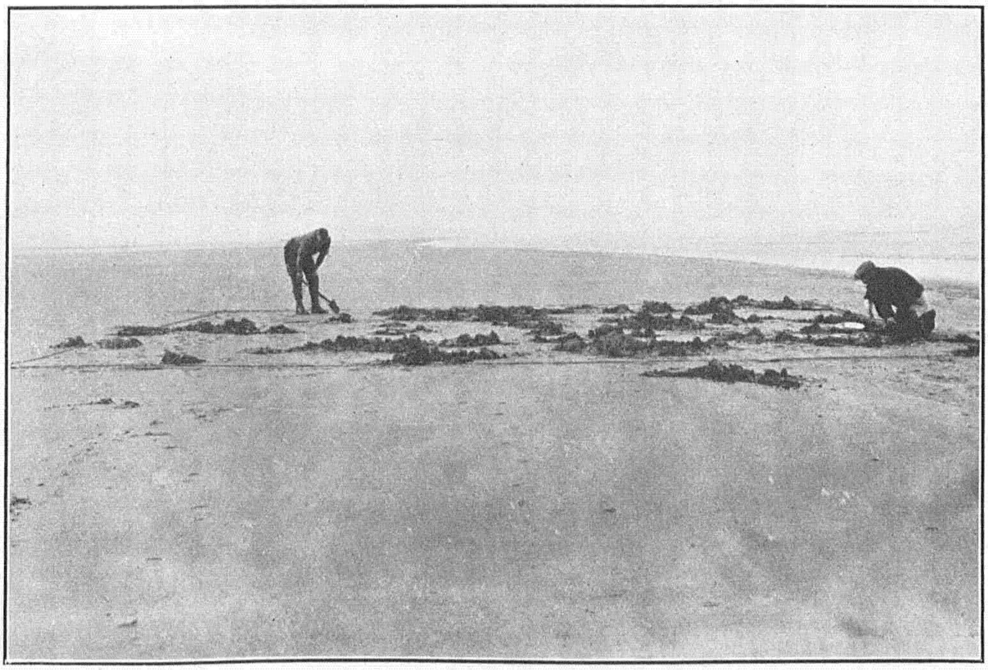

Fig. 21.—Digging marked area, Copalis beach

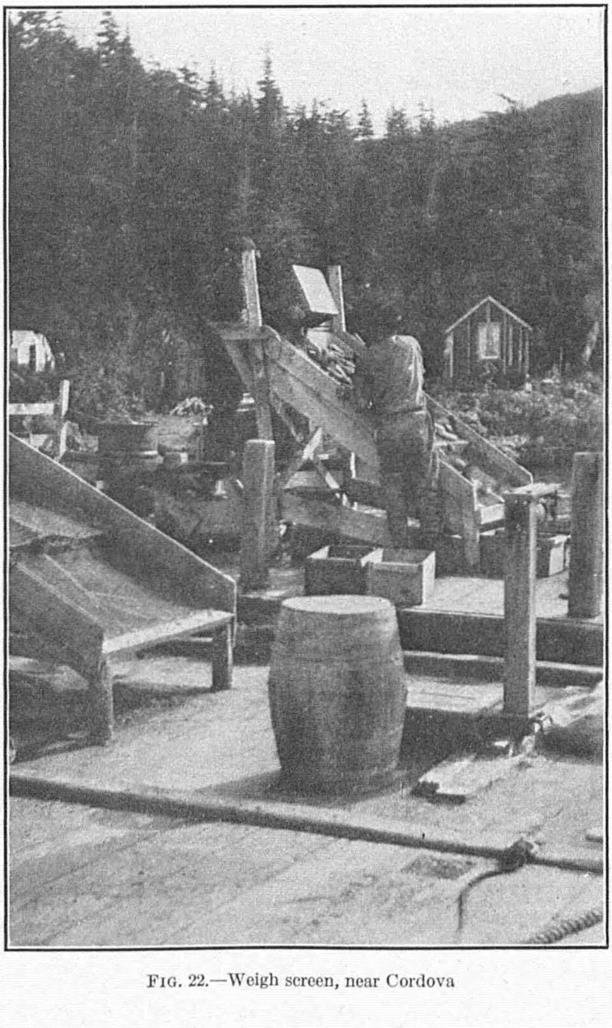

FIG. 22.—Weigh screen, near Cordova

BEACHES

No attempts have been made by the writers to explore areas that were not being exploited at the time the work was carried on in the field. It is impossible to find the unit population of any unit area, and in most cases it is difficult to get anything but a very rough idea of the size of the clam-producing beds. On undepleted beds the same area can be dug over on several consecutive days without apparent decrease in the day's catch, a fact which makes an accurate census impossible. Thus indications of depletion can not come from either a census or a survey of the beach, but, as we shall later see, show up quickly in the average size of clams in the commercial catch and in the average "dig" per man.

The clam-producing areas of the Washington and Oregon beaches can readily be measured. The beach is uniform in width, and the area exposed varies with the tide. The Alaska beds, on the other hand, are variable. Those in the vicinity of Cordova have been built up by sand brought down by the Copper River. They are made up of an intricate series of bars and channels which change their location at irregular intervals. In fact, the whole topography of the clam-producing area changes from year to year. Beds that are under several feet of water at the lowest tide of one season may be accessible to digging the next, and some high bars may be entirely submerged.

Swickshak beach changes less by shifting of bars and channels. The bottom slopes gradually, and the offshore water is very shallow, giving a wide intertidal zone. Since this beach is so flat, the height of tide governs the area exposed; on one spit it was estimated that a change of 1 foot in the tide was accompanied by a variation of 40 acres in the area of beach exposed. Owing to this, only rough estimates can be made of the areas.

The condition of the Snug Harbor beds, lying between Chisik Island and Harriet Point on the west side of Cook Inlet, is more like that at Swickshak than at Cordova. The tidal range over these beds is greater than elsewhere. Since the beach slopes very gradually, it is wide, the tide going out nearly 3 miles in one place. It was estimated that about 1½ square miles of beach were being dug during the summer of 1923. While this bed is not constantly being changed by the shifting of bars and channels, as at Cordova, portions of it are seriously menaced at times by deposits of glacial silt, which covers the beds and destroys the clams.

COMMERCIAL CATCH

As we have mentioned before, overfishing shows up in two ways—first, by the small size of clams taken, and, second, by the reduced average catch per man. On new beds, such as Swickshak in 1923, nearly all the clams taken were more than 5 inches in length. The same is true of the early digging at Cordova and for many years on the Washington beaches. On the northern beds the large clams appear to be very inactive, sometimes remaining with the siphon extended until dug. Therefore the large clams, on the whole, are more easily found and taken than the small ones. It takes as long to dig a small clam as a large one, and the result of taking them is apparent in the reduction of the average daily catch. On Washington beds, during 1924, the commercial diggers were able to get fair "digs" on but three tides of each "run" (two weeks), unless storms interfered, in which case the whole run was lost. The average size of the clams was small, being less than $4\frac{1}{2}$ inches. A large part of the catch had never spawned. Many were lost through the screens at the weigh sheds, and still more were thrown out by the cleaners because of their small size. Although the enemies of conservation explained the reduced pack as the result of an "off year," such a condition points to serious depletion.

The same was true at Cordova in 1924. The diggers took every clam that showed, regardless of size, and the cannerymen, in their turn, purchased anything that was offered. Many of the clams were too small to be used to advantage and would have doubled in weight by another year. Only serious results can be ex-

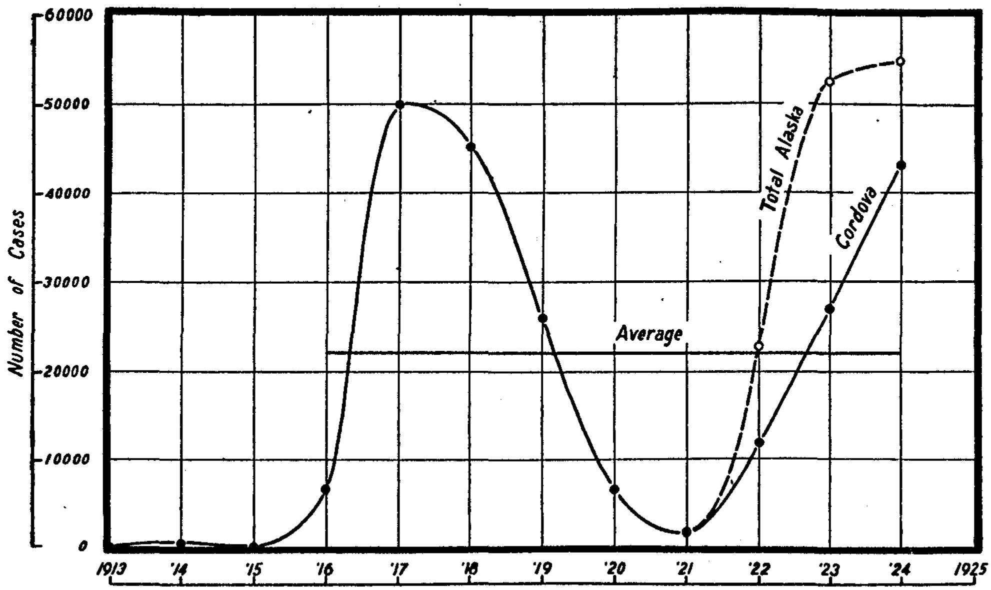

FIG. 23.—Showing the total clam pack of Alaska to date. Data from the "Pacific Fisherman"

pected from such treatment. Since the beginning of canning in Alaska in 1916 Cordova has produced between 80 and 90 per cent of the entire clam pack. The history of the pack is instructive (see fig. 23). After the opening of the beds in 1916 production leaped to approximately 50,000 cases in 1917 and 1918, and then rapidly dropped off, until only 1,600 cases were packed in 1921. This was in part caused by economic conditions, but the chief factor was the scarcity of clams, a number of operators claiming that the beds were completely exhausted and that it was unprofitable to attempt to pack. The demand for canned clams, however, led to exploration, and new beds were found adjacent to Cordova of such extent as to more than double the clam-producing area. Exploration to the westward at this time also led to the opening of Snug Harbor and later the beaches near Kukak Bay.

With the increased supply of clams the pack at Cordova again rose to 27,000 cases in 1923. The pack for 1924 was in excess of this, or about 43,000 cases. This expansion has been obtained by the entry into the field of one new cannery and a material increase in the number of diggers. The fact that in 1924 twice the area of beach and more than twice the number of diggers produced but little more than four-fifths of the number of cases packed in 1917 is in itself clear evidence that the beds have been overdug. If more proof is needed, it is furnished by the distinctly smaller average size of clams taken and the admittedly larger proportion of undersized clams. The clams naturally reach as large a size at Cordova as elsewhere. At Swickshak, in 1923, a clam less than 5 inches long seldom reached the cannery. We have only to contrast this situation with that at Cordova to realize how the intensive digging, by taking the older and larger clams, has reduced the average size.

If the entire pack of Cordova had been uniformly distributed over all the years from 1916 to 1924, inclusive, this average pack would have amounted to 23,000 cases. From the present state of the beach it is evident that 23,000 cases per year is in excess of what the beds can support. Perhaps 15,000 cases might be taken annually without serious depletion, possibly but 10,000, but the data at hand is insufficient to determine this.

It is clear from our investigations that a yield approaching, area for area, that of the Washington beaches is not to be expected of those in Alaska. This can not be too strongly emphasized, as estimates or expectations based on the production of the Washington beaches, with which most of the operators and diggers are familiar, must inevitably lead to disappointment and disaster. In the first place, the set of young on the Alaskan beaches has never equaled or even approached that on the southern beds. As has been stated, at Copalis in the fall of 1923 the small clams averaged over 1,400 per square foot. During 1923 and 1924 a careful search for the young on all the producing Alaska beds did not reveal a single location where a square foot would regularly yield even one small clam, and only a few of the diggers have even noticed these young, although acquainted with them in the south.

Secondly, the growth is far slower in Alaska. We have shown that a length of 4½ inches is reached in about three years at Copalis but in six years at Cordova. Because of this the recuperative power of the northern beds will be far less and the effects of protection will be slower in appearing. For instance, in a sample of 152 clams over 4½ inches in length, taken at one of the canneries during the present season (1924), 109 were hatched prior to the beginning of digging in 1916; of the remainder 23 were hatched in 1916. In other words, 87 per cent of the clams now being taken were in the beds by the summer in which canning started. Even if we include the undersized clams packed in the last few years, well over 90 per cent of the pack has been of clams already living when canning started, and the course of the industry would have been little altered if all spawning had ceased at that time. Thus, to an alarming and unrecognized degree, the industry has been consuming its capital. When the reduced spawning, resulting from the reduced number of spawners, begins to make itself felt the pack, even though materially reduced, can only be maintained by the ruinous process of drawing upon that part of the capital which has never given interest—the young before they have spawned.

It is therefore clear that the taking of clams must be drastically reduced or the industry will vanish before the prohibitive cost of obtaining the few scattered remaining clams. If this occurs, it must be remembered that its restoration is a long process. The first generation would not be numerous enough to sustain a commercial fishery, and for all of them to spawn would require six years, although part of them spawn at four or five years. For the second generation to reach even the minimum size of 4½ inches would require another six years. Thus no relief could be had before 12 years, and a material increase would of course require several years more.

In the face of this situation it may prove that the present size limit is insufficient to maintain the beds. It is desirable that the clam industry be made a permanent one, and the present size limit should be given a fair trial before additional and more complicated regulations are imposed. Should this fail to reduce the pack to a level that the existing beds can support, other measures remain. The size limit might be increased to 5 inches. This would practically close some of the beds in which the average size has been greatly reduced by intensive digging, and thus automatically afford protection where most needed.

It has been claimed by some that any size limit would be unsatisfactory. First, the size of the clam could not be known before it is dug, and the thin shells of the undersized clams probably would be broken by the digging operation and the clam eaten by gulls if left on the beach. Second, a size limit would be difficult of enforcement. The writers have considered both of these arguments and fail to find that either is cogent. If the individual "digs" of the men are examined, it will be found that many consist entirely of large or at least legal-sized clams, showing that it is quite possible to avoid the small clams and still make good "digs," for it will be found that these men usually have more clams than the average. The present regulation permits a small percentage of undersized clams, which would take care of those cases where small clams are accidently crushed in digging. Observation of many clams has shown that broken shells are repaired to a far greater extent than might be expected. From experience on every beach the writers feel sure that any person taking more than 1 per cent of undersized clams is either a new and totally inexperienced digger or does so by intention and not by accident. It requires no argument to show that, with the clams in the shell on the cannery floor for periods up to 24 hours, inspection of sizes would be easy.

Another method would be to close certain districts for a year or a term of years. This would be more difficult of enforcement and might affect some canneries more than others, but it would be effective if the necessity arose. A closed season has been proposed on the assumption that it would reduce the pack. It is open to the objection of discrimination, such a limitation of season falling more heavily upon the small local firms, at present operating over a long season, than upon the larger canneries, which now operate during a short season only. The same season, also, would not apply to all districts, and further investigation would be needed to regulate this, which would result in confusion. It is possible that such a regulation would only result in more intensive fishing during a shorter season and would bring about no reduction in the total pack.

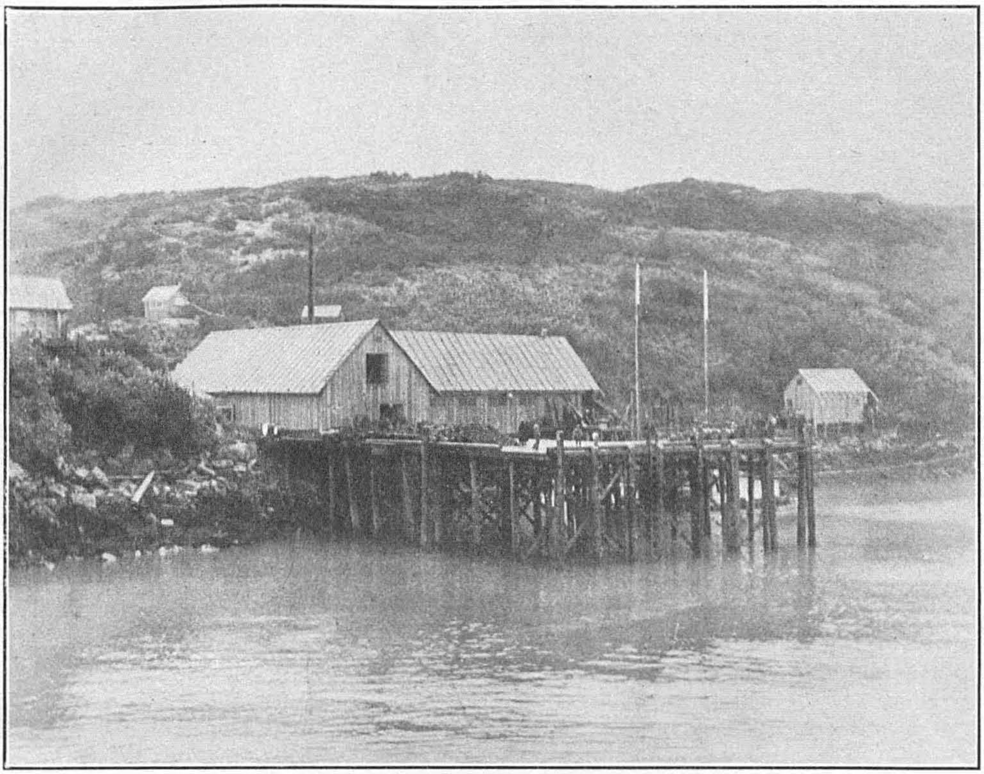

FIG. 24.—Cannery at Kukak Bay

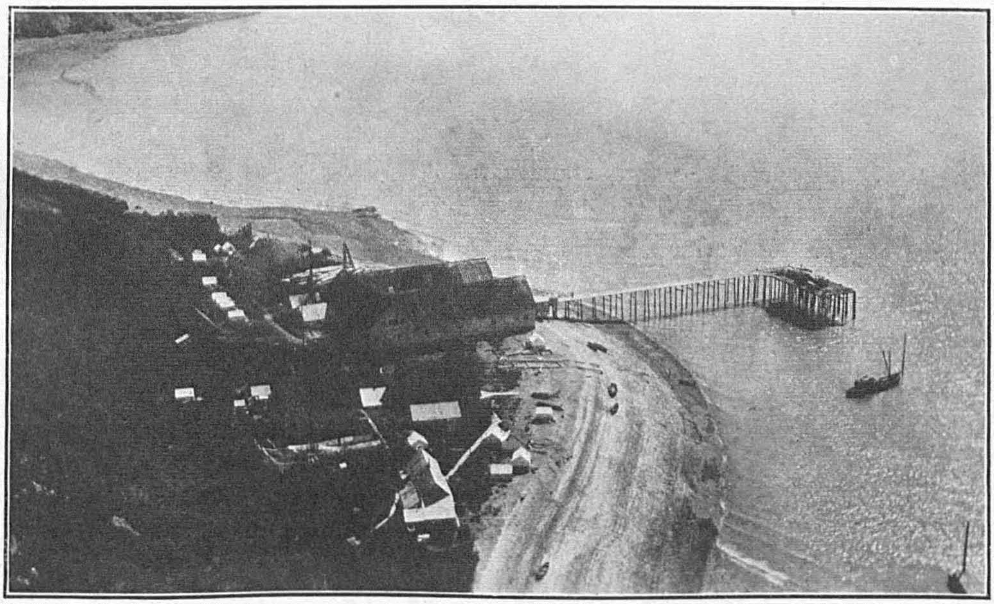

FIG. 25.—Cannery at Snug Harbor, Chisik Island

Fig. 26.—"Pickup" wagon, Snug Harbor

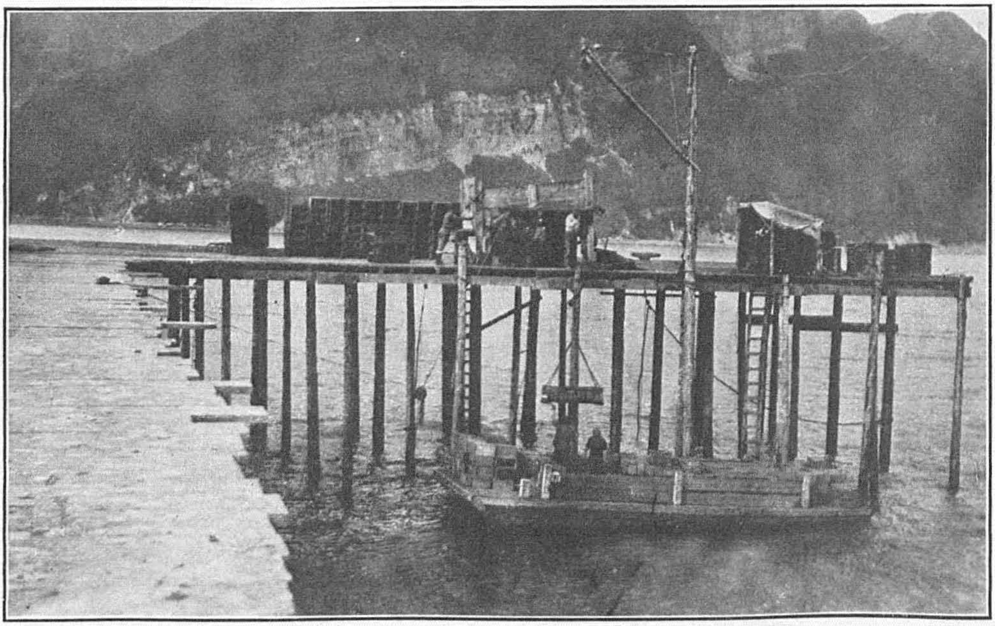

Fig. 27.—Unloading clams, Snug Harbor cannery

SUMMARY

The present paper deals with the Pacific razor clam (*Siliqua patula*), a form of commercial importance along the entire northwest coast from Oregon to the Alaskan Peninsula. This is considered to be a single species throughout this range, the observed variations being due to environmental conditions.

Spawning on the Washington coast takes place between the middle of May and the middle of June, while in Alaska the spawning season is less sharply marked and occurs from the first of July to the middle of August. Spawning apparently takes place on a sharp rise of water temperature at about 13° C. (55.5° F.).

The larval stage endures about eight weeks, during the greater part of which time the young are in the surface sand. At the end of this period they appear in the intertidal zone as small clams, differing little from the adult in structure or habits. The "set" of these young is sometimes enormous on the Washington coast, but is never so heavy in Alaska. The mortality of the young during the first two years may be very heavy. A yearly census for the purpose of determining the success of each spawning year and its future effect on the commercial catch is recommended.

The growth of the adult on various beaches has been determined from data obtained by a study of the annual rings. Norms are presented to show the relative rates of growth at the three places where the industry is most important.

The size and age at maturity has been determined by a study of the young clams. The size at maturity on all beds is in close agreement, but the age varies greatly. The relative influence of age and size on maturity has been determined mathematically and compared with other known forms.

The only feasible criteria of overfishing are, first, the reduction in the average size of clams in the commercial catch and, second, the reduction in the average daily "digs" per man. A size limit has been proposed which, by protecting the small, immature clams, would prevent serious depletion of the beds now greatly overdug.

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