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GROWTH AND SPAWNING CHARACTERISTICS OF THE SEA SCALLOP, *PLACOPECTEN MAGELLANICUS* (GMELIN), IN MAINE WATERS

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Abstract

Anatomical studies of Placopecten magellanicus agreed with previous investigations, except that a crystalline style was found, but only in fresh specimans. Ring mesh size of the dredge controlled relative frequency of size classes in commercial dredging, which yielded 97.7 per cent commercial sizes. Growth was most rapid during the first five years and slowest after the seventh. The minimum size for commerical utilization was about 80 millimeters, attained at about four years. The commerical catch was 60-8 per cent composed of ages up through seven years and 38.8 per cent composed of ages up through five. Maximum age was over 19 years. In 1948, spawning occurred during August and early September and gametogenesis began immediately afterward. Three year old, 60 millimeter scallops were the youngest and smallest found with well-developed gonads, but most matured at about 60 millimeters. The latter were taken commercially after one spawning. The sex ratio was 0.9 females per males. Recoveries of 5.2 per cent of 250 tagged and released scallops indicated only movement from shallow into deeper water. Harmful organisma were: the boring sponge, Cliona celata; the artic rock borer, Saxicava arctica; and the starfish, Asterias vulgaris. The commerical catch per unit of effort on four beds ranged from 0.22 to 0.40 gallons per 10,000 cubic feet dredged per hour and gave an approximation of relative abundance. This relationship was influenced by the type of gear, type of bottom, experience of

and time of the season. On six beds, average area dredged to obtain a single commercial sized scallop ranged from 182.4 to 364.8 square feet. It was recommended that:

1. A four inch mimimum law, enforced by regulation of dredge ring mesh size, be seriously considered.
2. The present open season be continued.
3. Scallopers be urged to destory all starfish dredged.
4. An intensive study of one bed be made over a full year period.
5. Further studies be made to include catch per unit of effort, age and growth, migration, early developmental stages, mortality and hydrographic characteristics of scallop beds.

PREFACE

This investigation was established in September 1947 as a fellowship by the Maine Department of Sea and Shore Fisheries, through the Department of Industrial Cooperation of the University of Maine.

The object of this program was, in general, to accomplish much of the fundamental work required for a more extensive scallop research project, and specifically, to investigate the features of the growth and spawning of the sea scallop in Maine waters. The study was begun in August 1947, active work was ended in December 1948, the fellowship was terminated in February 1949, and the analysis and compilatiom of data were completed in May 1950.

It is with a great deal of gratitude and appreciation that the following acknowledgements are made: to Commissioner R. E. Reed of the Maine Department of Sea and Shore Fisheries, for establishing the fellowship which made the study possible; to Dr. B. R. Speicher and Dr. J. T. Pedlow for their valuable advice and capable guidance; to Dr. M. C. Meyer for aid in taxonomy and identification; to Dr. C. H. Merchant for considerable help and encouragement in statistics; to Mr. A. C. Heanssler for his very generous loan of facilities at Sunshine, Maine,for his vast fund of information, and for his invaluable help in many ways; to Mr. J. H. Hunt for his very welcome assistance in field work and for securing the use of the boat, loaned by Mr. R. Kelly of Fairfield, Maine; to Mr. C. C. Taylor for obtaining permission to use an unpublished manuscript from the Atlantic Biological Station, St. Andrews, N. B.; and to the many scallop fishermen who were very generous with their advice, information, assistance, and permission to collect data aboard their boats.

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LITERATURE REVIEW

Two publications alone have dealt at any length with the sea scallop, Placopecten magellanicus. Smith (1891) conducted a survey of the fishery, including its history, economics, methods of fishing, and locations of the beds. The habits and biology of the mollusk were briefly covered by information taken mainly from scattered reports of the expeditions of the United States Fish Commission and the accounts of fishermen. Since no organized investigation was carried on, no concrete results were reported, but the conclusion was reached that there were great opportunities for expansion of the fishery, pending the development of markets and more efficient gear.

Drew (1906) made a thorough and detailed study of the anatomy, natural functions and embryology of the sea scallop. As a result of his work, he concluded that: the sexes were separate; the gametes matured at the same time, probably in late summer; larval development was typical of the lamellibranchs; and diatoms were an important food.

An unpublished manuscript by Stevenson (1936) included a survey of the Fundy Scallop Fishery, an investigation into the growth of adult scallops, and observations on the growth of larvae under laboratory conditions. Only the second part of this manuscript, dealing with adult growth, was available and was in condensed form. The results given in this part showed that winter rings were reliable indications of yearly growth, that scallops from some localities had wider hingelines than those from other areas, and that second year growth was the determining factor in ultimate size differences.

Royce (1947) discussed the gear used in the sea scallop fishery on Georges Bank. The article was limited to a description and drawings of a dredge and a list of materials for building one.

A short article by Medcof (1949) discussed the meat yield of Canadian scallops of various sizes and ages. It was a further justification of the Canadian four inch size limit and concluded that this minimum limit permitted the taking of scallops only after the most rapid growth had taken place.

A detailed account by Dakin (1909) of the anatomy and histology of Pecten maximus, with references to Pecten opercularis, was of some value in reference to anatomical and habit studies of the sea scallop. Habits, embryology and economic importance were briefly discussed. As a result of the work, it was concluded that: the mollusks fed largely upon diatoms, algal spores and micro-crustacea; empty shells were the results of starfish and whelk depredation; the two hermaphroditic species showed maximum reproductive activity in July and August; and they were readily injured by low temperatures.

Detailed reports on the bay scallop, Pecten irradians, by Belding (1910) in Massachusetts and Gutsell (1931) in North Carolina, thoroughly covered the life history of the bivalve and its relation to the fishery. Both concluded that the mollusk matured and spawned at about one year and seldom exceeded two years of age. The entire year class could be safely caught after the spawning season.

THE MAINE SCALLOP FISHERY

The Early Fishery

Smith (1891) made a very complete study of the early scallop fishery in Maine. The following account of this early period is a condensation of that part of his work.

The scallop fishery of Maine, definitely unknown before 1880, was thought to have originated in the town of Mount Desert in 1884. In the years immediately following, the principal dredging grounds extended from the mouth of the Sheepscot River northeast into Penobscot Bay, on through the waters about Deer Isle, into Blue Hill Bay and the waters about Mount Desert Island. The scallop beds worked most profitably in these areas were located in depths ranging from 24 to 240 feet. It was thought that there was undoubtedly an abundant supply of scallops in deeper waters, but the light equipment in use at the time did not permit dredging any deeper than 240 feet. The preferred depths were those at 30 feet and less. These beds were oval in shape, the main axis being in line with the current, and the length and breadth varying with the strength and direction of the current. The wide variety of the bottom conditions at these beds indicated no preference of the scallop for any definite type. Bottoms of soft mud, hard clay, rock and gravel seemed to support populations of comparable size. It was suggested that the presence of a bed of scallops may be attributed to favorable conditions of salinity and temperature, rather than to the character of the bottom.

The gear used in these early days varied widely between the various fishing communities. A typical dredge, similar to that used in hand dredging in this present investigation (Plate I, Fig. A), had a

mouth measuring 39 inches by six inches, with a bag four feet deep for catching the scallops as they were dredged. This bag consisted of a bottom mesh of iron rings, three inches in diameter, linked together and designed to stand the wear and tear of scraping over the bottom. The upper part of the bag, net-woven, was of cod line or marline. The open mouth of the bag was attached to the mouth of the dredge-frame. The dredge was pulled along on bottom from a boat, by means of a rope attached to a bail forward of the mouth of the dredge. It was dragged 200 to 300 feet before being pulled up, the distance depending upon the abundance of the scallops. The larger dredges would hold about a bushel of scallops.

The types of boats and methods of dredging also showed great variety. The boats most commonly used were small, usually rowed by two men and assisted by sail when the winds were favorable. Larger vessels were also used, in which case the small boats described about were still employed in the same manner, but the vessel served as living quarters for the crews and storage space for the catch. Another method using the larger vessels consisted of having the dredges taken out in the small boats, dropped to the bottom, and hauled in by winches aboard the vessel, riding at anchor over the bed. In 1880 a small steamer from Castine was tried for scalloping, but the attempt was unsuccessful.

The scalloping season depended chiefly upon the proximity of the market. When there was good local demand, the fishing continued all year. When only the distant markets were available, the season depended upon the cold weather which furnished protection for the shipments. The principal market at this time was Boston, with small amounts going to

Portland, Bangor, Augusta and Belfast in Maine, as well as to New York and Philadelphia. Table I gives an indication of the status of the fishery at this period.

TABLE I

STATUS OF THE SCALLOP FISHERY

1887 - 1889

	1887	1888	1889
Aggregate Output (bu.)	35,204	29,578	45,368
Aggregate Output (gals.)	23,277	19,028	29,851
Aggregate Output (lbs.) (from Smith's factor of 9 lbs. per gal.)	209,493	171,252	267,659
Total Value of Catch	$13,994	$11,278	$18,647
Boats in Use	101	109	133
Total Investment	$6,646	$8,028	$11,055
Persons Engaged	164	175	197

The need for an improved type of dredge that could be used in deeper waters was recognized. The United States Fish Commission had demonstrated that a beam trawl was the most successful type of gear, the one disadvantage being that a smooth bottom was required to avoid tearing the net. It was believed that small steamers could be used advantageously if the scallop demand and price increased enough to warrant the sizeable investment required, and the increased output resulting. Suggestions for the further utilization of scallop by-products included the use of the

waste portions of the mollusk for bait, and the sale of the shells for ornaments and other articles.

The Present Fishery

In recent years the fishery has expanded a great deal, especially into the offshore waters. In 1942, for example, 7,183,000 lbs. of sea scallop meats were landed on the East Coast of the United States. Of this quantity, 5,446,000 lbs. were landed at New Bedford, Massachusetts and were taken almost entirely from Georges Bank (Royce). This investigation is restricted to the Maine scallop fishery included within the three-mile limit of State waters. Table II indicates that, although a peak of over a million pounds was landed in 1933, the annual landings since 1942 show practically the same output as in the years 1887 - 1889 (Table I), despite improved types of gear, the greater number of beds fished and the greater number of men fishing.

TABLE II

MAINE SCALLOP LANDINGS

(in pounds)

1930 - 1945

1930	436,416	1938	792,900
1931	586,870	1939	394,965
1932	607,780	1940	485,424
1933	1,073,172	1941	316,414
1934	---[1]	1942	131,115
1935	743,200	1943	226,850
1936	---[1]	1944	100,692
1937	649,400	1945	105,308

[1]No data available.

The data in Table II was compiled from statistics furnished by Fiedler (1932-1935, 1938, 1940, 1941) and the Maine Department of Sea and Shore Fisheries (1941, 1943, 1944, 1947).

The locations of the beds fished in recent years extend from Portsmouth Bay in Kittery at the southern end of the State, to the northeastern end, off Lubec. The principal producing areas, however, are still those which supported the early fishery, from Muscongus Bay east to Blue Hill Bay.

The boats used today (Plate III, Fig. B) are, for the most part two-manned lobster boats, temporarily converted to scalloping by the installation of a power-driven winch and stepping a mast for hoisting gear. The majority of these boats are in the 30- to 40-foot class, although an occasional larger vessel is seen, designed for off-shore dredging and running to 60 or 80 feet.

The dredges commonly used are of two principal types, either a single dredge with a six foot by eight inch mouth, commonly used on muddy bottom, or two dredges, with three foot by eight inch mouths, attached to one yoke (Plate I, Fig. B), commonly used on rocky bottom. While the type of yoke may vary somewhat, the construction of the bag is usually the same and similar to that described in the early fishery, except for the size of the rings in the bottom. Two sizes of rings are commonly used. One (Figure 1), preferred for muddy bottom, has an opening with a three inch diameter. The one commonly used on hard bottom (Figure 2), has a 2-1/2 inch opening, and occasionally one with a two inch opening is used. The end of the bag is left open, with a piece of wood running the length of the top edge and a similar piece on the bottom.

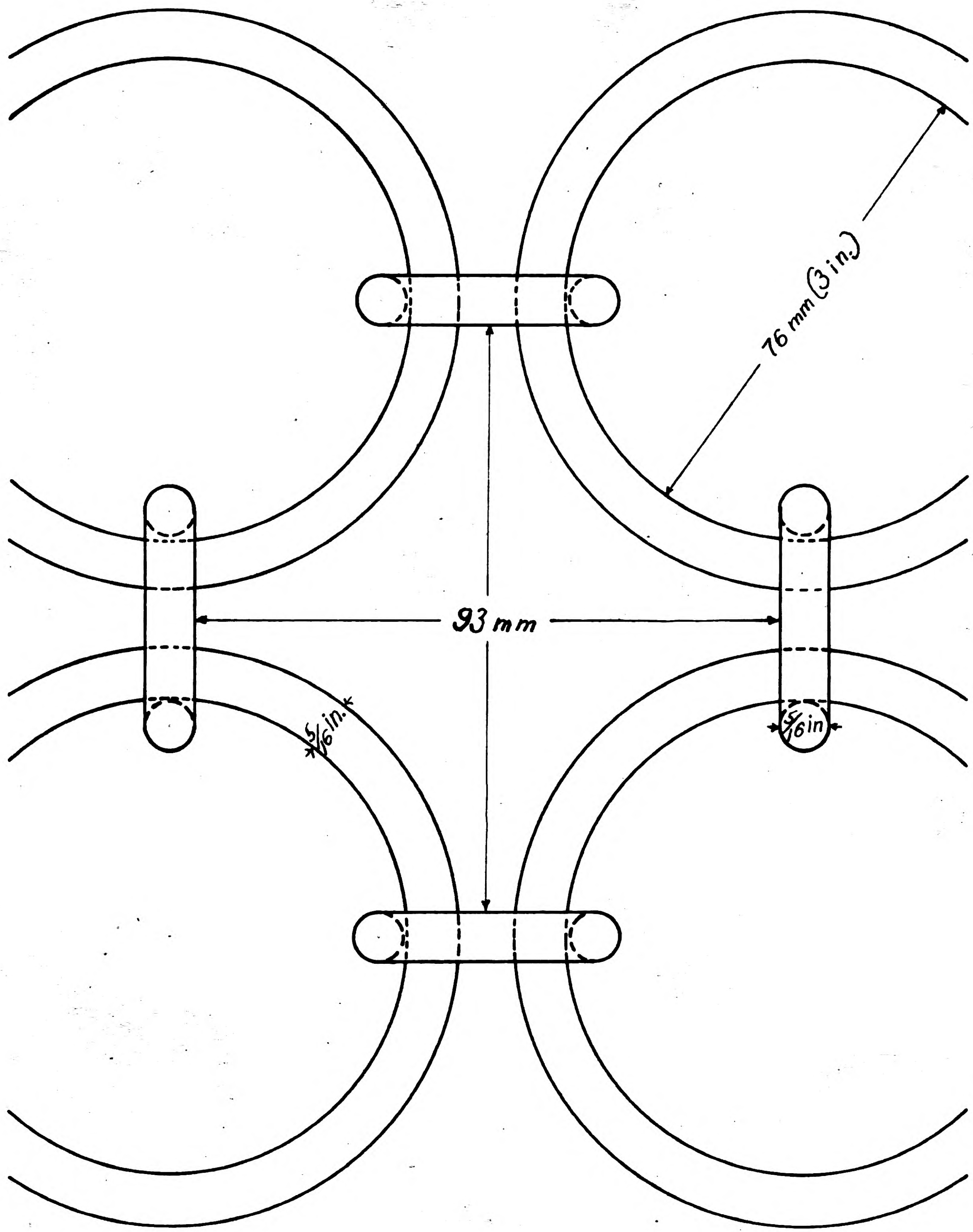

Figure 1. Ring mesh commonly used in large, single dredges.

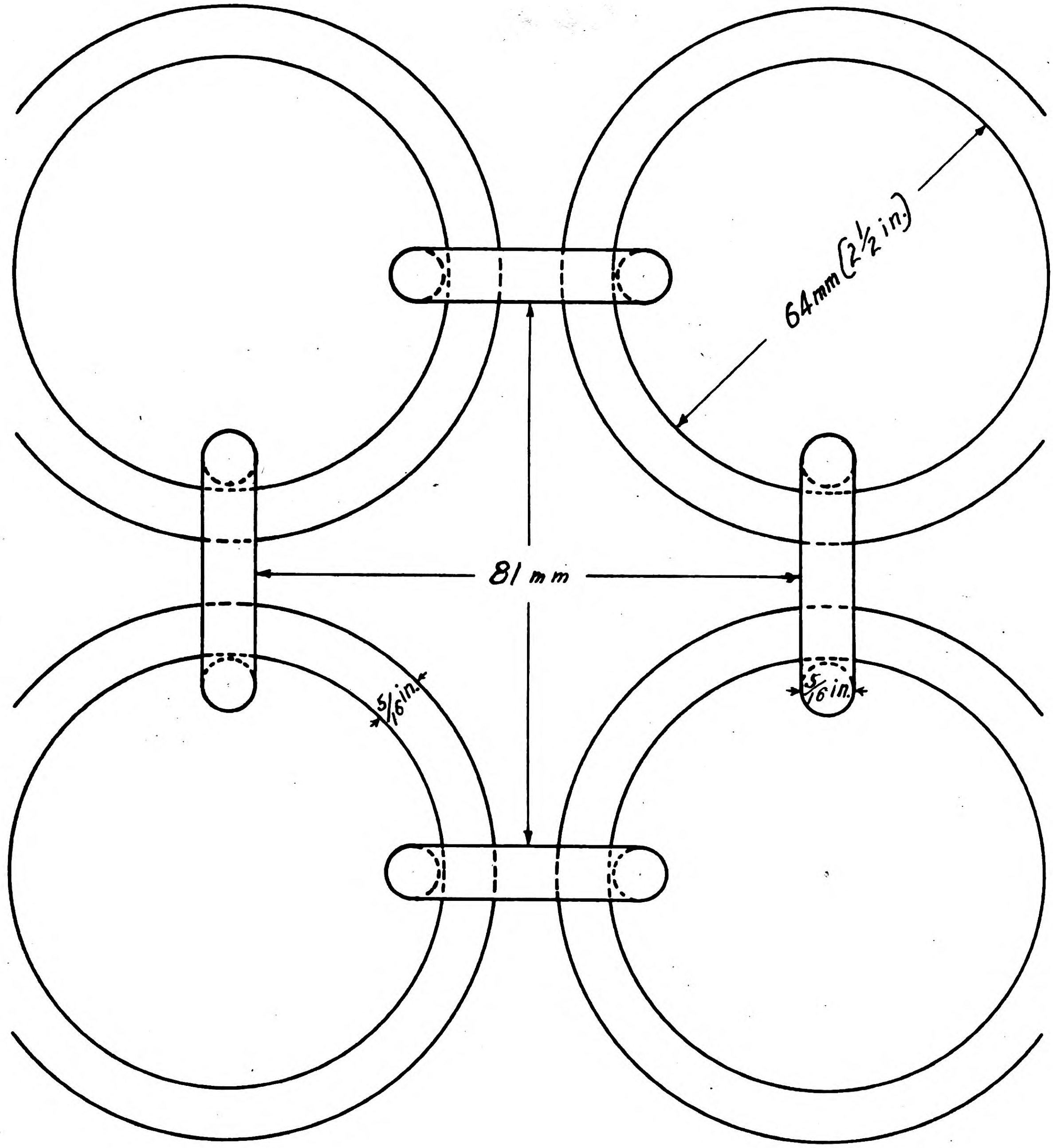

Figure 2. Ring mesh commonly used in twin dredges.

When dredging, these two edges are tied together with rope by means of a bowknot which may be quickly released to dump the catch on deck. The bag is attached at the forward end to a rectangular frame, forming the mouth of the dredge. The mouth is adjustable in relation to the yoke, changing the angle at which the lower, scraping edge of the mouth travels over the bottom. Thus the mouth can be tipped forward to ride lightly over the bottom, or tipped back to dig deeper.

The dredge is pulled with 5/16 inch wire cable. The length used overboard in dredging is two to three times the depth. This cable runs over a friction block on the stern of the boat, through a pulley on a very strong and well-braced davit at one side or the other of the pilot-house. Then it runs at right angles to the length of the boat to the winch at the forward end of the cockpit. The winch is usually powered by the same engine that runs the boat. A winch-head, also powered by the same engine, is used for the hoisting gear on the mast for the purpose of bringing the dredge aboard after it has been brought alongside by means of the winch.

For the purpose of dumping its load, the dredge is hoisted straight up, over the cockpit, with the bag hanging down. The bowknots holding the two edges of the bottom together are released and the catch is dumped on to the deck of the cockpit. As soon as the boat is on course again, over the bed, the bottom of the bag is tied up, the winch released, and the dredge dropped down to the bottom for another trip. The dredging distance varies with the size of the bed, but a run of a mile or more is very common. Meanwhile, one of the crew has sorted out the scallops of commercial size from the debris, and dumped them into

the shucking box at the side of the cockpit. The debris is then shovelled overboard. The scallop meat, consisting of the adductor muscle, is shucked out of each shell into a bucket, the unused portions of the scallop thrown overboard, and the bucket of scallop meats is dumped into a large galvanized container, in which they are taken ashore at the end of the trip.

The beds fished today are similar in most respects to those described in the early fishery. The same types of bottom are found, as well as the same general shapes and locations in relation to currents. The principal differences are that beds down to about 300 feet are now utilized, and that the scallops are far from being as abundant as they were on the early beds.

NATURAL HISTORY OF THE SEA SCALLOP

Nomenclature

The sea scallop has been known by a wide variety of scientific names. Without attempting to trace the complete synonomy of the species, some of the more recent names employed have been: *Pecten magellanicus* Gmelin, *Pecten grandis* Solander, *Pecten tenuicostatus* Mighels, and *Placopecten clintonius* Say.

In a letter dated Dec. 15, 1948, Dr. Harald A. Rehder, curator of the Division of Mollusks of the United States National Museum, stated that the name of the scallop now accepted by his institution was *Placopecten magellanicus* (Gmelin). He explained that *grandis* was thought to be invalid since it was improperly described in 1786. The name *magellanicus* Gmelin 1791 was the next valid one.

Biology

The scallop differs from most other bivalve mollusks in the fact that it is free-swimming. It does not burrow and remains attached, for the most part, only in its youngest period. Many of its morphological features have been modified to suit its swimming habit.

The shell of the scallop is rounded in outline, and flattened. In general the length[2] is greater than the height, and the dimensions of a large specimen might be 180 millimeters in length, 165 millimeters in height, and 40 millimeters in width. The left valve is convex, the right is more flattened and is generally the one upon which the animal rests.

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[2]The dimensions as used herein include the length, which is the greatest distance parallel to the hinge line, and the height, which is the greatest diameter at right angles to the hingeline.

For this reason, the left valve is usually covered with attached plants and animals, while the right is usually devoid of such growth. An exceptional specimen was dredged up, however, which evidently had lived many years upon its convex left valve, as this valve was clean while the right valve supported a heavy growth of organisms. No apparent change in the shape of the shell or the arrangement of the internal anatomy was effected by this prolonged reversal of its normal position.

The outer surfaces of the valves are covered with grooves and ridges radiating from the beaks to the margins. Fine, concentric growth lines are also visible on the surface, but in certain places they are more closely spaced and prominent than in others (Plate II, Fig. A). Stevenson proved that these more pronounced lines were formed in winter and were indicative of yearly growth. The lines on the lower valve often show a ragged outline where the old margin had been chipped, probably by clapping the valves together in swimming.

The abundant growth of organisms on the outer surface of the left valve is much more common in the case of the scallop than it is in other mollusks of the region. Drew gave as reasons for such growth, the facts that the scallop did not burrow, and did not have an adequate cuticular layer for protection. He added that a thin and discontinuous cuticle was laid down, but that in older shells it had been largely eroded away.

Each valve is marked on the inside by the centrally located, circular impression of the adductor muscle. The pallial line, where the mantle muscles are attached, is marked by a broad impression, concentric to and well removed from the shell margin.

The mantle lines the inside of each valve, and the lobe within one valve unites with the other at the hinge line. The shell, which Drew stated was made up of only the nacreous layer, is formed by secretions from glands in the surface and edge of the mantle. Its free margin is muscular, regulating the inflow and outflow of water, and on it are located two kinds of sense organs, the tentacles and the eyes. Drew also stated that the size of the eyes varied, even in the same individual, and that they were added as growth takes place. He suggested that they might possibly be used as indicators of age.

The most prominent part of the internal anatomy is the adductor muscle, stretched from valve to valve. It has two distinct parts, a large, rounded, anterior portion, and a much smaller, crescent-shaped, posterior portion which is tough and stringy and usually discarded from the market product. Sections of both parts of the muscle were made and studied. The fibers of the large, anterior portion showed definite cross-striation, while those of the posterior part were without cross-striation. Drew stated that, even though the two portions were so dissimilar, morphologically they were one, corresponding to the posterior adductor muscle of those mollusks having two. Dakin found the same arrangement of muscle tissue in *Pecten maximus* and *Pecten opercularis*. He stated that cross-striation was common in muscles given to rapid contractions, such as the motion of the valves of a swimming scallop, while a muscle without cross-striation was usually adapted to slower, more forcible and sustained contraction.

The major part of the rest of the body is made up of the liver, foot, and gonad, joined together and arranged around the anterior side of the adductor muscle. The liver is just ventral to the hinge, and contains

the esophagus, stomach, and the first part of the intestine.

The gonad joins the ventral side of the liver, and coils of the intestine run through it. The sexes are separate and the gametes of both sexes mature at approximately the same time. Fertilization takes place in the water, after the gametes have been expelled from the scallops. When immature the gonad is small or shriveled, and nearly transparent. When mature, the gonad is plump. The color of the sperm is white, while that of the ovum is pink or orange.

The foot joins anteriorly at the juncture of the liver and the gonad. It is of little use as an organ of locomotion, but can be extended and serves to attach the byssal threads. These threads, extruded from a gland near the tip of the foot, are the means by which the young scallops attach themselves to objects. Scallops as large as 99 millimeters in height were dredged up attached to objects by this means. One measuring 103 millimeters in height attached itself to the side of a wooden crate after having been confined and submerged in it.

The gills, which Drew designated as a pair, are suspended from the anterior side of the adductor muscle, on each side of the gonad, with the free edges directed anteriorly and ventrally. Water is taken in along the ventral and anterior edges of the shell. By means of ciliary action it is moved between the gill filaments and out of the shell between the posterior edges. Besides serving a respiratory function, the gills also strain food material out of the water and pass it on to the mouth.

The kidneys, paired and elongated, lie anterior to the adductor muscle, one on each side of the body. Drew stated that each opened at one end into the mantle cavity, at the other end into the pericardial cavity,

and was connected to the gonad by a genital duct through which the mature sex products were discharged.

The pericardial cavity, containing the heart, is posterior to the juncture of the liver with the adductor muscle.

The digestive tract begins with the palps, which act as lips, situated just dorsal to the foot. They pass the food into the mouth, which is followed by a short esophagus and the stomach. A large crystalline style lies with one end in the stomach, and extends into the first part of the intestine. This style, measuring nearly 100 millimeters in length in large specimens, was of the usual shape and consistency found in many pelecypods. When sectioned and examined, it showed a typically laminated cross-section. A style was consistently found to be present in fresh material, but scallops which had been kept a day or more in the same small quantity of water (limited food and oxygen supply) always lacked one entirely, or contained only a mass of mucous in place of a style. Drew did not find a definite style, only a quantity of mucous, and the reason for this may have been that he did not have strictly fresh material.

The remainder of the intestine runs ventrally into the gonad, dorsally into the liver, then posteriorly and ventrally, to open into the mantle cavity on the posterior side of the adductor muscle.

Habits

The swimming of the scallop is accomplished by clapping the valves together. The water, taken in when the valves are opened, is forced out when they are closed. The free edges of the mantle are muscular and control the direction of water outflow, thereby determining the

direction of movement.

The ability of the scallop to swim leaves an opening for much speculation as to the distance, direction, and purpose of its movements. Fishermen have long claimed that whole beds of scallops seem to shift their positions from time to time. Drew stated that, since the scallops always remained in fairly deep water, their movement could not be laid to either a change in temperature, or spawning. He thought that the most likely causes were enemies, continued dredging disturbances, or lack of food. Of these possibilities he favored the last.

The food of the scallop consists of plankton, minute plants and animals in the water, which are filtered out of the water by means of the gills. Drew stated that diatoms constituted much of the food. Stevenson gave peridinians, tintinnids, some ciliate protozoa, and some of the smaller diatoms as the most important. Dakin stated that Pecten's food consists largely of vegetable matter, such as diatoms, algal fragments and spores, and the smaller micro crustacea suspended in the water. Belding mentioned only diatoms as being used by Pecten irradians. Gutsell stated that the stomach contents of Pecten opercularis reflected the nature and variation of the plankton in general. He claimed that peridinians were abundant in late spring and summer, while diatoms, although always important, were especially abundant in fall and winter.

The habitat of the scallop, insofar as the beds are concerned, was presented in the introductory description of the scallop fishery. Little is actually known, aside from the locations and shapes of the

beds, and the nature of the bottom. Some preference seems to be shown for hard or gravelly bottoms, and as for depth, Smith gave 6 to 900 feet for the bathymetric range of living scallops, while empty shells were dredged up from as deep as 2400 feet.

METHODS AND MATERIALS

Work was started on the investigation in August 1947, and the first problem to be worked out was a method and means of sampling. It was decided that data and samples relative to size, age, growth, spawning, associated organisms, and mortality would be taken aboard commercial scallop boats during the open season from November 1, 1947 to March 31, 1948. It was desirable to start collecting as soon as possible, however, and since no dredging equipment or power boats were available, it was necessary to use a hand method. The only boat available was a 16 foot dory powered by a five horsepower Johnson outboard motor, both furnished by the Maine Department of Sea and Shore Fisheries. It could only be used in cooperation with Mr. John H. Hunt, who was also engaged in fisheries investigation. With a boat of this size a light, hand dredge had to be used. The frame of such a dredge finally was found in a barn in East Blue Hill, and purchased. A sufficient quantity of three inch iron rings for the bottom of the bag was salvaged from a discarded six foot dredge, and the top, end, and sides of the bag were woven from heavy cod line. When completed, the dredge was similar to the type described under The Early Fishery. The mouth was 30 inches in width by six inches in height, while the bag extended 20 inches back of the mouth. A view of the dredge is shown in Plate I, Fig. A. The dredge was rigged with 300 feet of 5/8 inch manila rope, and trial drags were made on several scallop beds in Blue Hill Bay. These trials were entirely unsatisfactory. On beds deeper than 50 feet, the dredge was too light to stay on bottom, and on beds less than 50 feet deep, the least obstruction on bottom would stop the boat. The light dory did not have enough momentum to overcome such obstacles.

A larger boat (Plate III, Fig. A), 20 feet long, decked over, and much heavier than the dory, was very generously lent by Mr. Ransome Kelly of Fairfield, Maine. It was anchored near Deer Isle, at Sunshine, because of the close proximity of many scallop beds in 50 feet of water or less. The same dredge and motor were used, and by taking advantage of the wind and tidal currents, satisfactory results were obtained.

A considerable amount of trial dredging was necessary to locate suitable beds, to perfect the method of dredging, and to gain experience. The scallops obtained by this means were used in several ways. Many were preserved whole in 10 per cent formalin, for examination and familiarization with their anatomy.

It was found, in the examination of fresh material, that sexes could be distinguished very readily by the color of their gonads. As described under Natural History of the Scallop, a gonad containing male sex cells is white, while one containing female sex cells is pink or orange. Thus, the sex can be recognized by the color, except in immature specimens, where microscopic examination is necessary. Hence, all immature individuals were grouped in a maturity class without regard to sex, as will be described subsequently.

The inspection of fresh material also revealed that all stages in the development of sex products could be found at the same location and on the same day. It was decided that a satisfactory indication of the spawning season would be that period of the year between the time when the occurrence of fully mature individuals was the greatest, and the time when their occurrence was the least.

Accordingly, four stages of sexual maturity, applicable to either sex, were set up arbitrarily, for the purpose of quick field identification. These stages were:

1 Completely immature, gonad small, translucent, with the intestine showing through. No differentiation made between sexes. Plate IV, Fig. A.

2 Partially developed, gonad somewhat filled out and showing some color, white or pink. Plate IV, Fig. B.

3 Nearly ripe, gonad distended, contents plainly colored, but showing no granulation. Plate IV, Fig. A.

4 Fully ripe, gonad distended, contents plainly colored, showing distinct granulation and gonoducts. Plate IV, Fig. A and Plate V.

Later in the season, when spawning occurred, two additional stages of spawning were adopted. These were:

1sp Partially spawned, gonad showing large patches of fully colored sex products and small patches of neutral colored, empty gonad.

2sp Almost completely spawned, gonad showing but few small patches of colored and granulated sex products, the rest being empty and neutral in color. Plate VI, Fig. A.

The first of the dredging samples, hereafter designated as collections, fully tabulated, and in sufficient quantity to use as data, was taken Oct. 12, 1947. The locations and dates of this and all subsequent collections are shown on Plates VII, VIII, IX, and X, and in Table III.

In obtaining and utilizing a single, typical dredging sample from a 50 foot depth, the dredge was thrown overboard, about 150 feet of rope run out, and the end of that length was made fast to the boat. The speed of the boat was adjusted to the maximum that would allow the dredge to remain on bottom. Any greater speed would lift the dredge off bottom, while any slower speed might fail to furnish enough momentum to over-ride bottom obstructions. The dredging distance varied with the type of bottom, experience indicating how long a drag was necessary to fill the dredge. The average distance was about 350 yards, at the end of which time the boat was brought about and the motor adjusted to low speed. The rope was then pulled in, hand over hand, being coiled on deck as it was brought up, ready to be payed out again. When the dredge had been brought aboard, it was turned upside down and its contents dumped on deck. The debris was sorted immediately and all living scallops were transferred directly to pails of sea water. If the debris consisted of much mud or gravel, it was carefully washed out to find all of the smaller sizes of scallops. Dredging was resumed immediately, while the scallops were either held to be measured and examined at the end of the day, or placed in a small, wooden, submerged crate to be measured the next day. Such dredging was usually accomplished alone, but at times an extra person was used to very good advantage to tend the motor.

TABLE III

THE COLLECTIONS: DATES, LOCATIONS AND CHARACTERISTICS

Collection No.	Date	Location	Characteristics	
			Depth in Feet	Bottom
1	Oct. 12, 1947	Greenlaw Cove. Plate VII	30 - 50	Sandy Gravel
2[3]	Nov. 20, 1947	Hardwood Island. Plate VIII	150 - 250	Clay-Mud
3[3]	Jan. 17, 1948	Swan's Island. Plate IX	100 - 200	Rocky
4[3]	Feb. 21, 1948	Penobscot Bay. Plate X	250 - 280	Rocky-Muddy
5[3]	March 23, 1948	Penobscot Bay. Plate X	150 - 300	Rocky
6	April 24, 1948	East of White Island. Plate VII	15 - 50	Muddy Gravel
7	May 15, 1948	Greenlaw Cove. Plate VII	30 - 50	Sandy Gravel
8	June 30, 1948	East of White Island. Plate VII	15 - 50	Muddy Gravel
9	July 9, 1948	East of White Island. Plate VII	15 - 50	Muddy Gravel
10	July 22, 1948	East of White Island. Plate VII	15 - 20	Muddy Gravel
11	Aug. 19, 1948	Greenlaw Cove. Plate VII	30 - 50	Sandy Gravel
12	Sept. 25, 1948	Greenlaw Cove. Plate VII	30 - 50	Sandy Gravel

[3]Commercial Collections

When a scallop was examined, its height was measured first. Height was selected, rather than other dimensions, because it includes only one thin edge of each valve on the ventral side and the hinge line on the dorsal side. The thin edges are subject to much chipping, leading to errors in the true dimension. The length, being the distance from the anterior edge to the posterior edge, would involve two thin edges of each valve. The thickness, while not including thin edges, is not a reliable indicator of size. Several scallops of the same height may vary a half-inch or more in thickness. Moreover, in the age and growth determinations described below, it was found that the measurements were much more easily made in the dimension of height.

Height was measured by means of the gauge shown in Plate II, Fig. B, which was patterned after the one used and described by Belding. It was made of heavy gauge brass angle stock, welded together in the form of an isosceles triangle, the two equal sides of which were 24 inches each, while the base was nine inches. The distances between the two equal legs were measured in millimeters and five millimeter intervals were marked on the two long legs. In use, the point of the gauge was held toward the body, the scallop was passed down the gauge between the two long legs until both the hinged edge and the ventral edge were touching the inner edges of the two long legs. The height of the scallop could then be read off either leg, interpolating to the nearest millimeter, and this figure was recorded in a field notebook.

In determining the sex of a scallop, its valves had to be opened. If it were not desirable to kill each one, they were left out of water for a few minutes before being measured. This was usually sufficient to cause

the muscles to relax and allow the valves to gap open. The gonad, lying on the ventral side of the shell, could be plainly seen through the open ventral edges of the valves. Thus, the sex and gonadal maturity of the individual were determined and recorded with its height.

The scallops whose shells were taken for age and growth study were merely shucked out, the method being to hold the scallop with its flattened, or right, valve up, with the hinged edge toward the body. A knife, inserted into the posterior end of the shell through the opening between the valves near the hinge, and pointed toward the ventral edge, is moved with a slicing motion, close to the inside of the flattened valve, back toward the hinge. This motion severs the adductor muscle close to the right valve. An upward flick of the knifeblade detaches the right valve from the left and leaves the internal anatomy exposed. The gonad is then partially hidden by the right pair of gills, which may be brushed aside to expose the gonad for examination.

The exterior and interior of the valves were examined for plant and animal organisms living thereon, and those found were preserved immediately in 10 per cent formalin for future identification. The internal anatomy was likewise examined for any sign of disease or parasitism although none was ever found.

The valves kept for age and growth studies were scraped clean, inside and out, and set aside, labeled with the locality and date, for future study.

Collections made in the months from November 1947 through March 1948, were made aboard commercial scalloping boats, and a similar procedure was followed on each. The equipment used aboard such a boat,

and the general dredging procedure followed were described under The Present Fishery.

The dragger would head for a scallop bed, previously located by trial dredging or previous reports of other scallopers. When the captain's landmarks had been sighted and the course was set over the bed, the dredge was dropped, and dredging began. After dragging for a mile or more, the dredge was brought aboard and its contents dumped into the cockpit. While the captain brought the boat back on course, and his helper picked up the scallops of suitable size, all the undersized scallops were picked out for measurement, sex examination, and preservation for later age and growth study. Meanwhile, the dredge was thrown overboard for another drag, and the helper started shucking out the scallop meats. Although it inconvenienced him somewhat, he would vary his technique sufficiently to furnish the samples desired. His shucking was similar to that described above, except that after the muscle had been severed from the flat, right valve, he slipped his knife between the left mantle and left valve and flipped it upward and toward his body. This removed the right valve and all the viscera from the left valve, except the adductor muscle, which remained attached to the left valve. The muscle was cut from this valve and dropped into a bucket, close at hand. The two valves and the remaining viscera were taken from the helper and examined. Since the helper could shuck many more scallops than could be examined, the extras were simply dropped overboard. The scallops examined were measured for height, and the sex and gonadal maturity were determined and recorded. Some valves were set aside to be saved for age and growth study, the others were thrown overboard. Representative samples of organisms found upon and within the shells were taken and preserved in 10 per cent formalin.

It was decided that microscopic and photographic confirmation of the appearance of the gonads in progressive stages of sexual development would be valuable evidence to have. Accordingly, six or eight scallops of various sizes, sexes, and stages of gonadal maturity were taken to the laboratory from each collecting trip. They were kept and transported in a four-gallon, galvanized cream container, filled with sea water. When the water temperature was kept between zero and five degrees, centigrade, it was found that the mollusks would remain alive for three days, without changing the water.

Whenever possible, the photographs were taken in the sunlight, on daylight type, Ektachrome color film, with a 2-1/4 by 3-1/4 inch, Kodak Recomar camera. In the absence of sunlight, the same film was used, with two No. 2 photoflood bulbs and reflectors, and a compensating blue filter was placed over the lens. This filter was a Kodachrome Filter for Photoflood. All light except that from tungsten bulbs had to be excluded, as it would show as different colored streaks on the film.

In preparing the scallop for photographing, its height was measured, then the left valve, left lobe of the mantle, and the left pair of gills were removed. This left the remaining viscera, notably the gonad, plainly visible lying in the right valve. The animal remained alive and was kept moist by dropping sea water upon it. The sex and gonadal maturity were recorded, and the specimen was assigned an identification number, printed on the edge of the right valve, or on a white paper background that would be photographed. A tripod, supporting the camera, was set up over the scallop, and an exposure was made. Representative prints of these films are shown in Plates IV and V and Plate VI, Fig. A.

The organism was usually still alive at this point, so two or three cubes of tissue about one centimeter on a side, were cut from the gonad with a scalpel. These were placed immediately in Bouin's fixative for subsequent sectioning. In one instance, samples of tissue from several parts of the body were taken in case the need should arise to examine the histology of such parts of the body. Samples were taken from the edge of the mantle, which included the tentacles and eyes, from the gills, foot, liver, style, and both parts of the adductor muscle. These were labeled and stored in bottles of fixative.

The gonad tissue to be used for slides and photomicrographs was removed from the fixative, rinsed and dehydrated through the alcohols, and cleared in cedar oil. It was then rinsed in xylol, infiltrated with and imbedded in paraffin, and sectioned at 10 microns. The sections were stained with either Delafield's hematoxylin and eosin, or Van Giesen's stain. The tissue was then covered with balsam and topped with a glass coverslip.

When the balsam had hardened sufficiently, the slide was set up under a microscope, equipped with a 16 millimeter achromatic objective and a X 10 Huyghenian eyepiece and illuminated by a substage light. The Kodak Recomar mentioned above was mounted, on a bracket, over the eyepiece of the microscope. With the bellows at full extension, the image could be focused on the ground glass in the camera-back, at about X 100. Using Ansco Super XX film, with the diaphragm closed to f22, an exposure of one minute was used for the lightest slides, 1-1/2 minutes for the average, and two minutes for the darkest slides. Representative prints of these photomicrographs, enlarged to about X 200, are shown in Plate XI, Fig. B, and Plates XII to XIV, inclusive.

The scalloping season closed on March 31, 1948, and in April, hand dredging was resumed. The same methods were used, and the same data taken, as described above.

In June, when full time could be spent on the work at hand, an experimental program of tagging scallops was started to gain information on their movements. This, and all subsequent field work, was done in the vicinity of Deer Isle, with Sunshine as a base.

The tags were made of heavy gauge copper, 1/2 by 1-1/2 inches, with a 3/16 inch hole in one end. The tags were numbered, one to 250, the numbers being inscribed in the soft metal at one end, while at the other were inscribed the identifying initials U of M. A method of attaching the tag to the shell by means of a hole drilled in the shell was discarded as being too time-consuming. Another method was tried in which the tag was attached by means of a rubber band around the "ears", just ventral to the hinge line. The method proved to be fast enough to be useful, and 30 scallops of various sizes were thus tagged. Fifteen were put into each of two wooden crates and left for three weeks to determine the lasting quality of the method of attachment. The crates were generously lent by Mr. A. C. Heanssler of Sunshine. They measured about four feet in length, two feet in width, and one foot in depth. The slats making up all six sides were separated by 1/4 inch cracks to allow for water circulation. When water-soaked and containing a few scallops, the crates would sink and rest on bottom in six feet of water at low tide. They were attached to an anchor and marked by a buoy.

After three weeks, none of the tags had been lost, and the rubber bands had prevented none of the scallops from opening its valves

enough to obtain sufficient food and oxygen to live. The method was considered satisfactory and it was believed that the rubber bands would last during the six months allotted to the experiment. The deadline set for the return of the tags was Dec. 30, 1948. The specimens to be tagged were taken from the regular collections, and the height and sex data of each were listed with its tag number. As described earlier, the scallops were kept alive during tagging and transportation, in buckets of sea water which were renewed frequently. Two easily located areas were picked, and there the tagged scallops were released and pertinent information recorded.

Six of the tagged individuals were picked up in subsequent dredging during the summer, and scallopers in the vicinity were asked to watch for the tagged shells when their season opened in November. The men were asked to turn in the tagged shells to Mr. Heanssler, where most of the catches are sold.

The locations of release are shown on Plate VII, and some further discussion of movement will be taken up under the heading, Movements.

When making the second July 1948 and the August 1948 collections, a record was kept of the proportion of live scallops to "clappers" brought up in each dredge-load. These "clappers" are empty shells, still held together by the hinge ligament and the spring cartilage, which is an indication that the scallop died by means other than those used by man. A scalloper, in shucking, must remove one valve completely to take out the muscle. The "clappers" counted were only those that had died within the past few months. This was indicated very roughly by the scarcity of

plant and animal growth on the inside surfaces of the valves. It was thought that the proportion of live scallops to "clappers" might furnish an indication of the natural mortality of the adult scallops. The result of the July collection, number 10, taken east of White Island, was 133 live scallops to 56 "clappers", or 42 "clappers" to each 100 live scallops. The August collection, number 11, taken in Greenlaw Cove, was 171 live scallops to 91 "clappers", or 53 "clappers" to each 100 live scallops. The results and importance of these data will be further discussed under Associated Organisms and Mortality.

During July and August 1948 a continuous test was run to determine to what extent the various species of starfish preyed upon scallops. The plan was to isolate several of each species with several scallops of various sizes, in a submerged car for an extended period of time. Six species of starfish were commonly found in dredging. Three of these, *Henricia sanguinolenta*, *Crossaster papposus*, and *Ctenodiscus crispatus*, were not abundant enough to be considered important and were grouped together, three of each species, in one car. Six scallops were included with them, the heights ranging from 53 to 157 millimeters. Neither the scallops nor the starfish showed any signs of damage after three weeks of confinement.

Solaster endeca was not abundant in the shallow waters near Sunshine, as it seemed to prefer depths below 50 feet. Scallopers had reported seeing this starfish with its oral surface cupped around small scallops, 20 to 30 millimeters in height. Two of this species although scarce, were secured by dredging and were confined in a car with six scallops ranging from 28 to 134 millimeters in height. After two weeks, no damage of any sort was found.

Large specimens of Asterias forbesi were commonly seen on mussel beds in one to six feet of water at low tide, but were seldom dredged up from the usual depths (30 to 50 feet) of the scallop beds. Nevertheless, their large size, 150 to 250 millimeters, made them a potential threat to scallops in the eyes of the fishermen. One 250 millimeter and two 205 millimeter specimens were caught and put into a car with six scallops ranging from 58 to 163 millimeters in height. At the end of two days, none of the scallops had been damaged, but the central body portion of one 205 millimeter starfish had been completely destroyed, presumably by one of the other two starfish. The five remaining rays of the damaged animal were removed to prevent their being consumed by the remaining starfish and the car was submerged again. No observations were made until a week had passed, when it was found that two of the shells were empty. The bodies of the scallops had not been consumed, however, as they lay intact but dead on the bottom of the car. They were entirely free of their shells, but showed no damage of any sort. The cause of this type of mortality was never determined. The remaining starfish and scallops were kept together during two additional weeks, but no more damage of any kind was found.

The most common starfish found on the scallop beds was Asterias vulgaris. In two instances a scallop was dredged up which contained a small starfish on this species feeding upon the remains of the mollusk. Accordingly, eight of these starfish, ranging in size from 63 to 154 millimeters, were left with six scallops, ranging in height from 41 to 146 millimeters. Overnight, two scallops were entirely consumed and a 67 millimeter starfish was found within a scallop measuring 160

millimeters in height, feeding upon the body. This example of damage is shown in Plate VI, Fig. B and Plate XI, Fig. A. The car was left for a week, during which time the starfish disposed of the remaining three scallops. Six of the starfish were then brought ashore and one was put into each of six three-gallon crocks with one average-sized (80 to 110 millimeters) scallop. The crocks were filled with sea water and covered to keep out the light. Close watch was kept over these during one day, but no bivalves were killed. No starfish were observed to find their way into any scallop shells, but an instance was noted where a large starfish (142 millimeters) was wrapped about a scallop, with its oral surface pressed close to the natural gap between the scallop valves just ventral and posterior to the hinge. The two were picked up for closer observation, but it could not be seen whether or not the stomach of the starfish had been inserted between the valves. When the starfish was picked off, however, it was noted that its stomach was everted. The two were put back together, but nothing similar happened again. It was concluded that, wherever Asterias vulgaris was common or abundant on scallop beds, it could be credited with a considerable amount of depredation.

In September 1948, when a high percentage of spawning occurred, a brief and unsuccessful attempt was made to induce spawning. The effort was made in hopes of obtaining early development stages of scallops, and as a check on the external appearances of the gonads in various stages of spawning.

Animals of both sexes with apparently mature gonads were saved out of the day's dredging. The bottom temperature at about 45 feet was 10° Centigrade. After they were brought ashore, the scallops were sorted

out into three-gallon crocks. One crock held three males, one held three females, and into each of four crocks were put three males and three females. The crocks were filled with sea water, which was changed every few hours.

The air temperature just at sundown was 11.7° Centigrade, and at 5:30 the next morning, it was 6.7° Centigrade. During the night one male, in a crock with two other males, had partially spawned. No others showed any sign of spawning. During the day, the air temperature rose to a high of 24.4° Centigrade, while the water in the crocks warmed to 18° Centigrade. No more spawning took place. The next day, the last available, the air temperature did not rise above the water temperature so the attempt was abandoned.

A sufficient number of shells was taken from five collections (2, 3, 4, 8, 11) to be used in age and growth determinations. The left, or upper, valves were used because the thin, outer edges were less chipped than the right valves, even though the left valves were consistently more badly eroded.

Stevenson's criterion was used in judging age and growth. This is the assumption that the scallop lays down a prominent winter ring, or a short series of them, for each year's growth. These annual rings are shown in Plate II, Fig. A.

The data were taken from each valve and tabulated separately for each collection. All measurements were taken on a line across the valve, perpendicular to the hinge line. The growth rings were counted, the distance from the umbo to each growth ring, and the total height of the scallop was measured. One hundred fifty shells were measured from each collection. The data for each collection were reduced to averages

to express the following terms: the average height at each growth ring, the average gain in height from the previous ring, the average total height of each age class, and the average gain in each age class from the last ring to the time of capture. The relationships of these averages will be discussed under Age and Growth.

On each of the scallop boats visited and on two of the hand dredging expeditions, data were taken for possible use in the calculation of fishing effort. The information taken was: (1) size of the dredge, (2) dredging distance, (3) total catch for the day, (4) number of dredging trips over the bed, and (5) hours of dredging.

The length and height of the mouth of the dredge, the dredging distance, and the number of dredging trips over the bed were multiplied together to give the total volume worked by the dredge in a day. Thus the total work put in could be compared to the results obtained, expressed in gallons of scallops. It might be thought more expressive to convert the gallons to dollars by multiplying the fishermen's price per pound to gallon, but this would introduce a variable factor which was independent of fishing conditions except in cases of extreme abundance or scarcity. The applications of fishing effort will be given more discussion under the heading, Fishing Effort.

SIZE FREQUENCY OF THE CATCHES

The size, represented by the height, of each scallop in a collection was entered in a frequency table (Table IV) having a class interval of 10 millimeters. Ten was chosen as a class interval because, with the sizes running from 10 to 191 millimeters, a smaller interval such as one or five would result in an unwieldy number of classes. Any larger class interval would mask many of the characteristics of the data.

The frequency of each height class in a collection was converted to a percentage of the total number in each collection, and plotted on a graph according to percentage and height class (Figures 3 to 6). These figures show graphically much of the information entered in Table IV. The conversion to per cent rather than the use of raw numbers allows better comparison of the various collections because the totals within the different collections vary from 133 to 807.

The first, most striking, feature of the frequency table and the graphs is their approach to the normal frequency distribution or bell-shaped curve. This is, of course, definitely not characteristic of a population frequency distribution, which should start with very high numbers in the youngest and smallest classes and decrease with increased age or size. The cause of this type of distribution is to be found in the method by which the samples were obtained.

The dredges used in securing collections 1, 2, 3, 6, 7, 8, 9, 10, 11, and 12 were equipped with an iron ring mesh in the bottom of the bag, that corresponded to the dimensions and arrangement shown in Figure 1, page 8. The largest scallop that could pass through the rings was 76 millimeters in its smallest diameter (usually height). Between the

TABLE IV

SUMMARY OF HEIGHT FREQUENCY COLLECTIONS

Height Classes in Millimeters	Frequency and Frequency Per Cent by Collections							
	Collection 1		Collection 2		Collection 3		Collection 4	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
11 - 20								
21 - 30			1	0.1	1	0.2	1	0.3
31 - 40			15	1.9	1	0.2	3	0.7
41 - 50			17	2.1	0	0.0	5	1.2
51 - 60	14	8.9	33	4.1	0	0.0	2	0.5
61 - 70	14	8.9	52	6.4	3	0.5	6	1.5
71 - 80	12	7.7	50	6.2	7	1.2	10	2.5
81 - 90	19	12.2	82	10.2	214	36.7	10	2.5
91 - 100	31	19.9	170	21.1	228	39.2	27	6.7
101 - 110	15	9.6	67	8.3	37	6.4	28	6.9
111 - 120	11	7.1	114	14.1	27	4.7	60	14.8
121 - 130	11	7.1	93	11.5	17	2.9	52	12.8
131 - 140	9	5.8	52	6.4	27	4.7	107	26.4
141 - 150	8	5.1	44	5.5	7	1.2	57	14.1
151 - 160	7	4.5	15	1.9	9	1.6	30	7.4
161 - 170	4	2.6	0	0.0	2	0.3	7	1.7
171 - 180	1	0.6	1	0.1	0	0.0		
181 - 190			1	0.1	0	0.0		
191 - 200					1	0.2		
Total	156	100.0	807	100.0	581	100.0	405	100.0
Average Height	100		101		97		123	
Average Commercial Height (81-90 up)	113		111		98		128	
Standard Deviation (Average Height)	29.7		26.7		17.4		24.9	
Standard Error of (Average Height)	2.4		0.9		0.7		1.2	
Standard Error of Standard Deviation	1.7		0.7		0.5		0.9	

TABLE IV (continued)

SUMMARY OF HEIGHT FREQUENCY COLLECTIONS

Height Classes in Millimeters	Frequency and Frequency Per Cent by Collections							
	Collection 5		Collection 6		Collection 7		Collection 8	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
11 - 20								
21 - 30			7	4.3			2	1.1
31 - 40			2	1.2			2	1.1
41 - 50			3	1.9			1	0.6
51 - 60			3	1.9	12	8.6	2	1.1
61 - 70			6	3.7	7	5.0	9	4.9
71 - 80			12	7.4	10	7.2	12	6.6
81 - 90	2	0.3	30	18.5	27	19.4	17	9.3
91 - 100	1	0.2	52	32.1	39	28.2	47	25.6
101 - 110	22	3.5	17	10.4	22	15.8	39	21.3
111 - 120	42	6.8	6	3.7	10	7.2	17	9.3
121 - 130	70	11.3	9	5.6	6	4.3	15	8.2
131 - 140	154	24.8	6	3.7	2	1.4	9	4.9
141 - 150	235	37.9	3	1.9	3	2.2	7	3.8
151 - 160	89	14.3	5	3.1	1	0.7	4	2.2
161 - 170	6	0.9	1	0.6				
171 - 180								
181 - 190								
191 - 200								
Total	621	100.0	162	100.0	139	100.0	183	100.0
Average Height	138		93		93		101	
Average Commercial Height (81-90 up)	138		102		101		108	
Standard Deviation (Average Height)	13.2		27.0		20.3		23.6	
Standard Error of (Average Height)	0.5		2.1		1.7		1.7	
Standard Error of Standard Deviation	0.4		1.5		1.2		1.2	

TABLE IV (continued)

SUMMARY OF HEIGHT FREQUENCY COLLECTIONS

Height Classes in Millimeters	Frequency and Frequency Per Cent by Collections							
	Collection 9		Collection 10		Collection 11		Collection 12	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
11 - 20	1	0.8			1	0.6	2	1.4
21 - 30	6	4.5	2	1.2	2	1.2	1	0.7
31 - 40	0	0.0	2	1.2	9	5.5	0	0.0
41 - 50	4	3.0	1	0.6	4	2.4	5	3.4
51 - 60	1	0.8	3	1.8	10	6.1	4	2.7
61 - 70	5	3.8	7	4.1	16	9.8	8	5.4
71 - 80	6	4.5	7	4.1	17	10.4	14	9.5
81 - 90	24	18.0	14	8.2	36	21.8	18	12.1
91 - 100	33	24.7	46	26.8	42	25.7	28	18.9
101 - 110	16	12.0	31	18.1	9	5.5	23	15.5
111 - 120	8	6.0	18	10.5	5	3.1	19	12.8
121 - 130	9	6.8	11	6.4	4	2.4	12	8.1
131 - 140	5	3.8	9	5.3	7	4.3	4	2.7
141 - 150	6	4.5	12	7.0	1	0.6	6	4.1
151 - 160	8	6.0	7	4.1	1	0.6	3	2.0
161 - 170	1	0.8	1	0.6			1	0.7
171 - 180								
181 - 190								
191 - 200								
Total	133	100.0	171	100.0	164	100.0	148	100.0
Average Height	98		104		84		97	
Average Commercial Height (81-90 up)	108		111		98		108	
Standard Deviation (Average Height)	30.7		26.0		25.0		27.0	
Standard Error of (Average Height)	2.7		1.9		1.9		2.2	
Standard Error of Standard Deviation	1.9		1.4		1.4		1.6	

Average Height of Total = 108 mm.
Average Commercial Height = 115 mm.

FIGURE 3

Occurrence of Height Classes in Collections 1, 2 and 3

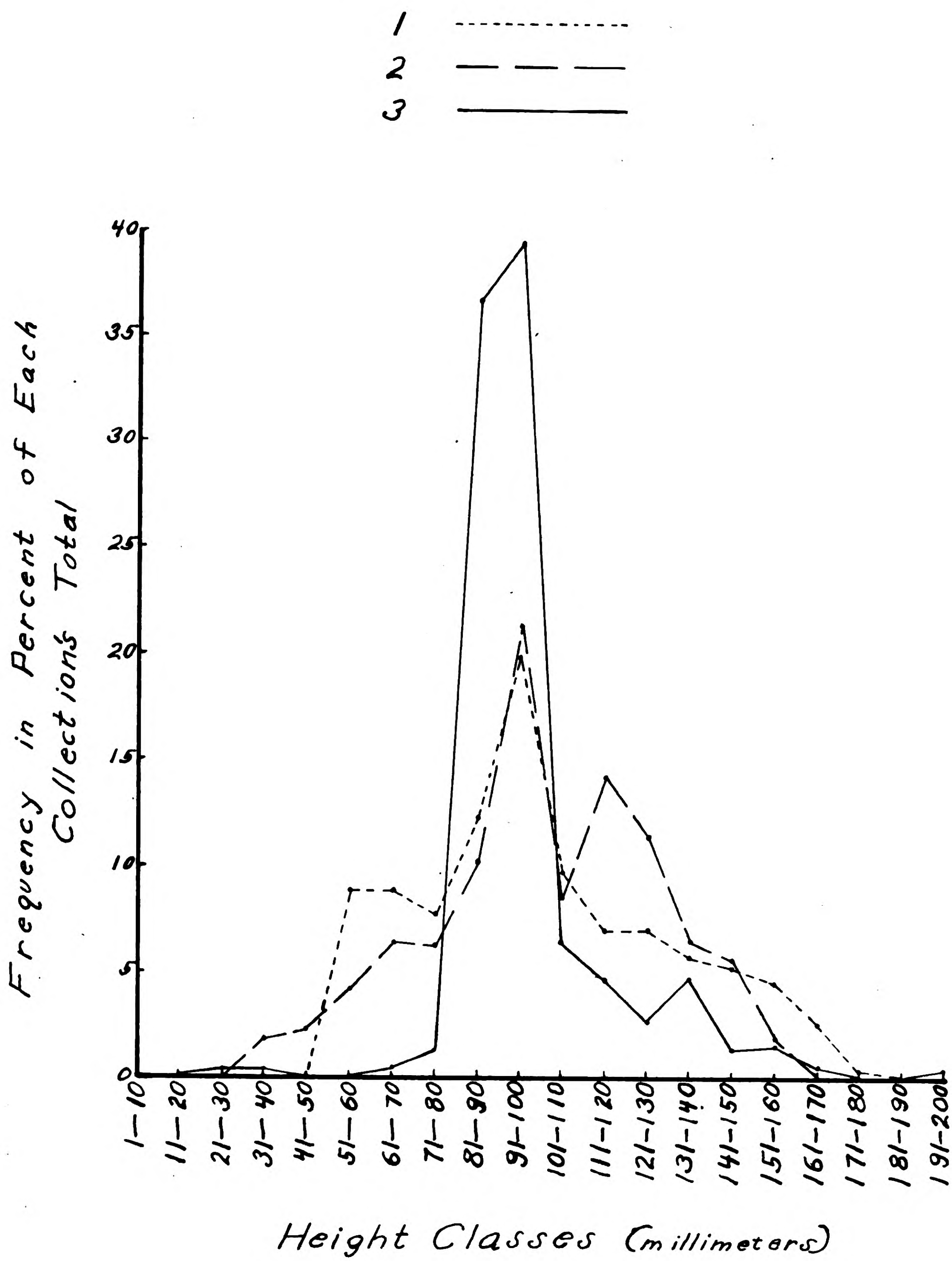


FIGURE 4

Occurrence of Height Classes in Collections 4, 5 and 6

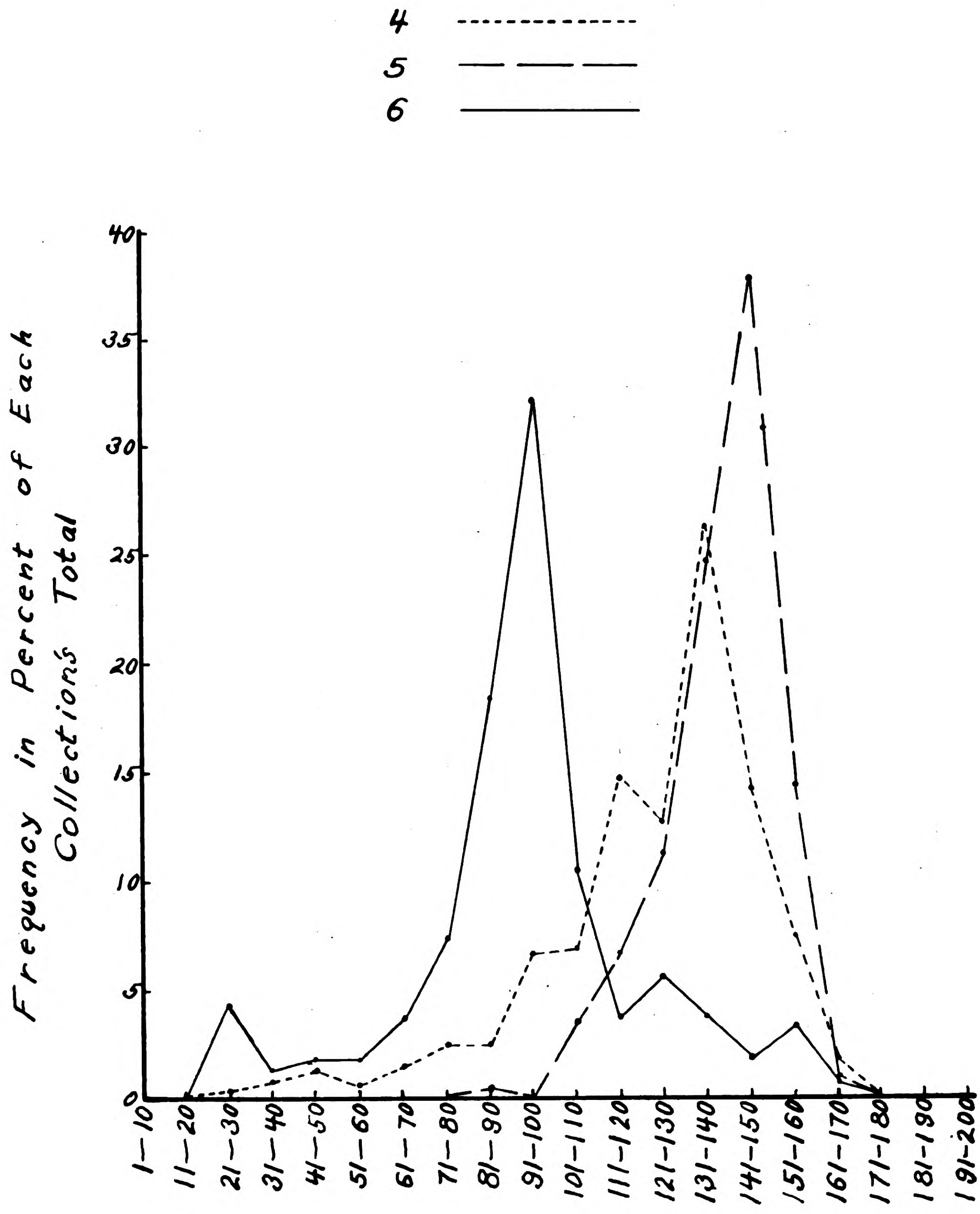


FIGURE 5

Occurrence of Height Classes in Collections 7, 8 and 9

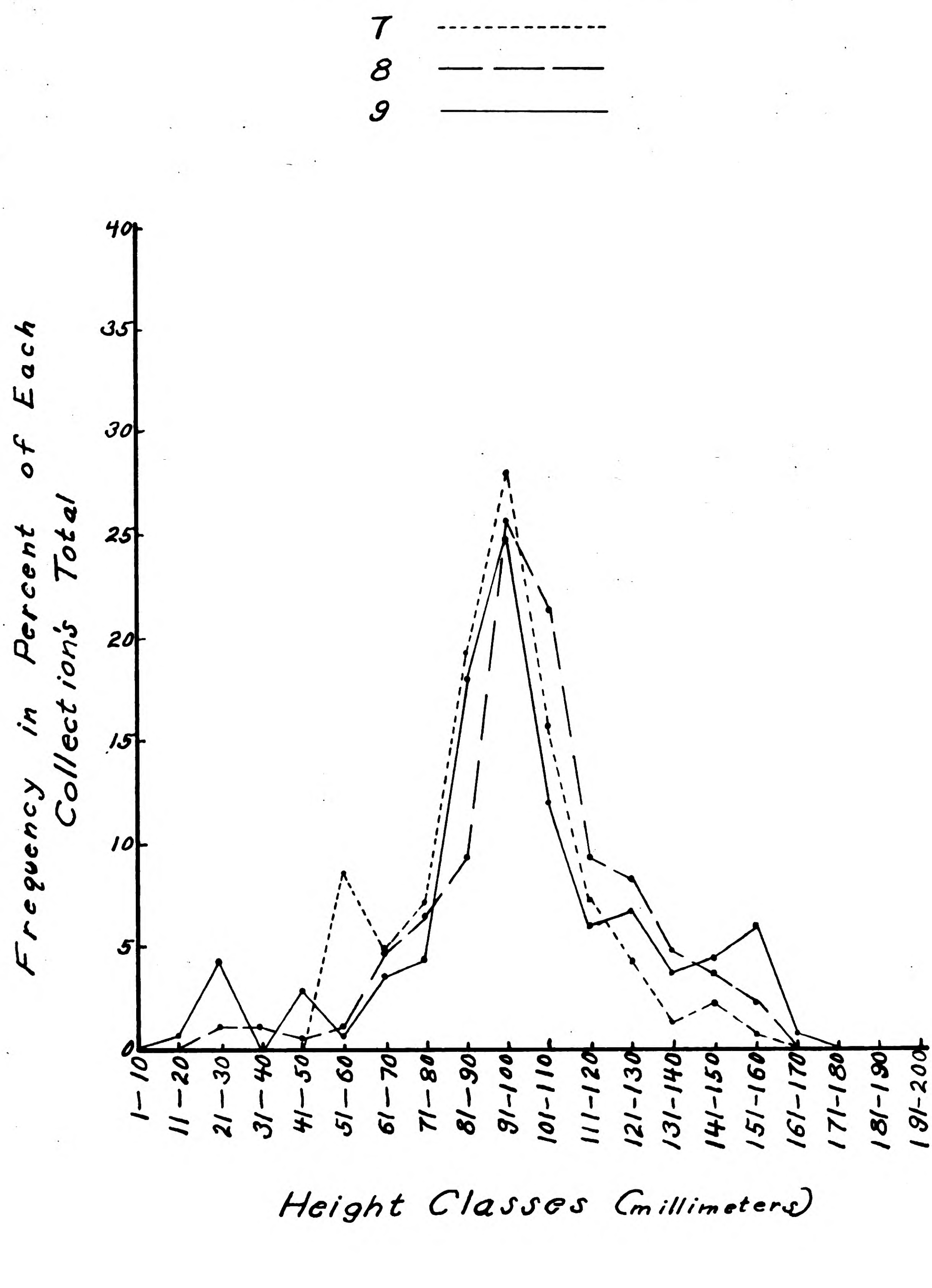
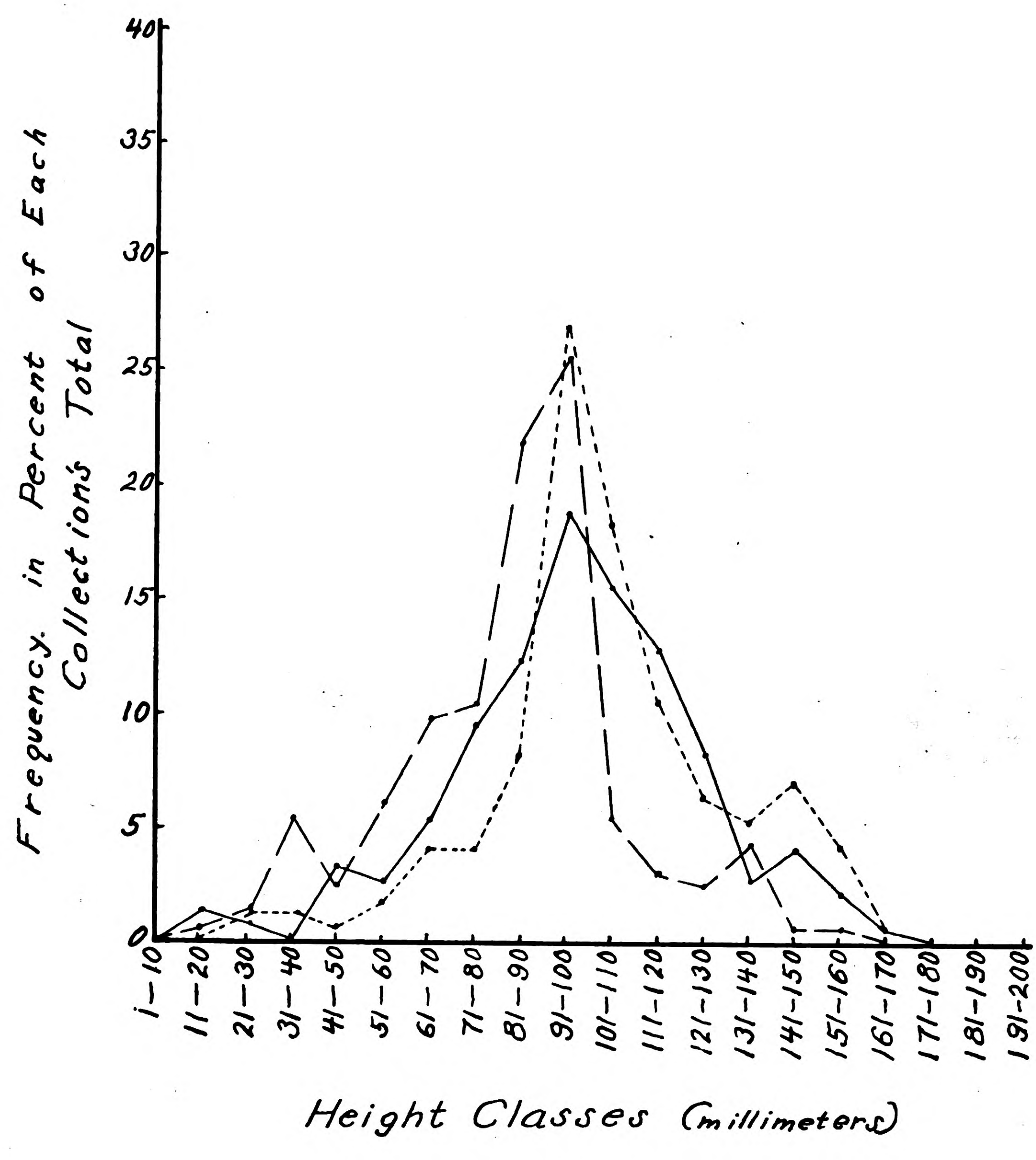


FIGURE 6

Occurrence of Height Classes
in Collections 10, 11 and 12

10 - - - - - - - - -
11 — — —
12 ————



rings, however, scallops as large as 93 millimeters could pass. The decrease in numbers toward the smaller sizes is due to the increased chance that each smaller height class has of slipping through the mesh. The frequency of the smaller sizes is not necessarily indicative of any scarcity of abundance of reproduction, however. The type of bottom that was dredged largely controls these frequencies, since mud, clay, and muddy gravel remain in the dredge and prevent the small sizes from washing out. On bottoms of rock or coarse gravel, nearly everything is washed out that will pass through the mesh. Thus those classes in the frequency distribution which represent sizes of 93 millimeters and over may be considered as true samples of the population, but those below this size are incomplete.

It will be noticed that the modal classes of the above-mentioned collections correspond with the sizes that theoretically should occur most frequently in the dredges. It is apparent, then, that mesh size has a very distinct influence over the composition of the catch.

The data for collection 2 appear to be bi-modal. This is atypical of the rest of the collections, and no explanation can be offered.

The data for collection 3 appear to be unduly concentrated in the two classes 81 - 90 and 91 - 100. Since the explanation may be concerned with age and growth, it will be discussed in the following section which deals with those features.

Collections 4 and 5 are distinctive in their nonconformance to the typical distributions found in other collections. Both were taken in Penobscot Bay, off Rockland, as shown on Plate X. Both were secured with dredges fitted with a ring mesh similar to that shown in Figure 2, page 9.

These smaller rings, having an inside diameter of 64 millimeters, would allow scallops, up to 81 millimeters in their smallest diameter, to pass between the rings. This, then, means that the normal peak of the distribution should have been in the 81 - 90 millimeter class. The indication is that some factor or group of factors has been preventing normal reproduction from filling in the smaller height classes.

The frequencies of the height classes were used in computing, for each collection, the average height, the standard deviation, the standard error of the average height, and the standard error of the standard deviation. These values were all calculated on the basis of each total collection, but an average was also found for the commercial sizes in each collection. Scallops less than 81 millimeters in height were seldom, if ever, kept by the scallopers, so the average was computed for all animals of that height and larger. As may be seen in Table IV, there is a considerable variation in this commercial average, even in repeated collections from the same bed. In considering the 3,218 individuals of commercial size in the 12 collections, however, one sees that the height of the average scallop used commercially is 115 millimeters, or $4\frac{1}{2}$ inches.

These commercial sizes comprised 87.7 per cent of the 3,670 individuals measured, but this percentage is low in relation to the actual composition of the commercial catches. In obtaining collections 2, 3, 4, and 5, aboard commercial vessels, only an estimated 25 per cent of all the sizes used for shucking were measured, but all the undersized ones were taken because of their scarcity. If this 25 per cent sample of 2,207 individuals, from the four collections, is increased to 100 per cent, it becomes 8,828, and when added to the 207 individuals constituting 100

per cent of the undersized scallops, the estimated total becomes 9,025. The commercial sizes, therefore, comprise 97.7 per cent of this total, leaving only 2.3 per cent of the catch unsuitable because of small size.

A check may be made upon the accuracy of the 25 per cent assumption. The total production of the four trips was 40 gallons of shucked meats. By actual count, it was found that approximately 200 scallops would yield one gallon of shucked meats, depending greatly upon the size of the mollusks. Thus, it is seen that the estimated total of 8,828 scallops produced 40 gallons at the rate of 221 scallops per gallon, which is only 10.5 per cent over the tested average.

The average height of the total of each of the four commercial collections, 2, 3, 4, and 5, varies from the average commercial height of each of the same four collections, only an average of four millimeters, as compared to the other eight collections, which vary an average of 12.5 millimeters. It seems probable that the lack of the smaller sizes in the commercial collections is the result of faster dredging and more thorough washing of the dredge-load before it is sorted.

The average height of the total 3,670 scallops measured is 108 millimeters, or 4¼ inches. The number of smaller scallops that make this average less is dependent upon the nature of the bottom, as described earlier.

The standard deviation is an indication of the grouping of the sizes of scallops about the average. In a normal distribution, the average, plus and minus one standard deviation, would include 68.3 per cent of the observations, plus and minus two standard deviations would include 95.5 per cent, and plus and minus three standard deviations would include 99.7 per cent of the observations. In collection 1, for instance, the average

of 100 millimeters plus and minus the standard deviation of 30, or a range of 70 to 130 millimeters, includes 100, or 64.1 per cent of the 156 observations. The average, plus and minus two standard deviations, giving a range from 40 to 160 millimeters, includes 151, or 96.8 per cent of the observations. The average, plus and minus three standard deviations, with a range from 10 to 190 millimeters, includes 156, or 100 per cent of the 156 observations.

It may be seen from Table IV that the two lowest standard deviations are those of two of the commercial collections. Both of these were taken on rocky bottom, and clearly illustrate the extreme degree to which the smaller sizes are sifted out of the dredge when there is no mud to retain them. The loss of these smaller sizes, of course, concentrates the frequencies in the larger size classes, and reduces the standard deviation. These two collections are examples in which the lower standard deviations cause the samples to appear more reliable than they actually are. Since the absence of these smaller sizes is the reason for this appearance, the fact remains that a true sample of the population was not obtained.

The standard error of the average bears the same relation to the averages of several collections as the standard deviation bears to the total catch. This would mean that, in a normal distribution, 68.3 per cent of the averages of repeated samples would fall near the given average, within plus and minus one standard error of the average. The relationships of 95.5 per cent for two standard errors of average, and 99.7 per cent for three standard errors of average also exist. In terms of the 10 collections, exclusive of 4 and 5, taken with dredges having a ring mesh similar to that in Figure 2, page 9, it is found that collection

9, with an average of 98 and a standard error of average of 2.7, approaches the closest to the theoretical. A range of plus and minus one standard error about the average includes four, or 40 per cent, of the 10 averages; plus and minus two errors includes eight, or 80 per cent; and plus and minus three errors includes nine, or 90 per cent.

The standard error of the standard deviation is a measure of the reliability of the standard deviation. In a nearly normal distribution, the true standard deviation will occur near the calculated standard deviation, within a range of plus and minus one standard error of standard deviation. In the case of the 10 collections mentioned above, taken by means of similar gear, it appears that the standard deviation of collection 10 is the most reliable. A range of plus and minus one standard error of deviation (1.4) on either side of the standard deviation of 26.0 includes six, or 60 per cent of the standard deviations of the 10 collections.

As a check on the significance of the differences between the averages of collections obtained by similar gear and on the same beds, the critical ratio was determined for all possible pairs of averages of collections 1, 7, 11, and 12, from Greenlaw Cove, and collections 6, 8, 9, and 10, from east of White Island. In this determination, the actual difference between the averages is compared to the standard error of the difference between the two averages. If this ratio is three or over, there is sufficient dissimilarity between the two averages to signify fundamental variations in the data. A ratio under three indicates no significant differences.

In the series of collections from Greenlaw Cove, the average of collection 11 showed significant variation from the other three averages, which showed none between each other. No explanation can be offered for this variance.

In the series of collections from east of White Island, all averages failed to show any significant differences, except the relationship between the lowest (collection 6) and the highest (collection 10) averages. Except for mention of the fact that these collections are respectively the first and last taken on the bed, the variation must pass unexplained.

If more commercial collections had been obtained from the same bed, there might have been a better comparison of the reliability of data from such related collections. As it is, it has been demonstrated that the two series of hand dredgings on the same beds have resulted in fairly reliable and consistent data, even though each of the eight collections numbered well under 200 individuals. While the collections are not true samples of the population, it appears that they are reliable samples of the commercial catch.

AGE AND GROWTH

Age and growth data, especially those concerning the commercial catch, are of vital importance to any future understanding of the yield of Maine scallop beds.

Smith (1891) believed that one or two years were required for the scallop to reach maturity, but that longevity after maturity was unknown. Estimates ran from one to 15 years. Many fishermen at the present time adhere strongly to the belief that tiny young scallops grow up to commercial sizes in one year. They base this theory mostly upon a very common phenomenon, that is, beds which in one season were dredged out, leaving only undersized scallops, were found fully stocked with a good distribution of sizes the next season. Further discussion of this occurrence will be taken up under Movements.

As described under Methods and Materials, the yearly growth rings of 150 shells were measured from each of five collections (2, 3, 4, 8, and 11). By referring to Table III, page 23, one may note that these collections are so spaced as to show variations due to differences in time, location, and use of gear.

Interpretation of Data

The growth pattern in Maine scallop beds, as represented by the five areas sampled, is very consistent during the first seven years, which are the fastest growing years. Figure 7 shows the rapid gains in these first seven years. It is remarkable that in these widely differing areas, the most important years of growth should result in essentially the same yearly gains.

Table V, from which Figure 7 was derived, was compiled by combining all the ring measurements of all ages of scallops. For instance, in collection 2 at the first growth ring, the average measurement of 20.5

FIGURE 7

Average Height at Each Growth Ring, Collections 2, 3, 4, 8 and 11

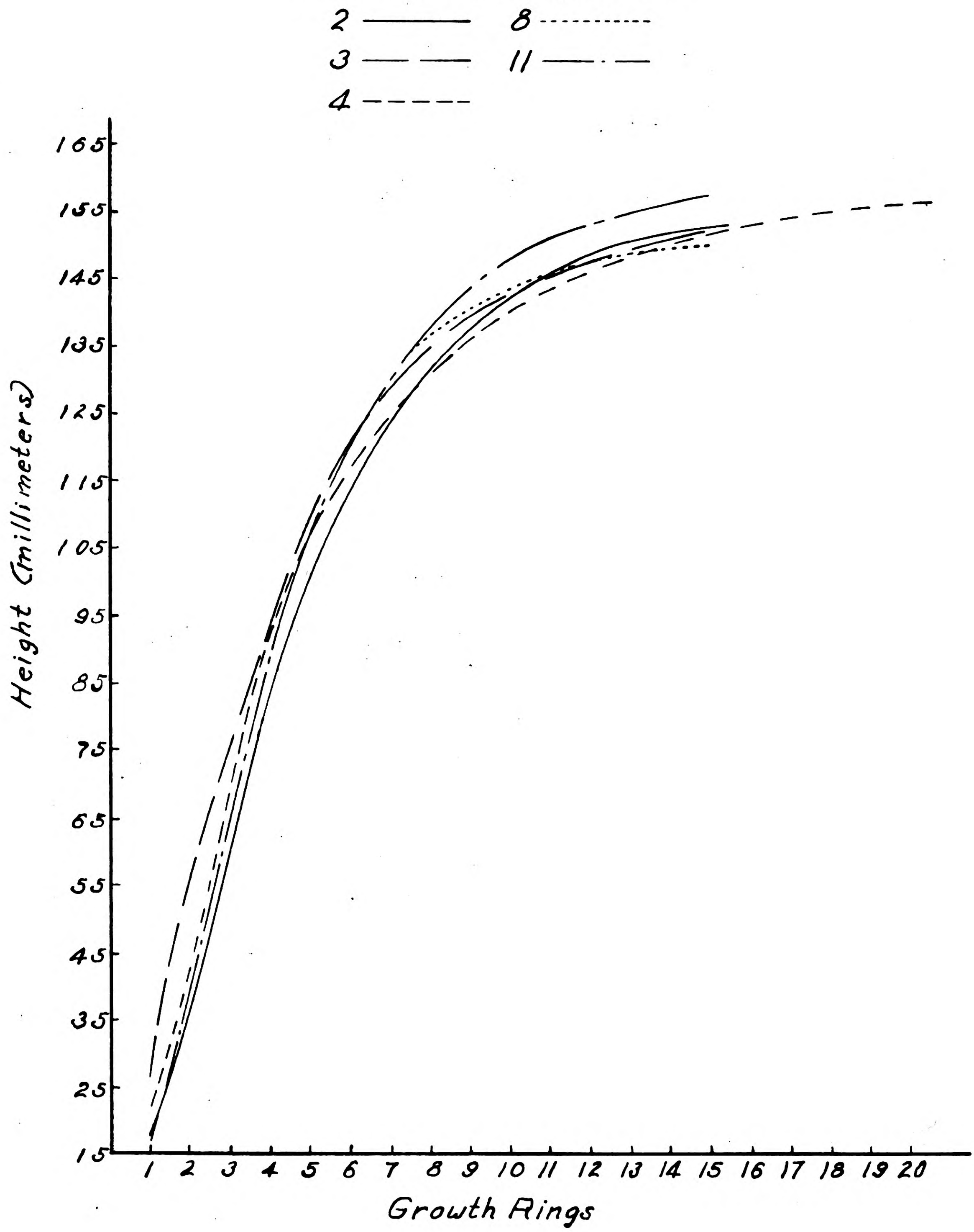


TABLE V.

AVERAGE HEIGHT AT EACH GROWTH RING

Number of Growth Rings	Collections									
	2		3		4		8		11	
	Freq.	Av. Ht.	Freq.	Av. Ht.	Freq.	Av. Ht.	Freq.	Av. Ht.	Freq.	Av. Ht.
0	2	25.0	0	------	4	25.3	0	------	1	21.0
1	148	20.5	150	25.6	146	21.2	150	18.7	149	16.4
2	127	41.7	150	59.3	135	42.8	146	39.8	140	39.3
3	108	66.6	122	78.1	125	73.1	128	70.4	117	72.8
4	93	86.6	61	94.2	117	93.2	86	90.9	61	91.0
5	71	103.0	36	111.2	106	108.2	65	105.7	33	104.3
6	51	115.0	25	122.7	97	117.0	42	119.2	21	117.7
7	34	124.9	22	130.9	90	128.3	26	130.7	14	128.2
8	29	132.6	13	136.0	82	132.8	17	137.9	9	140.1
9	18	140.2	6	138.0	68	137.3	12	140.5	7	145.1
10	14	143.8	5	142.2	58	140.6	8	142.7	5	152.0
11	9	146.9	3	151.3	47	145.1	7	146.1	4	150.2
12	4	150.0	2	152.0	39	147.9	4	150.3	3	158.3
13	3	151.3	2	155.0	29	150.2	3	150.9	1	160.0
14	2	153.0			18	151.0	2	151.2		
15	2	155.0			12	151.4				
16					5	155.6				
17					4	159.5				
18					4	161.3				
19					2	161.5				
Total	150		150		150		150		150	

millimeters, with a frequency of 148, was derived from the first ring measurements of all of the 150 individuals which had reached or passed the first growth ring. At first consideration, this method might seem to be too presuming of standard growing conditions to be worth using. It was not used without considerable previous testing, however.

The testing was carried out as follows. The same type of table was made up by utilizing only the oldest possible age class for each growth ring measured. That is, for the reading at the first growth ring, only those scallops were measured which had formed the first growth ring but not the second, individuals which had formed the second ring but not the third were measured for the second year's growth, and so on. The differences between this table and Table V, for each ring measurement in a collection, were used in a test of a null hypothesis. The calculations for this test are shown in Table VI. The null hypothesis makes the assumption that there is no difference between the two arrays of data, and according to Pearson and Bennett (1942), the differences are not significant unless t is 1.96 or more. From Table VI it is seen from the t values that none of the differences between tables is significant. Among the advantages gained by the use of Table V are larger frequencies and hence greater reliability, more complete data, and a smoother curve.

As a further check, the same basic data were then divided into two groups in each collection, individuals up to five years old and individuals of six years and over. The first group and the first five years of the second group in each collection were then treated in the same way as Table V. Variations between either of the two groups and

TABLE VI

COMPUTATIONS FOR THE TEST OF A NULL HYPOTHESIS

	Collections				
	2	3	4	8	11
n = No. of differences between Table V and test table	14	11	18	14	13
SX = Sum of individual differences (X)	-10.6	17.1	17.8	8.3	-10.5
$\bar{x}$ = Mean difference	- 0.8	1.6	1.0	0.6	- 0.8
Sx^2 = Sum of x^2s ($x = X - \bar{X}$)	71.20	217.45	354.38	81.25	376.61
$s^2 = \frac{Sx^2}{n-1}$	5.48	21.75	20.85	6.25	31.38
$s = \sqrt{s^2}$	2.34	4.66	4.57	2.50	5.60
$s_{\bar{x}}^2 = \frac{s^2}{n}$	0.39	1.98	1.16	0.45	2.41
$s_{\bar{x}} = \sqrt{s_{\bar{x}}^2}$	0.62	1.41	1.08	0.67	1.55
m = Hypothetical mean difference. .	0	0	0	0	0
$t = \frac{\bar{x} - m}{s_{\bar{x}}}$	- 1.29	1.14	0.93	0.89	- 0.52

the first five years of Table V, in each collection, were not more than 0.7 millimeters, indicating that scallops in the beds sampled apparently have not been influenced by extremely good or poor growing years in either of the periods sampled. This check was designed as a preliminary measure. If significant variations had been found, further analyses would have been made to determine the years in which undue influences took effect.

Since growth is influenced greatly by the character of food-carrying currents, the differences in growth shown in Figure 7, page 51 are probably due mainly to this factor. Temperature, of course, plays a very important role in limiting seasonal growth, forming the winter check line, and resuming spring growth. No data were taken in this study to demonstrate any growth differences as caused by temperature changes between beds. It may be noted, however, that the growth samples from collections 8 and 11, the only ones from shallow-water beds, follow the same course in Figure 7, median to the other three, until the age of five years is reached. The two, still together, show better growth than the other three up to the seventh year; collection 11 goes on to show the best growth of the five, while 8 drops off to show the poorest. The shallower water over these two beds is, of course, influenced much more by air temperatures than are the three deeper beds, but no explanations can be offered as to the extremes in growth in later years.

An indication of seasonal growth is shown in Table VII and Figure 8. These data were compiled by age classes, that is, the gain of 11.8 millimeters shown for the second completed growth ring in collection 2 is an average of all the measurements taken of the growth beyond

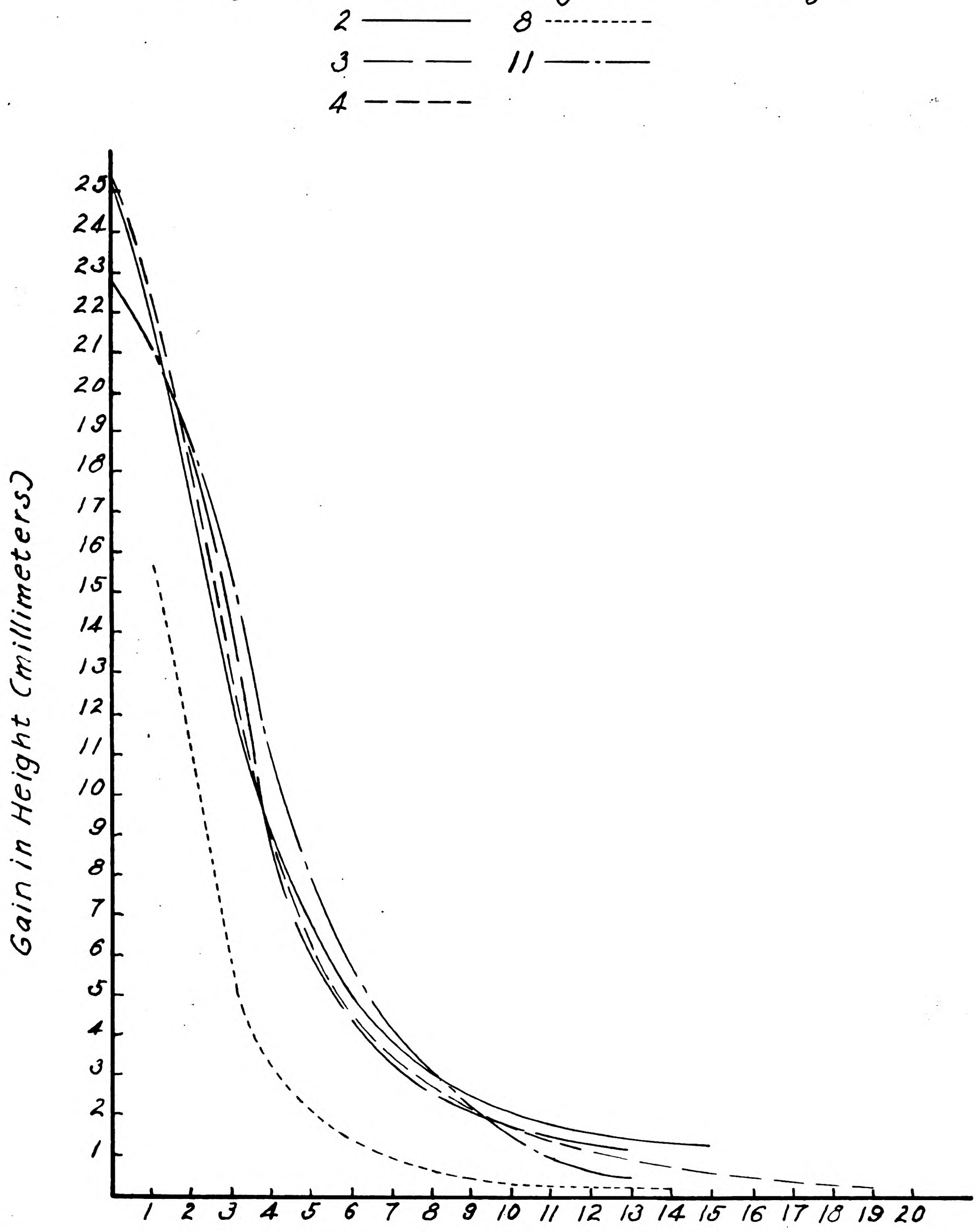
TABLE VII

AVERAGE GAIN, FROM LAST RING TO SHELL EDGE

Completed Growth Rings	Collections 2 11-20-47 Freq	Av. Gain	3 1-17-48 Freq	Av. Gain	4 2-21-48 Freq	Av. Gain	8 6-30-48 Freq	Av. Gain	11 8-19-48 Freq	Av. Gain
0	2	25.0	0	---	4	25.2	0	---	1	21.0
1	21	21.2	0	---	11	17.5	4	15.6	9	18.1
2	19	11.8	28	18.6	10	12.3	18	11.2	23	20.2
3	15	13.1	61	13.8	8	18.7	42	4.6	55	15.8
4	22	11.3	25	8.9	9	12.0	21	5.3	29	10.9
5	20	6.6	11	5.7	9	5.6	23	2.0	12	8.4
6	17	4.4	3	6.0	7	4.1	16	0.8	7	5.3
7	5	3.6	9	3.7	6	3.5	9	1.2	5	4.0
8	11	2.9	7	1.7	14	2.7	5	0.4	2	2.5
9	4	2.5	1	0.0	10	2.2	4	0.0	1	3.0
10	5	2.4	2	2.5	9	2.3	1	0.6	2	1.5
11	5	1.8	1	2.0	6	1.7	3	0.0	1	0.0
12	1	2.0	0	---	10	1.0	1	1.0	2	2.5
13	1	1.0	2	1.0	11	0.5	1	0.0	1	0.0
14	0	---			6	1.5	2	0.5		
15	2	1.5			7	0.4				
16					1	4.0				
17					0	---				
18					2	0.5				
19					2	0.0				

FIGURE 8

Average Gain, Last Ring to Shell Edge



the last growth ring in all scallops which had passed their second year but not their third. Taking into consideration the date on which the collections were made, a few differences in seasonal growth should be shown. Collection 8, taken in June, indicates that much of the annual growth of the individuals was to be added between June and the cessation of growth.

Since many marine animals seem to have an annual cessation of growth due to spawning, it may be well to point out that this influence is not indicated in the case of the scallop. Spawning, as discussed in its own section, occurs through August and the first of September. Collections 2, 3, and 4, however, taken during the cold season, show a full year's growth, with no sign of a check that might indicate a spawning disturbance. It is most probable then, as inferred by Stevenson that the annual rings are caused by the interruption of growth by winter temperatures.

Commercial Aspects

Scallops first come into the size range used commercially when they exceed 80 millimeters. In referring to Figure 7, page 51, it may be seen that this size is generally reached between the third and fourth winters.

The maximum age of the scallop is probably several years in excess of the 19 years recorded in Tables V and VII, this limit being set by the legibility of the growth rings. These older and larger scallops are not preferred by the fishermen, however, as the meats tend to become dark-colored and flabby.

It appears from Figure 7 that the best growth generally occurs up to the fifth year and drops off sharply after the seventh year. It

would be well to consider the relative portions of the commercial sizes in each collection that occurred in these growth periods. From Figure 7, page 51, it is seen that five-year scallops range from 101 to 110 millimeters in height, and seven-year scallops range from 125 to 130 millimeters. In referring to Table IV, pages 37-39, one may see that these age groups fall into height classes 101 to 110 and 121 to 130, respectively. Computing the frequency per cent of the portion of commercial sizes between these height classes and the smallest commercial size (81 to 90 mm. class), based on the total number of commercial sizes as 100 per cent, one arrives at the results shown in Table VIII.

It appears from this table, that the commercial fishery on the four beds sampled depends, for little over one-third of its catch, on scallops of the age classes over seven years and for less than two-thirds of its catch on scallops over five years old. This table would tend to suggest that any law limiting the lowest size of commercial scallops to four inches, for example, would cut the fishery, at its present rate of production, approximately to two-thirds of its usual volume. There was no work done in this investigation that would form a basis for suggesting that the remaining breeding population, under such a plan, would maintain or build up the supply; but it is an important factor that should be considered in any such plan of management.

It is worthwhile to mention that the Canadian Atlantic Coast scallop fishery is being successfully regulated by a four inch size law. In further justifying the use and emphasizing the value of such a regulation, Medcof found that Canadian scallops showed their greatest increase in weight between the fourth and fifth years. At the end of this time the scallops had grown from $3\frac{1}{2}$ to 4 inches in diameter and

TABLE VIII

FREQUENCY PER CENT OF THE PORTION OF COMMERCIAL SIZES BETWEEN THE MINIMUM SIZE AND EACH OF TWO AGE GROUPS, BASED ON THE TOTAL NUMBER OF COMMERCIAL SIZES AS 100 PER CENT.

Collection	Frequency Per Cent: 5 years 101 - 110 mm. (4 Inches)	Frequency Per Cent: 7 years 121 - 130 mm. (5 Inches)
1	56.0	75.0
2[4]	49.9	82.3
3[4]	84.2	91.9
4[4]	17.2	46.8
5[4]	4.0	22.1
6	76.7	88.4
7	80.0	94.5
8	66.5	87.1
9	66.4	81.8
10	61.1	80.5
11	82.9	91.4
12	60.5	87.7
Average Freq. % in Commercial Collections	38.8	60.8
Average Freq. % in Non-commercial Collections	68.8	85.8
Average of Total	55.5	77.5

[4]Commercial Collections.

added a 50 per cent increase in weight. It is surely a great waste of potential growth to take smaller scallops, when older scallops show relatively less growth.

This four inch law would seem to be a sound basis for regulation, but the age, growth-rate, and size relationships are favorable for only two of the Maine beds checked in this investigation (collections 4 and 5). Further sampling of beds, and checks on weight increases should be made.

The unusual grouping of sizes in collection 3, shown in Table IV, pages 37-39, and referred to under Size Frequency of the Catches, seems to be more a result of the fishery, characteristics on the bed than some biological peculiarity. Figure 7, page 51, and Table V, page 52, show that growth in this bed is at least comparable to the other commercial beds. In all probability the combination of fishery and bottom characteristics have been such that the larger sizes were more readily eliminated from the population than has been the case in the other commercial beds.

It should be of some interest to those people concerned with the Maine fishing industry to compare growth rates in the samples from Maine areas with growth rates from several locations on the Canadian coast (Table IX). The Canadian growth rates are from Stevenson. This table is self-explanatory and shows that Maine scallops evidence a little better growth than the Canadian scallops, most of which come

TABLE IX

COMPARISON OF HEIGHTS AT EACH GROWTH RING

Growth Rings	Height at Each Growth Ring			
	Least	Greatest	Average	
1	15.7	23.2	18.9	Canada,
2	34.9	52.0	44.95	
3	54.6	80.1	70.8	Including Nova Scotia,
4	71.9	103.1	90.5	
5	86.5	119.7	105.1	Province of Quebec,
6	99.9	132.1	116.1	
7	110.2	142.5	124.9	and New Brunswick
8	119.2	152.4	132.5	
9	123.4	159.3	138.1	
1	16.4	25.6	20.5	Maine,
2	39.3	59.3	44.6	
3	66.6	78.1	72.2	12 Samples
4	86.6	94.2	91.2	
5	103.0	111.2	105.9	of
6	115.0	122.7	118.3	
7	124.9	130.9	128.6	Six Different Areas.
8	132.6	140.1	135.9	
9	137.3	145.1	140.2	

SPAWNING

The determination of the spawning period, beyond its obvious biological interest, is of importance in the calculation of seasonal growth, and in the determination of several factors vital to a proper management of the fishery.

A good deal of speculation has taken place concerning this spawning season. In one of the very few publications on the subject, Drew mentioned that in the vicinity of Mount Desert Island, in 1901, several specimens which had not spawned by August 20, started spawning August 23, after being kept near the surface of the water.

The method of studying this problem was presented under Methods and Materials. The results, indicating an August and early September spawning period, were also included in the section.

Photographic and Photomicrographic Evidence

The more obvious progressive gonadal changes used as typical stages for field observations, are shown in Plates IV and V, and Plate VI, Fig. A. Color plates of the whole gonads are combined with black and white photomicrographs of cross-sections of the same gonads.

The immature, stage one gonad shown in Plate IV, Fig. A, is barely visible around the adductor muscle. It is translucent and the intestine within it can be clearly seen. The same gonad is shown in cross-section in Plate XI, Fig. B, and illustrates the undeveloped and barely differentiated nature of the follicles or spaces in which gametogenesis occurs. The sex at this stage cannot be readily identified in the field, and the stage is one of sexual immaturity, rather than of quiescent gamete production between spawning seasons.

The male gonad in stage two of development, shown in Plate IV, Fig. B, indicates how the organ has filled out and become opaque. It is to this stage that the scallops apparently revert after spawning, rather than to stage one. Plate XII, Fig. B, shows a cross-section of the same gonad. The most obvious feature, microscopically, is the expansion of the follicles since stage one.

Stage three of the development of a male gonad is not illustrated macroscopically, but is similar to the stage three female organ in Plate IV, Fig. A. The color is white instead of red, the tracings of the gonoducts are somewhat apparent, but the granular appearance of a mature gonad is not yet evident. Plate XIII, Fig. B, shows a cross-section of a male gonad at a comparable stage. Compared with stage two, the follicles have been greatly enlarged and are filled with maturing sperm.

Plate V, Fig. A, illustrates a male gonad in stage four of development. The advanced granular appearance of the organ, and the prominent gonoducts are particularly noticeable. In Plate XIV, Fig. B, is shown a cross-section of the same fourth stage gonad mentioned previously. The follicles are nearly the same size as they were in stage three, and nearly all of the sperm are ready for extrusion.

The female gonad in stage two of development is not illustrated, but is identical to the male gonad in Plate IV, Fig. B, except that it shows the first suggestion of a pinkish color. Plate XII, Fig. A, shows a cross-section of a female gonad at this stage and it is seen that the follicles have expanded in size since stage one.

Plate IV, Fig. A, showing a female gonad in stage three of development, indicates the vivid red color characteristic of the sex.

The gonoducts are somewhat apparent, but not the granular appearance of a mature organ. Plate XIII, Fig. A, shows a cross-section of the same female gonad, and indicates the enlargement of the follicles and ova since stage two.

Stage four of the development of a female gonad is illustrated in Plate IV, Fig. A, which shows the prominent gonoducts, and in Plate V, Fig. B, which demonstrates the advanced granular appearance of the organ. The final colors of the mature female gonads range from a vivid red to a bright orange. Plate XIV, Fig. A, shows a cross-section of the same gonad represented in Plate V, Fig. B, and indicates a slight enlargement of the ova since stage three, although the size of the follicles remains the same.

The third stage gonads are more advanced than could be ideally desired, since the photomicrographs show a much closer similarity to stage four than to stage two. It is meant to be understood that the stages were designated only as a quick and simple means of field classification. Necessarily, the limits of each stage were indefinite, but the modes were distinct.

The first stage of spawning is not illustrated, but is similar to stage four, with patches of empty gonad being visible. Plate VI, Fig. A, illustrates a male in the second or final stage of spawning. The major part of the gonad is empty and resembles a stage two organ, with a few scattered patches of characteristically colored sperm. It is presumed that, after the sex cells are entirely extruded, the gonad returns to the stage two classification once more. This is discussed further below.

Analysis of Data

Table X is a compilation of the changes in gonadal development throughout all the collections. The chronology of the collections renders the table also a year's record of gonadal changes. Figure 9 is a graphic representation of the same data, showing the shift of the high percentages from the stages of least development in collection 1 (October 1947), to the stages of greatest development, and to the spawning stages in collection 12 (September 1948). This figure is composed of individual graphs, one for each collection, superimposed on the same page, but with the horizontal axes separated vertically. The vertical axes are all graduated in like units, but are separated both vertically and horizontally for greater clarity.

It is seen by examining this figure that spawning began soon after July 22, 1948 (collection 10), for it was well underway by August 17, 1948 (collection 11). The high percentage of fourth stage gonads had dropped noticeably and the spawned stages had risen substantially. Evidence seems to indicate that once the gametes have been entirely extruded, the gonad becomes a stage two organ again. This is supported by the sharp rise in the percentage of stage two gonads in collections 1 (October) and 2 (November), after the decline of the high percentages of the spawning stages in collections 11 (August) and 12 (September).

The sudden rise in the percentage of the advanced stages of gonadal development in October, after the termination of spawning, probably indicates that gametogenesis begins immediately after the gonad has been emptied. Figure 9 also shows that development continues through most of the winter although it slows down markedly from March to May (collections 5 to 7). Loosanoff (1937) found that in Venus mercenaria, the development of gametes progressed during much of the winter, though

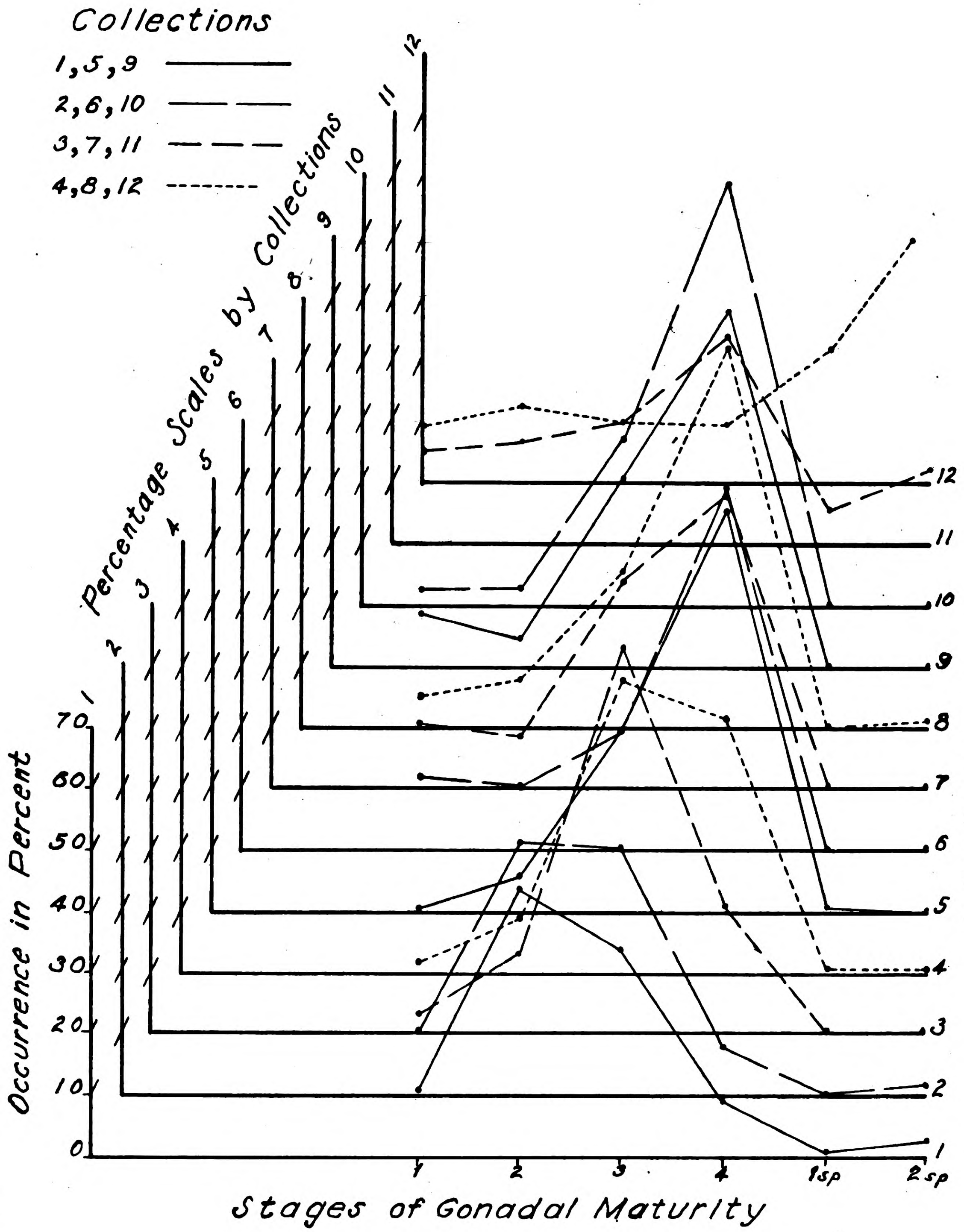
TABLE X

PERCENTAGES OF VARIOUS STAGES OF GONADAL DEVELOPMENT AND SPAWNING IN ALL COLLECTIONS

Collection	Development				Total not Spawned	Spawning		Total Spawned	Grand Total	Frequency Comprising 100%
	Stage 1	Stage 2	Stage 3	Stage 4		Stage 1sp	Stage 2sp			
1	10.9	43.6	33.3	8.9	96.7	0.7	2.6	3.3	100.0	156
2	9.9	41.2	40.2	7.2	98.5	—	1.5	1.5	100.0	401
3	2.9	12.8	62.9	21.4	100.0	—	—	—	100.0	267
4	1.5	8.9	47.2	41.5	99.1	0.3	0.6	0.9	100.0	335
5	0.7	4.9	28.9	64.8	99.3	—	0.7	0.7	100.0	284
6	11.7	9.9	19.1	59.3	100.0	—	—	—	100.0	162
7	10.1	7.9	33.8	48.2	100.0	—	—	—	100.0	139
8	4.9	7.1	25.1	61.8	98.9	—	1.1	1.1	100.0	183
9	8.3	3.8	30.1	57.8	100.0	—	—	—	100.0	133
10	2.4	2.9	26.8	67.9	100.0	—	—	—	100.0	168
11	14.6	15.9	19.5	33.5	83.5	4.9	11.6	16.5	100.0	164
12	8.1	12.8	9.5	8.8	39.2	21.6	39.2	60.8	100.0	148

FIGURE 9

Seasonal Changes, by Collections, in Gonadal Maturity



often at a reduced rate. He stated, however, that this winter development was rather unusual among other pelecypods.

It seems possible that, since gonads of mature appearance occur throughout the winter, a few individuals may spawn early in the summer for some undetermined reasons. Such early spawning would account for the extremely good growth often observed in first-year scallops.

The minimum size and age of spawning scallops do not seem to be well-defined. Individuals as small as 60 millimeters in height were found in the third stage of development. According to Figure 7, page 51, scallops this size would be between their second and third winters.

Most scallops mature, however, apparently at a size of about 80 millimeters, that is, in the spawning period prior to the fourth winter. As brought out in the previous section, Age and Growth, scallops at 80 millimeters are just entering the size range of the commercial catch and so, after one spawning, are lost to the breeding stock. The establishment of a four inch minimum size would insure that every scallop taken would have spawned at least twice, since four inches (102 millimeters) is usually not attained until the fifth winter.

The sex ratios in the 12 collections ranged from 0.6 females per male to 1.3 females per male, averaging 0.9 females per male for the 2,375 individuals that were sexed.

From the foregoing it seems certain that the spawning occurs in August and September. Since this period is at the end of the warmest part of the year, and since the spawning of most mollusks is largely dependent upon temperature, it is entirely likely that temperature is a major controlling factor in determining the spawning period. It appears that a great deal of gametogenesis takes place immediately after spawning, before a complete winter cessation of body activity, and it is seen that dredging without a size limit cuts deeply into the spawning population.

MOVEMENTS

The movements of the scallop were lightly touched upon in this investigation. As mentioned in the section on Natural History of the Scallop, this mollusk possesses a remarkable power of locomotion, but its employment of this ability has long been a subject for speculation. The type of movement most generally reported by the fishermen is the mass evacuation of the scallop population from a bed (usually heavily dredged).

The type of tag and the methods used to obtain data on scallop movements were discussed under Methods and Materials. Table XI is a compilation of the data obtained from the recoveries.

The tagged scallops picked up on Sept. 24, 1948, were obtained by the writer, using fairly short dredging distances (100 to 200 yards). Their positions were well established, and indicated that their movement had been very nearly directly off-shore, towards deeper water and more current flow, a distance of 200 to 300 yards.

The single recovery on Nov. 5, 1948, made by a commercial boat, shows the same type of movement, that is, toward deeper water and more current. The exact location of the tagged scallop is not known, since the commercial boats make a continuous drag until the dredge is full. The mere fact that it was picked up in a commercial dredge, however, indicates that it had moved out from the shallow water, unpopulated zone in which it was released.

One will notice that the recoveries on Nov. 12, 1948 and Dec. 21, 1948, both taken by commercial boats, were reported from a bed other than the one near which they were released. There is a very good

TABLE XI

RECORD OF TAGGING RESULTS
1948

Date Released	Location Released	Date Recovered	Location of Recovery	Tag No.	Alive of "Clapper"	Height at Recovery (mm.)	Growth since Release (mm.)
July 23	East of White Island. Shallow water near shore. Plate VII.	November 12	Greenlaw Cove. Location of Collections 1, 7, 11, and 12. Plate VII.	22	Alive	151	3
				28	"	154	0
July 23	Same as above.	December 21	Same as above.	13	Clapper	97	0
				31	"	93	0
				33	"	129	0
				35	"	93	0
August 20	Same as above.	September 24	East of White Island. Location of collections 6, 8, 9, and 10. Plate VII.	109	Alive	91	2
				114	"	98	1
				123	"	143	1
				139	"	137	0
				141	"	106	1
				147	"	121	0
August 20	Greenlaw Cove. Shallow water near shore. Plate VII	November 5	Greenlaw Cove. Location of Collections 1, 7, 11, and 12. Plate VII.	73	Alive	109	3

possibility that this apparent movement is due to faulty reporting, stemming from either indifference or inaccuracy because of excessively long dredging distances.

At least two factors are against movement from the White Island bed to the Greenlaw Cove bed (Plate VII). White Island, directly between the two is the first, and the second is the fact that the major currents (ebb and flood) flowing past the White Island bed run northwest - southeast. Here again, however, is evidence that the scallops at least moved out into deeper water, since the location of their release was in shallow water where no commercial vessel would dredge.

The poor return of the tags (5.2 per cent) and the meager evidence gleaned therefrom allow one to draw only one conclusion. That is the fact that scallops will move from shallow water (6 to 10 feet at Mean Low Water) to deeper water. The fact that more current movement is found in the location of the deeper water may be either coincidence or the principal reason for the movement, since more current means more favorable feeding conditions.

It is in the light of the last named possibility that an explanation will be offered for the condition mentioned under Age and Growth, whereby a bed is often dredged out, leaving insufficient numbers for profitable dredging. The following season, however, this same bed is often found to contain as heavy a population as was present at the beginning of the previous season. Fishermen were most apt to feel that rapid growth of the smaller sizes had accomplished this feat. Since it is now known that the growth is considerably slower than was previously believed, the true explanation must depend upon some type of movement.

The concentration of scallops in beds may be due to an accumulation of larval scallops by certain current movements, or it may be due to movements of the older scallops. The most likely conjecture is a combination of the two, since the same current movements that might concentrate larvae in the water would likewise concentrate the minute, planktonic forms which form the food of the scallop.

The movement of the scallop is not stimulated and guided by premeditated mental processes, but rather by such chemical and physical stimuli as food, light, and disturbance. A scallop in an environment lacking in one or more desirable factors would be expected to receive some sort of irritating stimulus and would move about erratically until it reached an environment in which that irritation was relieved. It is not known whether a scallop can respond with intentionally directional movement in response to certain stimuli, but if this were the case, the facts would remain the same, movement would be only more direct.

If these assumptions were true, then the thinly scattered populations, resulting from wide distribution of larvae on somewhat unfavorable bottom or the dispersion of adults by dredging, would be in a state of constant movement until they reached a favorable environment. The resulting concentration would become a bed, and steady recruitment to the bed would come from adults moving in, as well as from yearly sets of young.

ASSOCIATED ORGANISMS AND MORTALITY

In the course of this investigation, an effort was made to determine the various types and sources of injury and mortality exerting drains upon the scallop population. Although no reports were received and no evidence found that might indicate mass mortalities in any area, several lesser types and sources of injury were found. These, including the effects of dredging and of several animal associates, are discussed.

Effects of Dredging

The effects of shucking and discarding waste portions of the scallops over the beds have long been a matter for speculation. According to the Maine Commissioner of Sea and Shore Fisheries (1915), an investigation of the condition of certain beds revealed a great deal of refuse in an advanced stage of decomposition on the beds late in the spring, after a full winter of fishing. The accumulation of waste was credited with attracting great numbers of starfish to the beds with resulting depredation of the scallop population. The principal recommendation of this investigation was that shelling on the scallop grounds be stopped.

The same condition of accumulated waste was found during the present investigation. As late as March, very little decomposition was evident and there was little evidence of feeding by scavengers. It is probable that low winter temperatures retard both decomposition and the activities of scavengers. The effect of the eventual decomposition of the mass of debris upon the population is not known.

According to Galtsoff and Loosanoff (1939) *Asterias forbesi* did not detect the presence of food unless it was very close, and so

would not be attracted to an abundant supply. If one may assume that Asterias vulgaris reacts similarly, then its presence in a littered scallop bed is the result of wandering into a supply of food and remaining because the supply is good. The end result is similar, whether the presence of the starfish is deliberate or accidental, but the invasion would be much slower in the latter case.

It seems that the economy in time and labor gained by the scallopers' shucking on the beds may outweigh any advantage gained by forbidding the action. An important point to consider also, is the use of the discarded shells as cultch for newly setting scallops, especially on muddy bottom. However, further research will be needed to reveal the effects of this decomposing debris.

Commercial dredging affects the population both through the disturbance of the bottom and the handling of the undersized scallops brought to the surface in the dredge. As brought out in Size Frequency of the Catches, the percentage of unacceptable sizes handled on deck is very low (2.3 per cent) due to the sifting action of the dredge. These percentages are probably insignificant segments of the population, and evidence indicates that the individuals are relatively unharmed. These discards remain on deck for a short time only before they are shovelled overboard. An assortment of sizes from dredgings was kept in a crate in 3 to 12 feet of water for three weeks without showing any ill effects from the handling. The effect of dredging on the population remaining on bottom is unknown, but it seems logical to assume that many young scallops are buried and killed as a result. The beds from which collections 4 and 5 were taken are distinctive in the scarcity of young scallops and in a long history of intensive dredging.

The number of "clappers" as compared to live scallops was determined in collections 10 and 11, as described under Methods and Materials, but the value of this information is minimized by the lack of repeated counts on the same beds. The substantial number of "clappers" found in the two beds, 42 and 53 per 100 live scallops, respectively, indicates a lethal effect of some sort. A third bed, in the Islesboro - Castine area, visited in January 1949, having a heavy population of starfish, averaged 40 "clappers" per 100 live scallops. The data collected from these three beds are too few to enable one to draw any conclusions, but it is entirely possible that, if additional work can be done on this phase, a direct relationship may be worked out between counts of "clappers" and total mortality over a certain period.

Associated Organisms

The collection of all macroscopic plant and animal organisms found within or upon the valves of the scallops collected, as described under Methods and Materials, resulted in the compilation found in Table XII. The majority of these organisms are doubtless innocuous, and the ones whose ill effects were evident or in doubt will be discussed.

The identification of the organisms listed in Table XII was made with the aid of the following publications: Bigelow and Welsh (1924), Clark (1902), MacBride (1906), Morris (1947), Pratt (1948), Proctor (1933), Smith (1941), Taylor (1937), Van Name (1912), Verrill (1873), Webb (1942), Webster and Benedict (1887), and Whiteaves (1901).

The boring sponge, Cliona celata, produces a fine network of holes in the outside of the valves of the scallop. The result is a weakening of the shell, the opening of additional avenues of attack for

TABLE XII

MACROSCOPIC ORGANISMS FOUND ASSOCIATED WITH PLACOPECTEN MAGELLANICUS

	Name	Relative Abundance	External or Internal	Extent of Injury
	PORIFERA			
	Cliona celata	Common	External	Boring, weakening shell
	Unidentified species	Rare	External	None
	COELENTERATA			
	Lafoea dumosa	Rare	External	None
	Alcyonium carneum	Rare	External	None
	Metridium dianthus	Common	External	None
	BRYOZOA			
	Gemellaria loricata	Common	External	None
	Dendrobeania murrayana	Common	External	None
	Hippodiplosia pertusa	Common	External	None
	ANNELIDA			
	Lepidonotus squamatus	Common	Both	None
	Phyllodoce grönlandica	Common	External	None
	Brada granosa	Rare	External	None
	Polydora sp.	Abundant	External	None
	Pseudopotamilla oculifera	Rare	External	None
Fauna	Spirorbis spirorbis	Abundant	External	None
	MOLLUSCA			
	Trachydermon ruber	Common	External	None
	Crucibulum striatum	Common	External	None
	Crepidula fornicata	Common	Both	None
	Crepidula plana	Common	External	None
	Anomia aculeata	Abundant	External	None
	Anomia simplex	Abundant	External	None
	Saxicava arctica	Abundant	External	Boring, weakening shell
	ECHINODERMATA			
	Asterias vulgaris	Common	Both	Destruction of viscera
	ARTHROPODA			
	Balanus sp.	Common	External	None
	CHORDATA			
	Ascidia sp.	Rare	External	None
	Tethyum sp.	Rare	External	None
	Boltenia sp.	Common	External	None
	Molgula sp.	Common	External	None
	Pholis gunnellus	Common	Internal	None
	PHAEOPHYCEAE			
	Dictyosiphon sp.	Abundant	External	None
	Laminaria saccharina	Common	External	None
Flora	Laminaria digitata	Rare	External	None
	RHODOPHYCEAE			
	Chondrus crispus	Rare	External	None
	Membranoptera denticulata	Common	External	None
	Polysiphonia sp.	Common	External	None

agents of erosion, and irritation of the mantle by occasional complete perforation of the valve. The action is probably never fatal, only irritant. Verrill, Smith (1891), and Drew mentioned that Cliona sulphurea riddled the valves with holes, resulting in a weakened shell, so apparently the ravages of the boring sponge have been recognized for many years.

The tube-building annelids, Polydora, are a prominent external feature of the older scallops. The tubes are built in excavations in the upper valves. Polydora has often been blamed for the major portion of the serious erosion in older shells, but Smith (1891) believed that the borings were made by sponges and later occupied by worms. Smith (1891), quoting Rathbun of the National Museum, stated that no worm affecting shellfish in Maine waters was capable of puncturing a shell. Procter also referred to the habit of Polydora in building tubes in and upon shells, especially those of Pecten (= Placopecten), but took no stand as to the boring. Pratt, however, stated that Polydora concharum often burrowed in shells.

Another annelid genus, Dodecacerea, was found by Verrill to be excavating galleries in shells of Pecten tenuicostatus (= Placopecten magellanicus), among other shells, in the Bay of Fundy. The genus was not cataloged by Whiteaves in eastern Canada, but Dodecacerea concharum was found in old shells by Procter in the Mount Desert region. It was not found in the present investigation.

Dakin found a Pecten maximus killed and partially eaten by a large dog whelk.

In the course of the present investigation, it was found that a moderately heavy infestation of small arctic rock borers, Saxicava

arctica, resulted in considerable erosion of the upper valve of P. magellanicus. As far as is known, this type of attack has not been previously reported. Plate XV, Fig. A, shows the typical upper surface of an older scallop, while Plate XV, Fig. B, shows the galleries that lie beneath, when the outer surface has been removed. Many of these borings were occupied by the tubes of Polydora sp. The position of the borers as well as the progressive increase in the diameter of some of the galleries strongly suggests their being caused by Saxicava arctica. Due to the difficult dissection necessary to trace a gallery to its end, typical counts of the infestation per shell were not attempted. It may be seen, however, in Plate XV, Fig. B, that the upper valves of older scallops are very seriously weakened by such attacks. It was found that the ends of many of the burrows were separated from the mantle by only a paper-thin layer of nacre, and often these inner ends of the burrows were built up as warts beneath the mantle. This condition would seem to indicate a constant irritation of the mantle by the close proximity of the borer and perhaps by its occasional perforation of the nacreous lining. This irritation and continuous deposition of nacre would constitute a considerable drain upon the vitality of the scallop.

The damage inflicted by Asterias vulgaris was discussed under Methods and Materials, where it was concluded that the species was definitely an enemy of the scallop population. Only one of the number of scallopers consulted during the investigation took the time to kill the starfish brought aboard in the dredge. It appears that dealing with the pests directly as they are brought up by the scallop dredges may be the only practical method of treatment. According to the Maine Department of Sea and Shore Fisheries (1941), starfish removal by means of dredging

was tried on some of the Penobscot Bay beds. Observations during the dredging season immediately following the operation seemed to indicate fewer starfish and more young scallops, but it appeared advisable to try to find a more economical method of eradication. The cooperation of all those engaging in the fishery would do much to help in reducing the depredation of this starfish.

The ectoparasitic copepod, Lichomolgus maximus, was found by Dakin on the gills of Pecten maximus in British waters.

The tiny crab, Pinnotheres maculatum, was found by Smith (1891) in the gill cavity of the scallop, but apparently was not harmful.

The rock eel, Pholis gunnellus, was found to be very common within the shells of live scallops in the course of this investigation. No injury to the mollusk was evident, and it is believed that the small fish utilized the partially opened valves of the feeding scallops as a hiding place. Smith (1891) mentioned Liparis sp. as an accidental inhabitant of scallop shells. In addition to Pholis gunnellus, Bigelow and Welsh listed the sea snail, Neoliparis atlanticus; the striped sea snail, Liparis liparis; and the squirrel hake, Urophycis chuss, as common harmless inhabitants of the shells of scallops.

Apparently, then, the principal causes of mortality are the unknown effects of bottom dredging upon the smaller sizes, and the depredation of starfish upon all sizes. There is little that can be done about the first cause, and for the second, all that can be accomplished at present is to obtain the cooperation of all scallopers in killing dredged-up starfish.

CATCH PER UNIT OF EFFORT

In fishery management, figures concerning catch per unit of effort are most useful when they maintain a constant ratio to fluctuations in the population. They can then be used to check population changes, a procedure which has been successfully applied to the razor clam, Siliqua patula, by Schaefer (1939).

In practical use, however, it is generally found, due to variables peculiar to each fishery, that the catch per unit of effort is not a constant ratio to the fluctuations in abundance. One objective of the biologist, then, is to recognize and measure, if possible, the variables which warp the ratio. Another necessary objective is the collection of accurate and complete statistics on the fishery, statistics that are basic and simple for members of the industry to keep.

At this point it is not known how closely the Maine scallop fishery may conform to the proportional ideal of the catch per unit of effort and the abundance. In considering the procedure of dredging, several variables become apparent, but it is possible that some of them may be worked directly into the expression of the catch per unit of effort.

The preliminary nature of this investigation precludes the possibility of proving the true relationship of the catch per unit of effort, or even of establishing the most effective unit of effort. The limited amount of data obtained permit only a comparison of four individual beds, an example of the application of the data, and a comparison of the apparent density of scallops on bottom for six beds.

In using the methods and data outlined under Methods and Materials, it was decided that the volume per hour worked over by the dredge would be used as the unit of effort. Ordinarily, in the case of

most shellfish, area would be sufficient. The scallop, being very active, however, propels itself through the water when disturbed, and so brings into consideration the vertical dimension, that is, the size of the mouth of the dredge. Thus, five variables: the width of the dredge mouth, its height, the length of each trip, the number of trips for the day, and the time required were utilized in computing the unit of effort. An arbitrary figure of 10,000 cubic feet per hour was selected as a standard unit. This corresponds to a six foot dredge with an eight inch mouth, travelling 0.41 nautical miles in one hour. The catch per unit of effort for the four commercial beds is shown in Table XIII. The two hand-dredged beds, 10 and 11, were not used in this computation since time records were not kept for them.

TABLE XIII

CATCH PER UNIT OF EFFORT

Collection	Catch Gals./10,000 cu. ft./hr.	Square Feet per Scallop
2	0.40	182.4
3	0.27	273.6
4	0.23	324.3
5	0.22	364.8
10	----[5]	344.8
11	----[5]	338.7

[5]Hand-dredged collection, no time records available.

Two additional variables which might affect the catch are the type of gear and the type of bottom being dredged. It is thought that one may compensate for the other, since the six foot single dredge is generally used on smooth bottom, while the twin three foot dredges are designed for the more efficient dredging of rough bottom.

Experience is another factor which may have a definite effect upon the catch per unit of effort. Practically every scalloper has his "marks" by which he locates each bed, and considerable experience is required before the newcomer can establish his "marks" in the most advantageous location. Dredging in comparatively unproductive areas is bound to lower the catch per unit of effort.

Upon examining Table XIII, it is seen that the bed on which collection 2 was made provided a much better catch per unit of effort than did the other three beds. Two factors contribute to this. In the first place, the characteristic decline in abundance during the dredging season, as discussed under Movements, may exert a strong influence. The dredging for collection 2 was done only 20 days after the opening of the season, while the other three collections were taken considerably later. In the second place, collection 2 was the only one of the four with a near-normal height-frequency distribution (Table IV, pages 37-39). Collection 3 showed that bed to be composed mainly of smaller and more active sizes, while collections 4 and 5 showed those beds to be composed principally of the larger and scarcer sizes.

The decline of abundance during dredging on individual beds and their recovery the following season will probably cause a cyclic change in the catch per unit of effort, based on a one-year period. The catch per unit of effort, in order to be a true measure of abundance, should probably be based on an average for the season.

From the data used in the computation of catch per unit of effort, an estimate was made of the density of scallops on the bottom. The conversion factor of 200 scallops per gallon of shucked meats was used. This figure represents the average of several actual counts. While admittedly not indicative of the total population, the results do show the density of that segment of the stock taken by dredge. As shown in Table XIII, the average area allotted to each scallop is surprisingly large. It must be remembered, however, that due to the dredging distances of up to a mile, many unproductive or uninhabited areas are included in the estimation.

The results shown for the hand-dredged collections 10 and 11, suggest a much sparser population than was actually the case. The combination of inefficient operator and dredge, and underpowered boat lowered the catch appreciably.

When further research has resulted in the development of techniques for the management of the fishery and has led to the decision of what statistical data are required for the program, the next step is the establishment of a routine for the accumulation of such data from the fishery. These statistics preferably should be very elementary and essential, since fishermen are much more ready to cooperate when cooperation means a minimum of effort. Even accurate total catch data are not presently available. The impression was gained, during the investigation, that very substantial quantities of scallops cannot be accounted for by usual means. The boats land at small towns and docks everywhere, and often the catch is disposed of directly from the boat or dock, or else in small local stores.

Catch per unit of effort is an important link in the management program if its full value can be determined. It is to the biologist's advantage, then, to pursue this phase to its conclusion.

RECOMMENDATIONS

The object of this investigation, as stated in the Preface, is to accomplish the preliminary work required for a more extensive program and, if possible, to provide certain methods and principles to be used in such a program. It seems fitting, then, to enumerate several recommendations which, it is believed, would be of some value to the fishery and to succeeding research.

The Fishery

1. The four inch minimum size law, such as is now in force in Canada, should be seriously considered. Its advantages are: the taking of five year or older scallops, the protection of fastest growing years, and the assurance that each scallop taken will have spawned at least twice. This investigation has shown the extreme degree to which the size range and frequency of the catch are controlled by the size of the ring mesh in the dredge. It is suggested, therefore, pending satisfactory trial demonstrations, that the ring mesh of all scallop dredges be limited to the maximum size which would retain four inch scallops with a minimum percentage of smaller sizes. The fishermen would then be permitted to use all scallops brought on deck. Considering the custom of shucking on the beds and the widely dispersed locations of the beds, such a regulation could be much more effectively enforced than a minimum size limit on the scallops themselves.

2. From the standpoint of this investigation, the present open season for scallops, November 1 through March 31, is entirely satisfactory. Its beginning comes well after the cessation of spawning. Economically, the season is well situated as it is usually a slack one for the lobster fishermen who make up the bulk of the scallopers.

3. It should be urged that scallopers destroy all starfish brought aboard in the dredges, which at present is the only practical method for control.

Further Investigations

1. The general plan of future investigations should include the pursuit of its various phases throughout at least one calendar year, on at least one bed, seeking seasonal changes and the effects of dredging.

2. The catch per unit of effort, in order to b e of use in the management of the fishery, requires a great deal of work. The simplest, most effective, unit of effort must be found, and its effectiveness proved. The necessary statistics must be decided upon and the means determined for obtaining them from the fishery.

3. Further age and growth determinations should be carried out in various parts of the State. Also, the meat yield by sizes and ages should be calculated, similar to the work of Medcof. Knowledge of the meat yield is an important supplement in the establishment of production at the highest sustained level.

4. A great deal remains to be discovered concerning the movements of scallops. Extensive tagging projects should be carried out in an attempt to determine the nature of and the reasons for the movements.

5. More knowledge of the earlier stages of the scallop is desirable. Identification of the planktonic stages, a satisfactory method of sampling for the smaller sizes on the beds, and a study of the conditions influencing good and poor sets would make valuable contributions to the complete understanding of the scallop.

6. The investigation of some of the older Penobscot Bay beds should reveal the effects of long and intensive dredging. These were

among the first beds to be fished in Maine and reports of the Commissioner of Sea and Shore Fisheries indicate a long record of fair to poor production from the areas.

7. Continuous work toward an effective reduction of mortality is worthwhile. This should include methods of starfish eradication and the determination of the effects of accumulations of shucking debris on the beds.

8. Hydrographic work to determine the characteristics of scallop beds, as well as the reasons for their locations, should be a valuable guide to the discovery of new beds.

SUMMARY

1. Anatomical studies of *Placopecten magellanicus* agree with previous investigations, except that a crystalline style is demonstrated, although it occurs only in fresh specimens.

2. In commercial fishing, ring mesh size of the dredge affects the relative frequency of the various size classes caught. Of all scallops dredged, 97.7 per cent are commercially usable. Skewed size frequency curves from commercial beds may indicate overfishing. Low frequency collections, ranging from 133 to 183 in number, were reliable samples of the part of the population subject to being taken by dredge.

3. Growth is most rapid during the first five years and slows down a great deal after the seventh. The present commercial minimum size limit, purely voluntary, of about 80 millimeters, is reached between the third and fourth winters. Ages through seven years comprised 60.8 per cent of the commercial catch, and ages through five years comprised 38.8 per cent. The maximum age is well over 19 years. There is no indication of great variations in growth having occurred in the past 10 to 15 years.

4. In 1948, spawning occurred during August and early September. Macroscopic, microscopic and statistical studies of gonadal changes indicate that gametogenesis begins immediately after the spawning period. Although the minimum size and age for spawning is not definitely known, well-developed gonads appeared in sizes down to 60 millimeters, a size which is attained during the third summer. Most scallops mature prior to the fourth winter, at about 80 millimeters. These latter, taken commercially, are lost to the breeding stock after one spawning. The sex ratio is 0.9 females per male.

5. Two hundred and fifty tagged and released scallops yielded 5.2 per cent recoveries. The only conclusive movement was from shallow into deeper water.

6. Dredging causes little harm to the population through the unused few that are brought to the surface, but effects on the bottom population are not known. Harmful organisms are: the arctic rock borer, Saxicava arctica; the boring sponge, Cliona celata; and the starfish, Asterias vulgaris.

7. The commercial catch per unit of effort on four beds ranged from 0.22 to 0.40 gallons for every 10,000 cubic feet of bottom dredged per hour and gave an approximate indication of abundance. Variables influencing this relationship are: type of gear, type of bottom, experience of crew and time of season. On six beds, the average area dredged to obtain a single commercial sized scallop ranged from 182.4 to 364.8 square feet.

8. It is recommended that:

a. A four inch minimum law, enforced by regulation of dredge ring mesh size be seriously considered.

b. The present open season be continued.

c. Scallopers be urged to destroy all starfish dredged.

d. An intensive study of one bed be made over a full year period.

e. Further studies be made to include catch per unit of effort, age and growth, migration, early developmental stages, mortality and hydrographic characteristics of scallop beds.

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BIOGRAPHY

Walter Raynes Welch was born in Rumford, Maine on Oct. 25, 1920. He attended Stephens High School in Rumford, and graduated from there in 1938.

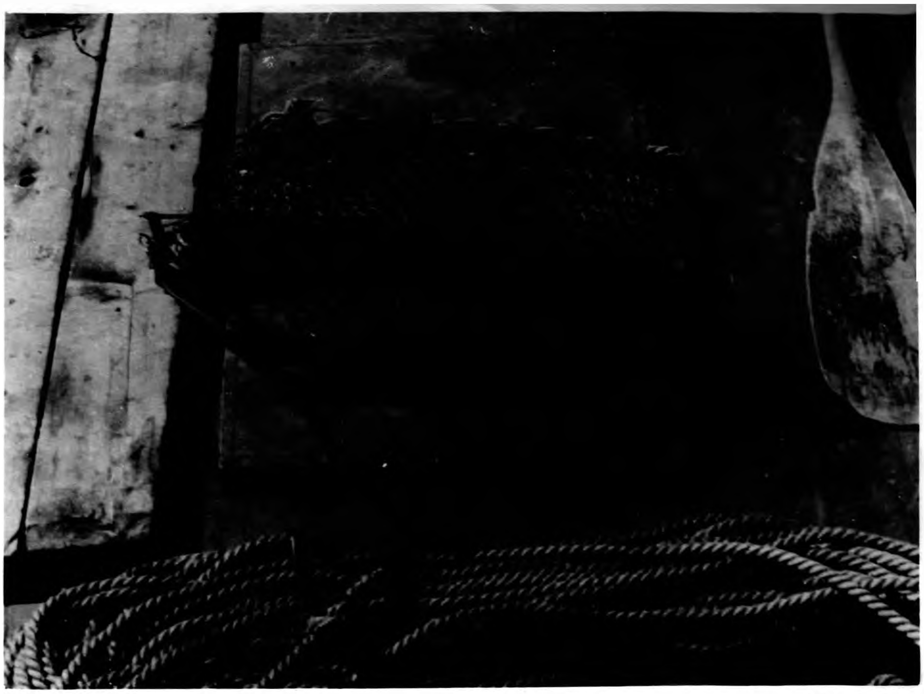
He entered the University of Maine at Orono, Maine in 1939 and attended until June 1942. After serving in the United States Army Air Forces and the Manhattan Engineering Project until February 1946, he returned to the University of Maine and received a Bachelor of Science degree in Wildlife Conservation in 1947.

In September 1947 he enrolled in the Division of Graduate Study at the University of Maine under a Maine Department of Sea and Shore Fisheries fellowship and served as research fellow for a year and a half.

He is a member of The Wildlife Society and the Atlantic Fisheries Biologists. Since February 1949, he has occupied the position of fisheries research biologist in the Clam Investigation project of the United States Fish and Wildlife Service. He has joint authorship of two manuscripts submitted for publication entitled "Management Studies of the Soft Clam (*Mya arenaria*) in Maine, 1949." and "A Geological and Biological Study of a Maine Tidal Flat". His thesis, entitled "Growth and Spawning Characteristics of the Sea Scallop, *Placopecten magellanicus* (Gmelin), in Maine Waters" was submitted, and the Master of Science degree was awarded in June 1950.

APPENDIX

Plates I to XV inclusive.



-edge used in the present investigation
_ ar to those used in the early fishery.

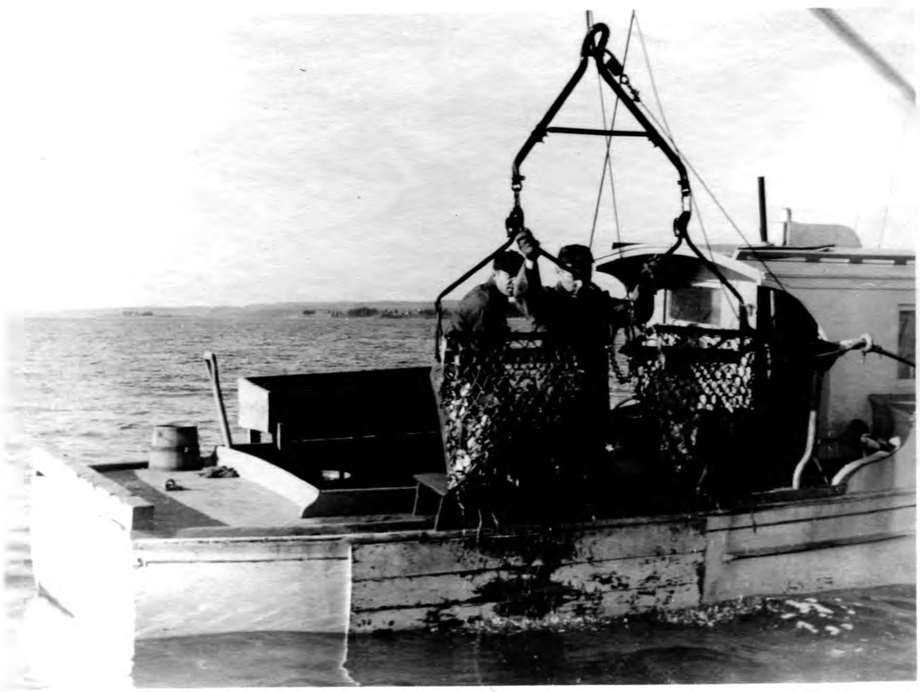


Fig. B Twin dredge used commercially in the present fishery.

Plate I

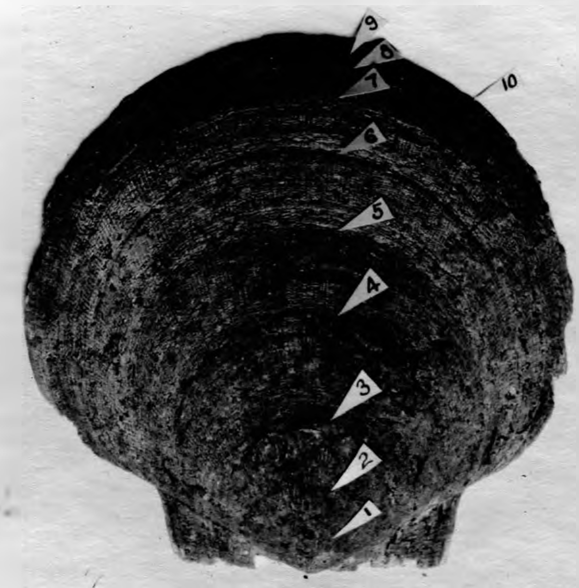


Fig. A Annual rings on the upper valve.

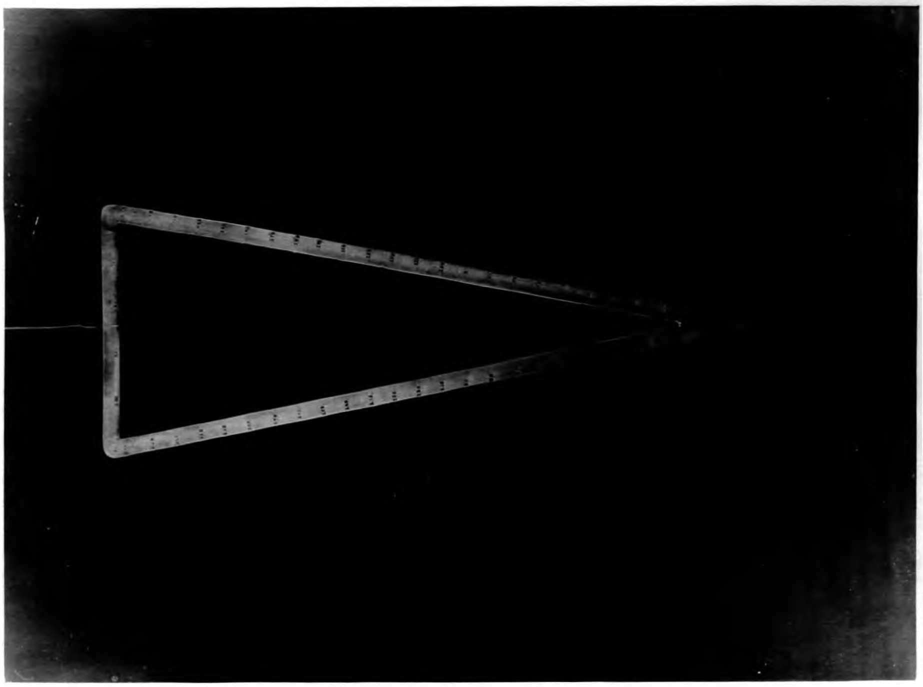


Fig. B Gauge used for measuring shell height.

Plate II

Fig. A Boat used for hand dredging in the present investigation.

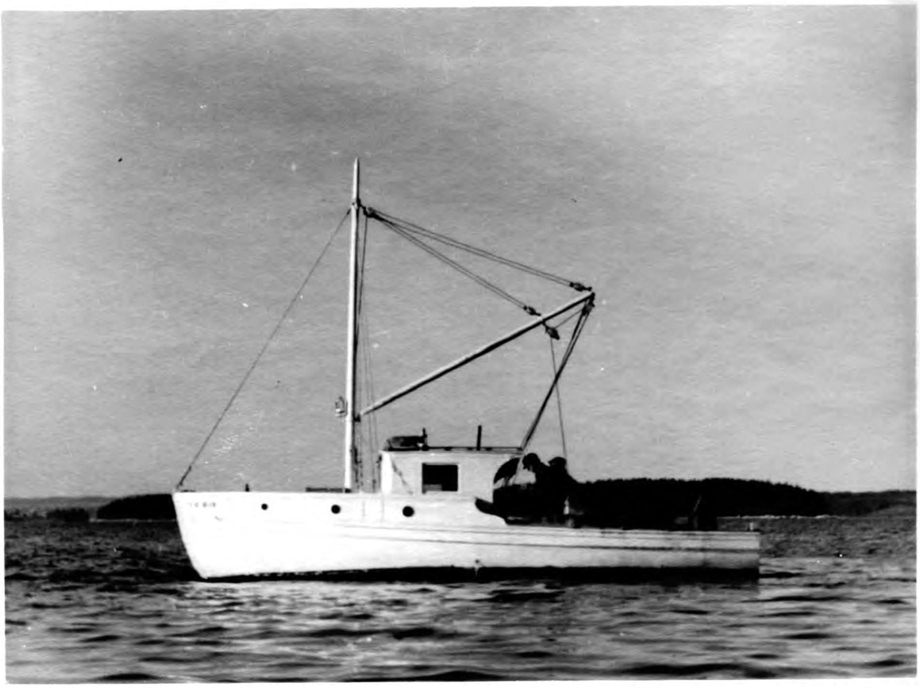


Fig. B Commercial scallop boat typical in Maine waters.

Plate III

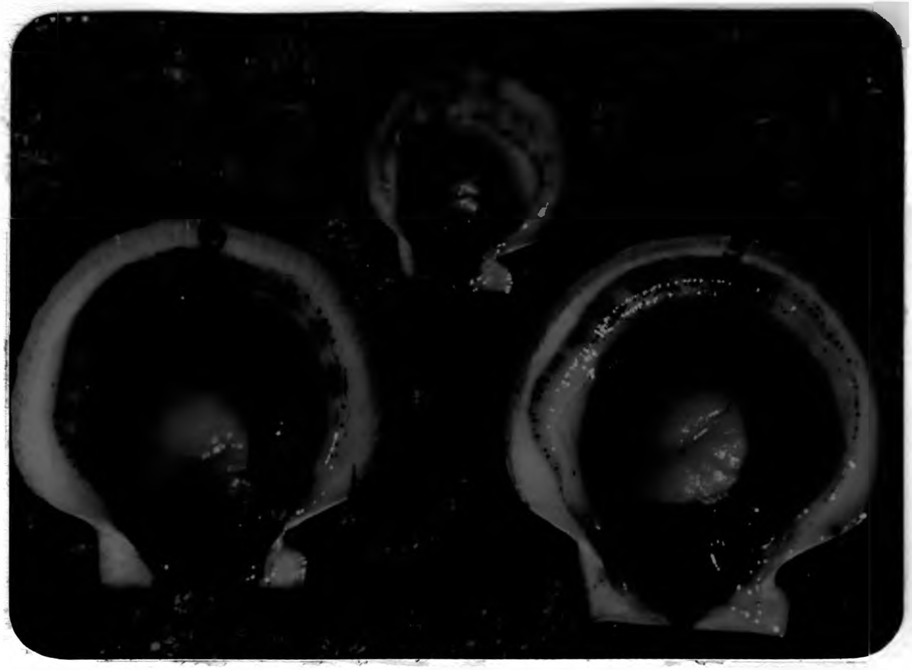


Fig. A Stages of gonadal development. Left gonad is stage three, female. Center gonad is stage one. Right gonad is stage four, female.

Fig. B A male gonad in stage two of development.

Plate IV

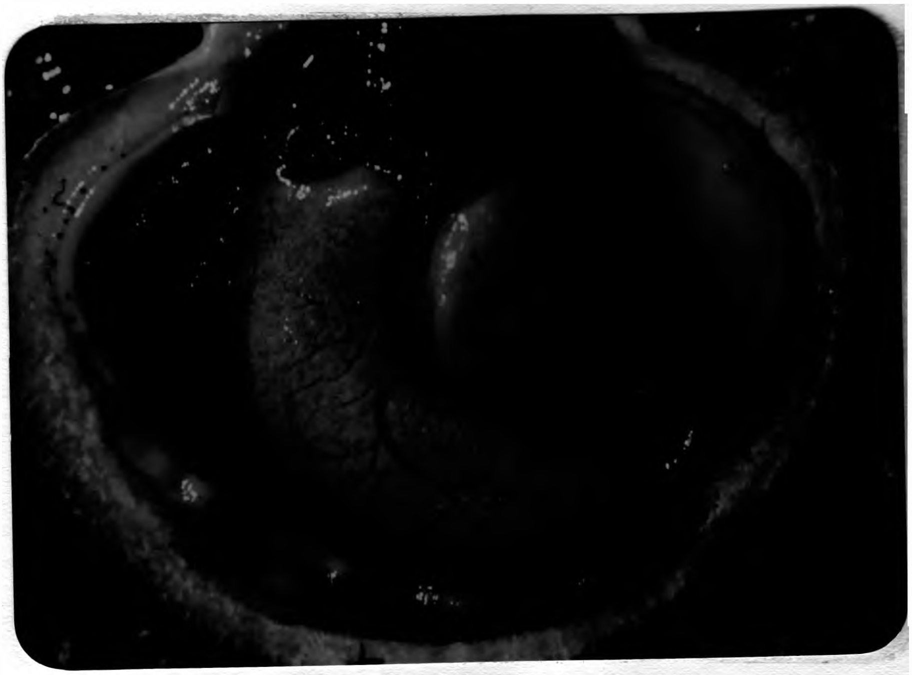


Fig. A A male gonad in stage four of development.

Fig. B A female gonad in stage four of development.

Plate V

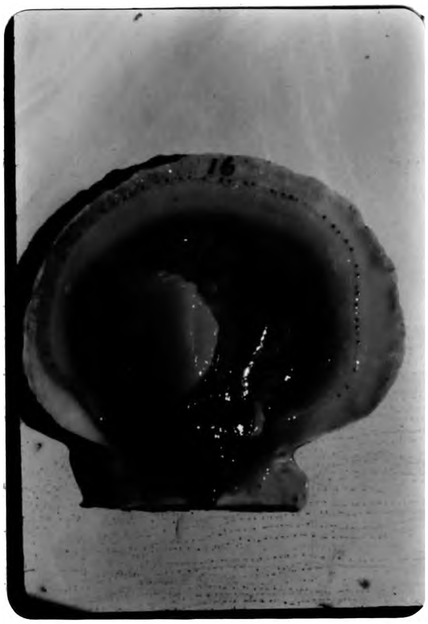


Fig. A A male gonad in stage two of spawning.

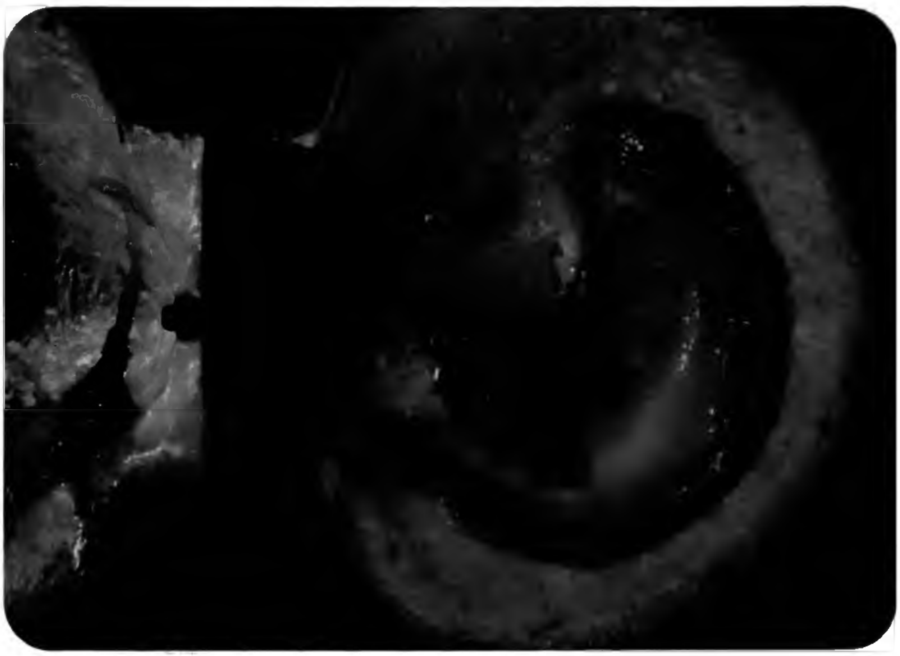
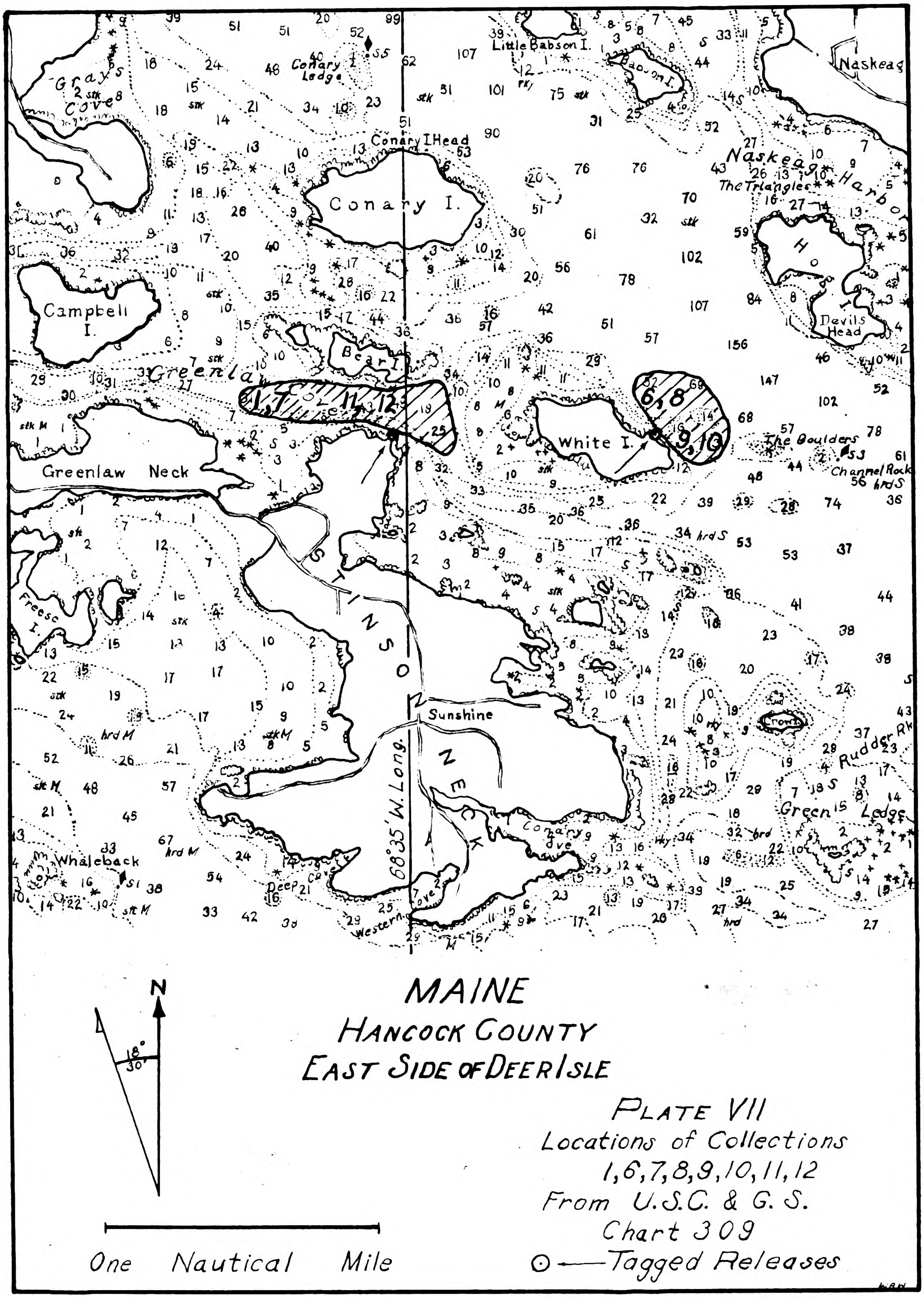


Fig. B Starfish feeding upon a scallop that it had apparently killed.

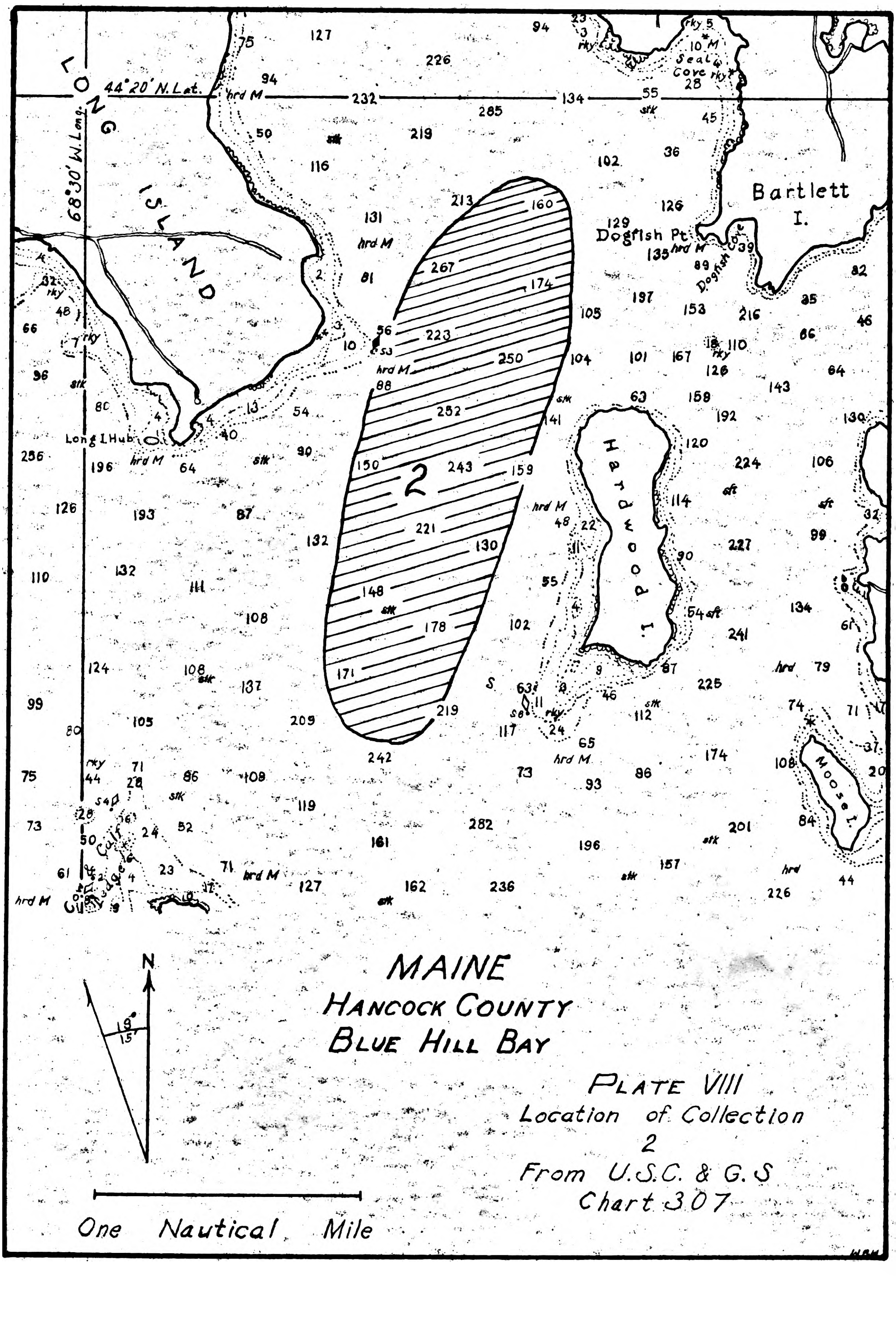
Plate VI



MAINE

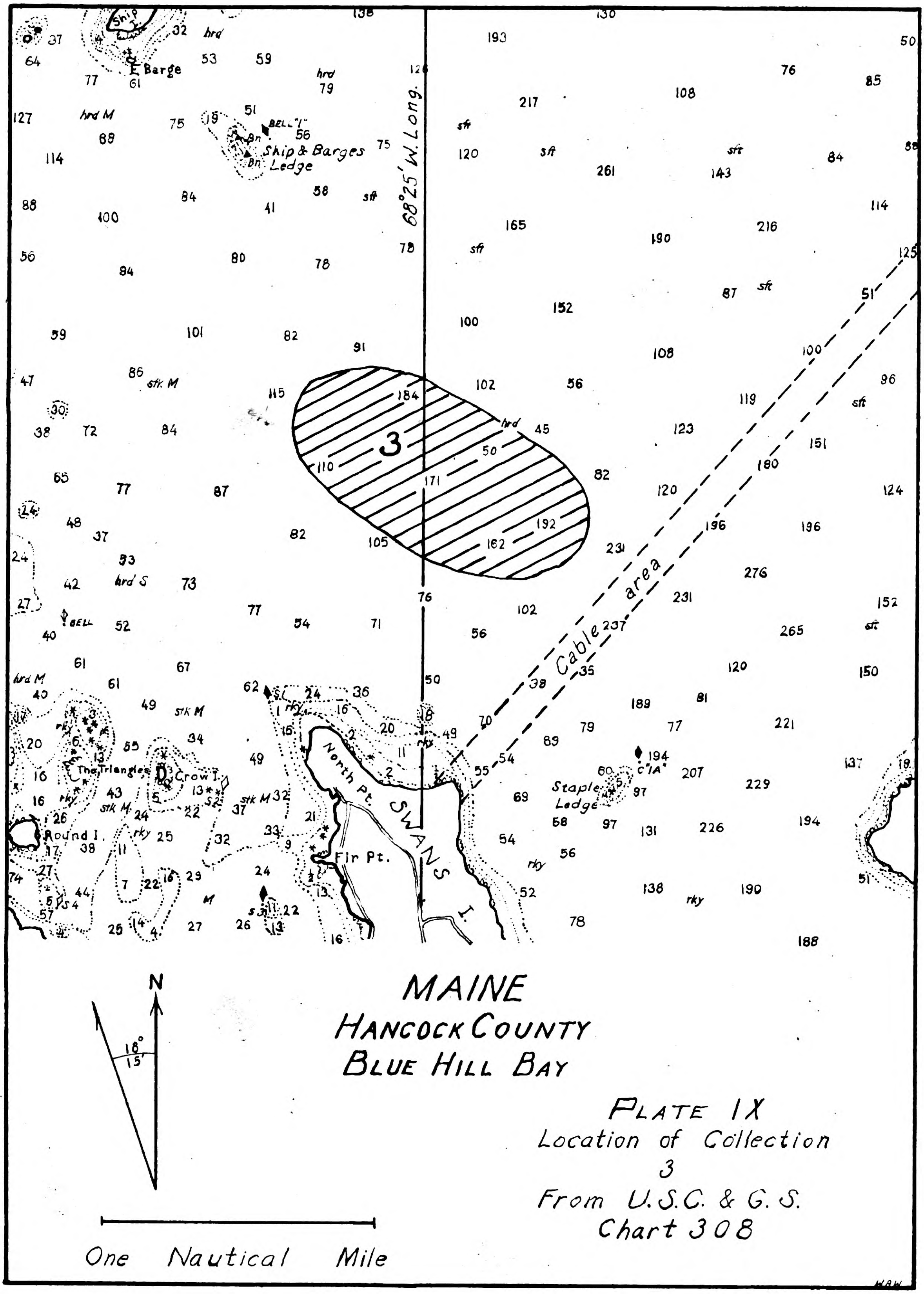
HANCOCK COUNTY
EAST SIDE OF DEER ISLE

PLATE VII
Locations of Collections
1, 6, 7, 8, 9, 10, 11, 12
From U.S.C. & G.S.
Chart 309



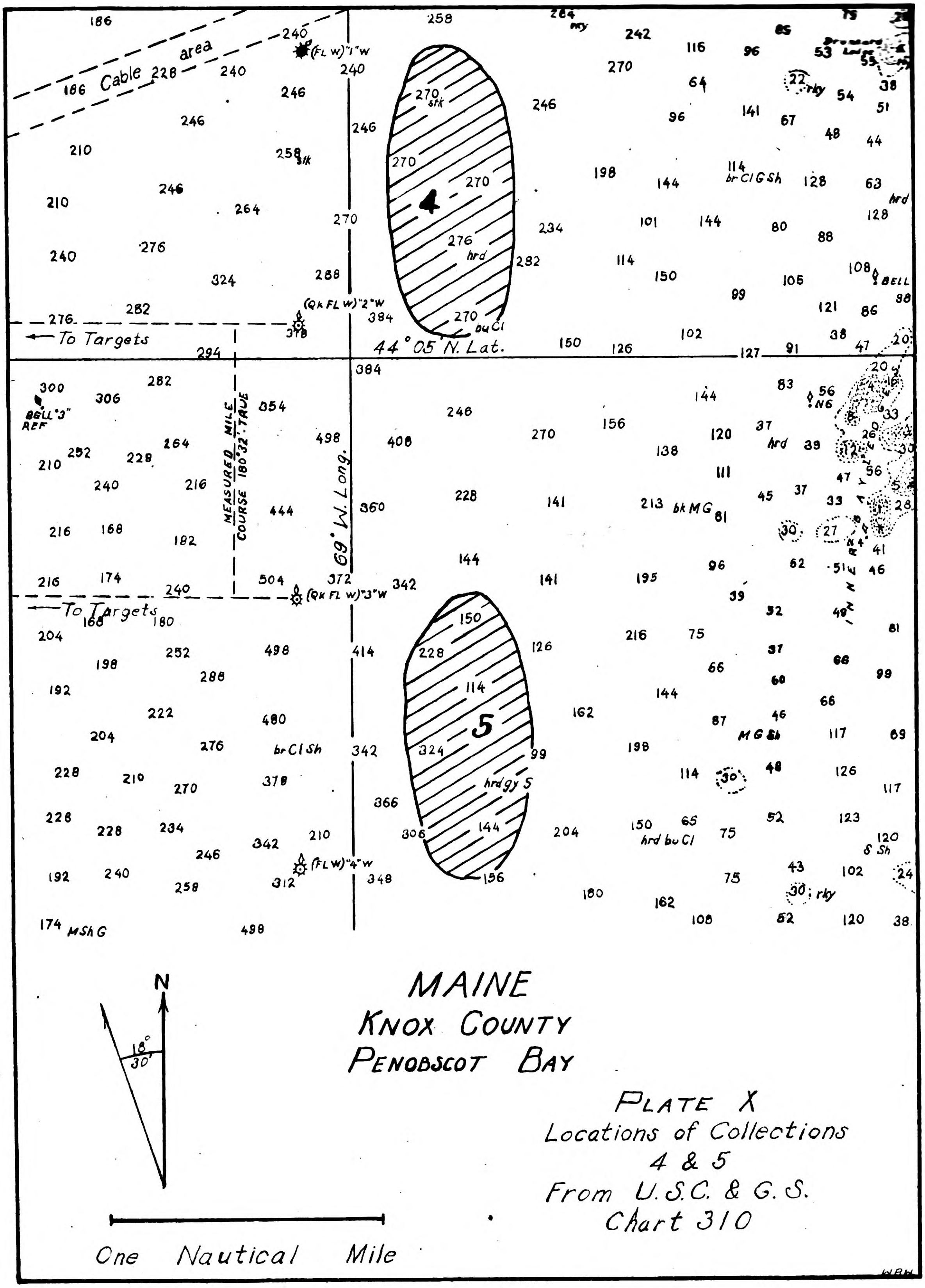
MAINE
HANCOCK COUNTY
BLUE HILL BAY

PLATE VIII
Location of Collection
2
From U.S.C. & G.S.
Chart 307



MAINE
HANCOCK COUNTY
BLUE HILL BAY

PLATE IX
Location of Collection
3
From U.S.C. & G.S.
Chart 308



MAINE
KNOX COUNTY
PENOBSCOT BAY

PLATE X
Locations of Collections
4 & 5
From U.S.C. & G.S.
Chart 310

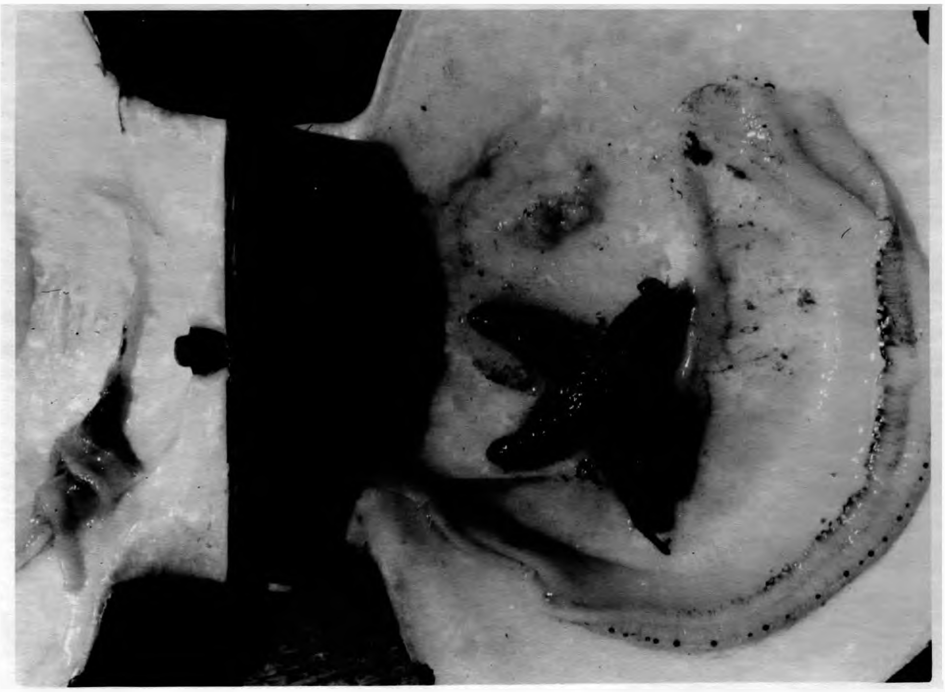


Fig. A Asterias vulgaris feeding upon scallop remains.

Fig. B Photomicrograph of a cross-section of a gonad in stage one of development. About X 200.

Plate XI

Fig. A Photomicrograph of a cross-section of a female gonad in stage two of development. About X 200.

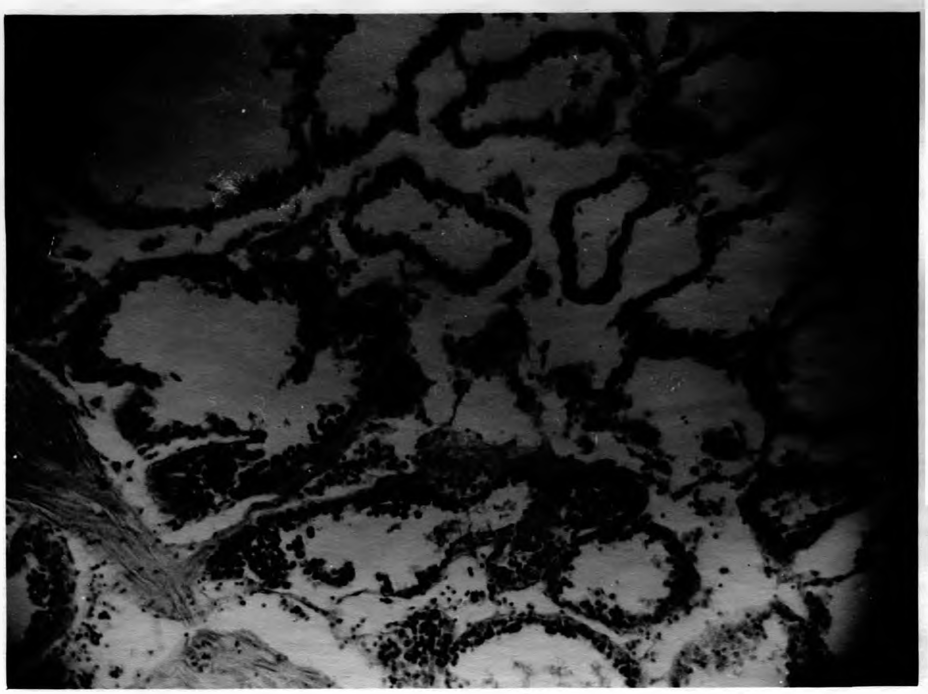


Fig. B Photomicrograph of a cross-section of a male gonad in stage two of development. About X 200.

Plate XII

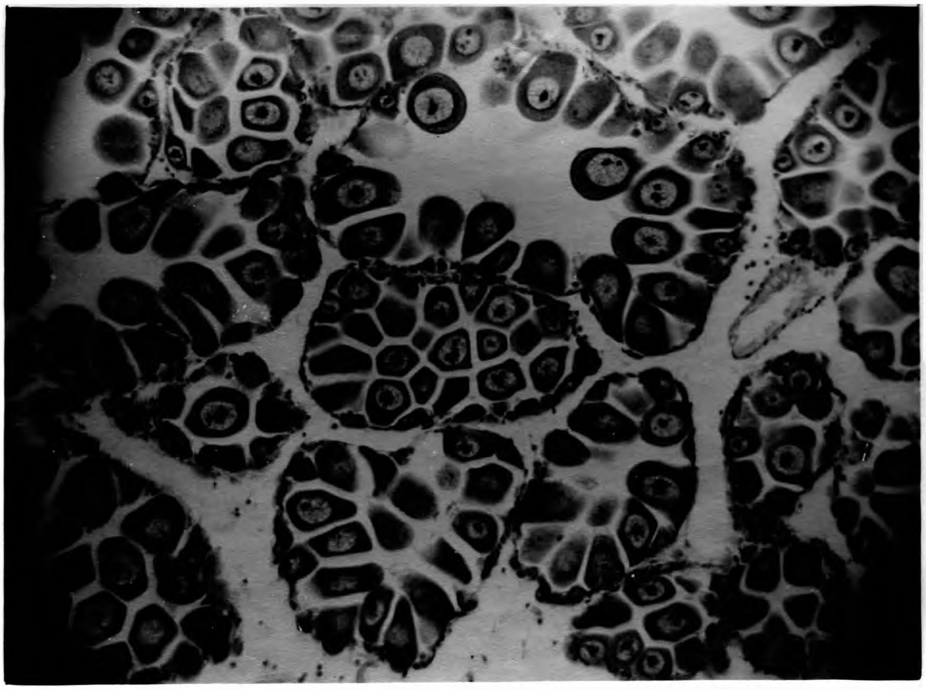
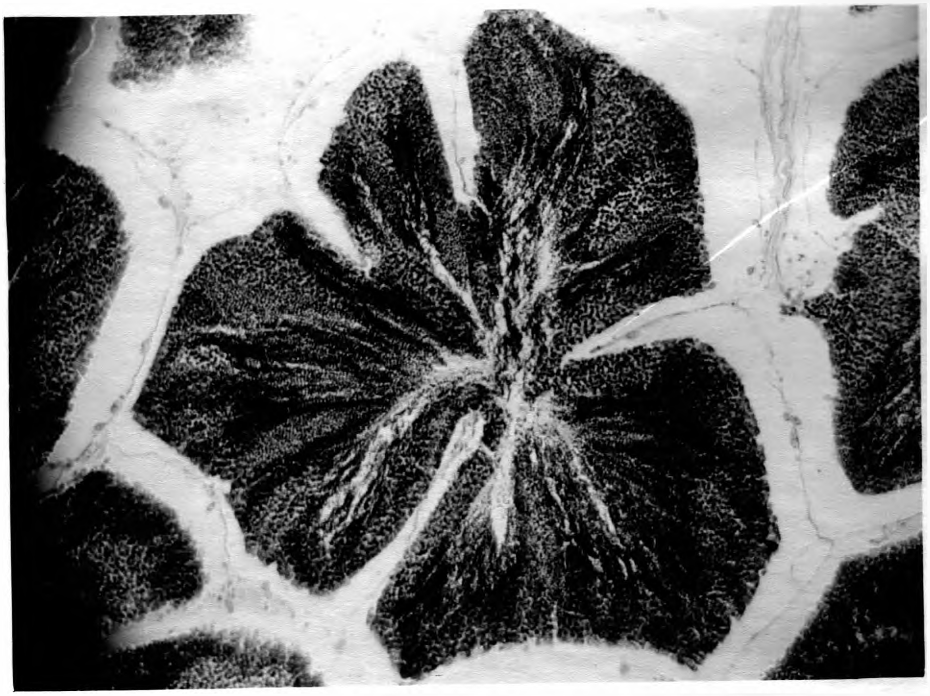


Fig. A Photomicrograph of a cross-section of a female gonad in stage three of development. About X 200.



Photomicrograph of a cross-section of a male gonad in stage three of development. About X 200.

Plate XIII

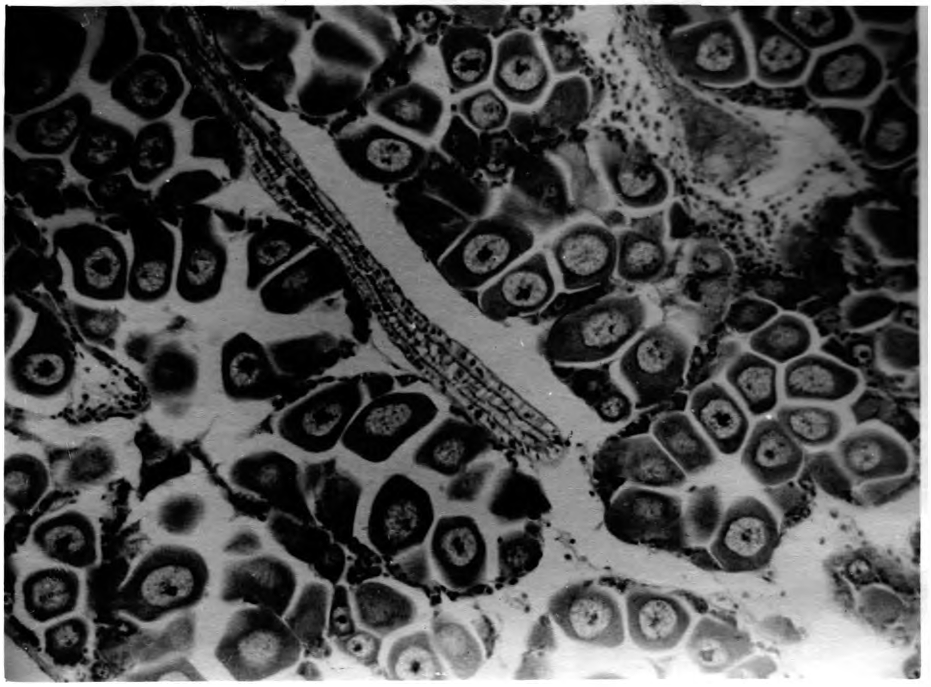


Fig. A Photomicrograph of a cross-section of a female gonad in stage four of development. About X 200.

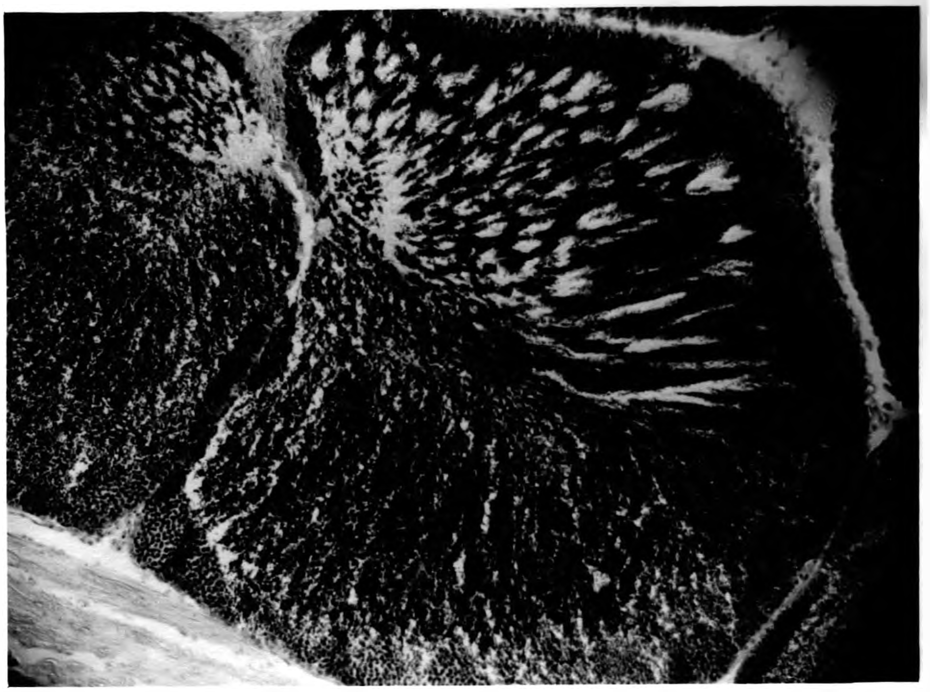


Fig. B Photomicrograph of a cross-section of a male gonad in stage four of development. About X 200.

Plate XIV

Fig. A Upper valve of an older scallop, showing extreme erosion.

Fig. B A similar valve with the top layer removed; showing the many galleries excavated within.

Plate XV