PEARL AND HERMES REEF, HAWAII, HYDROGRAPHICAL AND BIOLOGICAL OBSERVATIONS

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INTRODUCTION

Discovery of Pearl Oyster Beds

Until a few years ago the supply of marine pearls and mother-of-pearl shells in the United States was entirely dependent on importation from abroad. It is easy, therefore, to understand that the discovery of pearl oyster beds within outlying territory is of considerable interest to the public and attracts the particular attention of importers and dealers in pearls and mother-of-pearl shells and of those who are chiefly concerned with the development and conservation of the natural resources of the sea.

The honor for the discovery goes to Capt. William G. Anderson who in 1927, when fishing for a commercial concern, found a large pearl oyster bed in Pearl and Hermes Reef, an atoll lying near the western end of the Hawaiian archipelago approximately 1,100 miles from Honolulu. In 1928 several tons of shells were brought to Honolulu and sold to manufacturers of pearl buttons in San Francisco and New York. The newly discovered beds were yielding considerable numbers of pearls which were offered at the local market in Honolulu and sent also to New York and Paris. During the years of 1927 and 1928 Hawaiian fishermen made several attempts to reach Pearl and Hermes Reef in their fishing boats (sampans), but with one exception the boats were either lost at sea or were forced to return home, having failed to reach their destination. One successful Japanese fisherman brought back to Honolulu about six tons of shells. Intensive shelling operations were carried on, however, by the Hawaiian Sea Products Co. (Ltd.), which dispatched to Pearl and Hermes Reef the schooner *Lanikai,* the former interned German vessel *Hermes* which was bought at auction and equipped for fishing operations with various gear and a freezing apparatus. By permission of the Governor of the Territory of Hawaii the company erected several buildings on one of the islands inside Pearl and Hermes lagoon. The *Lanikai* carried a large fishing crew which included several Filipino divers employed exclusively for taking pearl oysters.

In 1929 the Hawaiian Sea Products Co. made an application to the Biological Survey of the U. S. Department of Agriculture for a lease of Pearl and Hermes Reef, where it planned to erect a cold storage plant and establish a fishing station. The applicants intended to obtain exclusive fishing rights in the lagoon. A similar application was filed by the Hawaii Tuna Packers Co. There were sound reasons to expect that the example of the Hawaiian Sea Products Co., which was successful in bringing to Honolulu pearls and shells, would be followed by others and that a number of fishermen would make new attempts to proceed to Pearl and Hermes Reef and adjacent islands and make general raids on the pearl oyster beds.

Purpose of Observations

In order to protect the newly discovered pearl oyster bottoms from destruction the Territorial Government requested the U. S. Bureau of Fisheries to outline methods for their conservation and development. In response to this request the Bureau offered the following preliminary recommendations which defined also the purpose and the methods of the proposed investigations:

1. Conduct a preliminary hydrographic and biological survey of Pearl and Hermes Reef beds and adjacent areas.

2. On the basis of information received from these sources, take such legislative or executive action as may be necessary to insure regulated exploitation and development of the resource under proper scientific control.

3. The ultimate goal of the proposed survey of the newly discovered pearl oyster beds on Pearl and Hermes Reef is the outlining of practical measures of conservation and control that will permit a fuller exploitation of the resource without causing its depletion and destruction. Since the beds are admittedly limited in extent, it appears to be expedient that all pearl oyster fishing on these reefs be prohibited pending the completion of a survey. It is assumed that the Territorial Government has authority to take such action, and since the pearl shells must be marketed at the larger ports of the territory, that the government is able to provide the necessary machinery to make such prohibition effective.

4. Any recommendation for an efficient program of conservation and development of natural resources of the ocean must be based upon the knowledge of the abundance and distribution of the species in question in a given section of the sea, and its life history. The first and most important task is to determine the exact location and extent of pearl oyster beds and to estimate the density of their population. This can be accomplished by a regular hydrographic survey accompanied by a biological investigation.

5. The hydrographic surveying will consist in the delineation of the pearl banks, sounding, sampling of bottom, taking temperature and salinity records. The biological studies will comprise the estimation of the number of oysters in various sections of the atoll, the determination of the age groups and their relative abundance, and observation of spawning and setting of the oysters. Inasmuch as conditions similar to those existing on Pearl and Hermes Reef may be found on other islands, it seemed desirable to extend the operations to cover other atolls in the vicinity of Midway Island.

6. One of the most important problems in conservation of the pearl oyster fishery in Hawaii is the possibility of cultivation and propagation of pearl oysters in the waters near Honolulu. It appears desirable to experiment along this line and to have several

thousand bushels of pearl oysters planted on suitable bottoms in convenient harbors and bays. It is one of the tasks of the proposed investigation to discover the locations suitable for such experiments.

7. Pearl oyster fisheries in other parts of the world generally have proved to be highly variable and are usually conducted under strict governmental supervision. On the completion of the preliminary survey, it should be apparent what steps are necessary to regulate the Hawaiian fishery, what can be done to augment the natural stock, and whether cultivation in new areas is feasible. No regulation can be successful, however, without continued observation and extensive research, and plans should be made to provide technical as well as administrative personnel, by the responsible government, to undertake continuous studies in regulation and development as may be warranted by the economic importance of the products.

Following these recommendations the Legislature of the Territory of Hawaii passed an act relating to pearl oyster fishery which upon approval by the Governor became effective on May 1, 1929. The full text of it follows:

Act 209. (H. B. No. 376.) An Act Relating to Pearl Oyster Fisheries and the Conservation and Utilization of the Same. Be it Enacted by the Legislature of the Territory of Hawaii:

Section 1. The Board of Agriculture and Forestry is hereby authorized to make or to cooperate with the Federal Bureau of Fisheries in making a survey of the pearl oyster fisheries in all the waters under the jurisdiction of the Territory of Hawaii, to determine their extent and value, and the rate of growth, spawning season and other information relating to such pearl oysters; and shall, with the approval of the Governor, as soon as reasonably practicable, make and promulgate rules and regulations for the conservation and utilization of such pearl oysters, with a view to the development of the pearl oyster industry without depleting the supply of the pearl oysters. Such rules and regulations shall, when promulgated, have the effect of law. Such rules and regulations shall provide, among other things, for the issuance of permits to proper and responsible persons or concerns to collect, for their own use, pearl shells, upon condition that the permittee shall at his or its own expense provide suitable accommodations upon any boat used by him or it between Honolulu and the said fishing grounds and between the said fishing grounds and Honolulu, for the accommodation and sustenance during the period of transportation of such person or persons as shall be named by the Territorial Board of Agriculture and Forestry or the United States Bureau of Fisheries, for the purpose of such survey, and also for the proper sustenance during such trip or trips, and shall also provide at such fishing grounds proper shelter and sustenance at his or its own expense for the persons so named for said purpose.

The sum of twenty-five hundred dollars ($2,500.00) is hereby appropriated for such survey out of the moneys in the treasury of the Territory not otherwise appropriated.

Section 2. It shall be unlawful for any person, firm or corporation to take, collect, molest or destroy any kind of pearl oyster, sometimes known as mother-of-pearl shell, in any of the waters under the jurisdiction of the Territory of Hawaii, contrary to such rules and regulations when passed as aforesaid.

Section 3. Any person, firm or corporation violating any of the provisions of this Act or such rules and regulations, shall be subject to a fine of not more than five hundred dollars ($500.00) or to imprisonment for not more than six (6) months, or to both such fine and imprisonment in the discretion of the court; one-half of all such moneys collected from any fine imposed under this section shall be paid to the person or persons assisting in the arrest and conviction of the offender.

Section 4. This Act shall take effect from and after the date of its approval.

Approved this 1st day of May, A. D. 1929. W. R. Farrington, Governor of the Territory of Hawaii.

Program and Methods

The small amount of money allotted by the Territorial Government for the proposed investigations was insufficient to defray the expenses of chartering a ship and hiring a crew. The difficulty was overcome, however, when at the request of the Secretary of Commerce the Navy Department assigned the U.S.S. *Whippoorwill,* a mine sweeper stationed at Pearl Harbor, to assist the Bureau of Fisheries in a biological survey from July 15 to September 1, 1930. It was estimated that about four weeks would be spent in surveying Pearl and Hermes Reef, and that two weeks would be needed for reaching the place, visiting Midway Island, and returning to home port.

By the direction of the Commissioner of Fisheries the author was placed in charge of the expedition. It had been decided that money appropriated by the Territorial Government should be spent for hiring divers and buying such equipment as could be obtained at Honolulu. Scientific instruments comprising water bottles, reversing thermometers, hydrometers, titration outfit, set of hydrogen-ion indicators, plankton nets, meter wheels, and diving helmet were provided by the bureau. Traveling expenses of the author were also paid out of the bureau's regular appropriations.

On June 6, 1930, the author arrived at Honolulu, established headquarters at the Marine Biological Laboratory of the University of Hawaii, and began a survey of local waters with the view of ascertaining their suitability for the cultivation of pearl oysters. In a short time about two dozen pearl oysters of various sizes were found on one of the coral reefs in Kaneohe Bay, Oahu. The oysters collected there were used for a number of physiological experiments which were carried out in June and during the first half of July. It was found that adult oysters over 10 cm. long had ripe gonads and were easily induced to spawn in the laboratory aquaria. The presence of ripe pearl oysters in Kaneohe Bay was considered good evidence of the suitability of this body of water for the cultivation of the species. It was decided, therefore, to bring several hundred oysters from Pearl and Hermes Reef and to plant them near the island Mokualoe. For that purpose two tanks, built by the Navy Yard at Pearl Harbor, were installed on the deck of the *Whippoorwill.*

Preparations for the expedition were greatly facilitated and expedited by splendid cooperation received from the commanding officer, Lieut. M. M. Nelson, the officers, and the crew of the U.S.S. *Whippoorwill.* Generous assistance rendered by the Navy can be appreciated from the following list of supplies which were received from the Navy Yard at Pearl Harbor: lumber for construction of signals, 20 drums of gasoline, 25 empty drums for buoys, over 400 pounds of scrap iron for buoy anchors, iron wire, equipment for small radio station, 24 breakers for fresh water to be used in the camp, one drum of kerosene oil for lanterns and stove, and approximately 15 tons of ice which were placed in a large temporary ice box especially installed on the deck. Fresh provisions and stores for a period of 46 days were taken on board.

The Board of Agriculture and Forestry of the Territorial Government provided a 16-foot skiff, full camping outfit for a party of 10 men, and various fishing gear.

Previous to departure the vessel was fueled to capacity. The consumption of fuel oil, lubricating oil, and gasoline during the 6-week period was as follows: fuel oil, 69,323 gallons; lubricating oil, 290 gallons; and gasoline (for motor boats), 800 gallons.

The two motor boats which were used in surveying Pearl and Hermes Reef averaged 3.5 miles to 1 gallon of gasoline. It is estimated that both boats made about 2,800 miles.

Lieut. M. M. Nelson took great interest in the proposed investigation and offered to take personal charge of the hydrographic part of the program. His valuable assistance was very helpful and materially contributed to the success of the expedition. Besides the officers and the crew of the U.S.S. *Whippoorwill,* the personnel of the expedition consisted of the author, in charge of the expedition, N. S. Castle and John F. Reppun, assistants, and Leon Amboy and Anatolio Polo, native Filipino divers who were employed in 1929 by the Hawaiian Sea Products Co. and had a good knowledge of the location of the pearl oyster bottoms.

Upon arrival at Pearl and Hermes Reef the ship was anchored in 15 fathoms of water outside the lagoon off the western corner of the reef. Headquarters for field work were established in the buildings on Southeast Island (fig. 1), about 12 miles from the anchorage. Besides the scientific staff and the divers, the party living on the island consisted of officer's cook, mess attendant, radio operator, engineer, coxswain, and two seamen. Provisions, excepting fresh fish and turtles that were easily obtainable in the lagoon, and fresh water were supplied every other day from the ship. On July 22 the scientific equipment taken from the *Whippoorwill* was unpacked and put in order, all the preliminary work in fitting up the camp and laboratory was finished, and the party was ready to begin the survey.

While the scientific staff was occupied at this base Lieut. Nelson and his crew were at work making necessary astronomical observations, determining the exact position of the islands, and erecting the signals.

In order to complete the work in the short period of time allotted to the investigation it was necessary to carry out the biological part of the program independently of hydrographic surveying. Inasmuch as the determination of the location of stations constitutes a primary requirement of field work, the inability to plot this position at the time the biological observations were made caused considerable difficulty, which was aggravated by peculiar local conditions. The greatest portion of the bottom of the lagoon is covered by numerous coral reefs forming a labyrinth of barriers intersected by a few narrow passages. It often happened that boats used in the survey would circle for hours in search of a cut or opening in the reefs through which deep water could be reached. Under these conditions it was not always possible to estimate the location of the station by recording the course of the boat and the running time between the two given points. On the other hand, because of the considerable area of the lagoon and lack of prominent objects no bearings could be taken.

To overcome this difficulty the following method was adopted: the location of stations was marked either by buoys or by flags attached to sticks and pipes which had been erected on the reefs by the Hawaiian Sea Products Co. There were 13 stations (fig. 1), the location of which was identified by signals (tripods) erected by the hydrographic party, and 21 stations marked by buoys or sticks (fig. 1, circles). The position of 34 intermediate stations (fig. 1, dots) was estimated by running a boat at a known speed between two signals or buoys. Of course this was possible only in places where bottom conditions permitted steering along a straight course. After the hydrographic party had erected a series of 36-foot signals (fig. 1, triangles) and had set three of them in the middle of the lagoon, the location of some of the intermediate stations was determined by taking horizontal angles with a sextant. The location of all the tripods was accurately determined by Capt. Nelson's party. Following an established practice the signals were marked with flags of the international code and given the corresponding names that appear on the chart. The three signals placed in the middle of the lagoon (pl. 3, *A*) had platforms about 15 feet above the surface of the sea and were built sufficiently strong to sustain the weight of three men and astronomical instruments.

To determine the position of buoys and other marks the following procedure was used: after the party with the instruments was left on the platform of the tripod the boat would proceed to the stations, hoist the flag, and remain at the desired spot until a signal from the tripod would direct her to proceed farther. The position of the boat was determined from the tripod by taking bearings and ranges with compass and meter range finder. Obviously the results obtained by this method were less accurate than those usually expected in hydrographic surveying. However, under the circumstances this was the only practical method that could be used. It must be borne in mind that the primary purpose of the present survey was a biological study. No attempts were made, therefore, to prepare a complete map of the lagoon showing the exact configuration of the inside reefs, for the latter task would require a much larger crew and longer time than were at our disposal. It is believed that for the purpose of determining the location of pearl oyster bottoms the chart prepared by the expedition is sufficiently accurate.

A glance at figure 1 shows that stations where biological observations were made are rather uniformly distributed over the whole area of the lagoon with the exception of southwestern and southeastern corners occupied by extensive sand flats. It is therefore very doubtful that any important pearl oyster bottoms of the atoll have been overlooked.

Oceanographic and biological observations comprised daily temperature and salinity records, study of the distribution of temperature and salinity in the lagoon, determination of the character of the bottom, study of plankton, determination of the abundance of pearl oysters in various sections of the lagoon, and ecological observations on coral reef animals. Daily readings of temperature and salinity determinations of the surface water were made at 7:00 A.M. and 7:00 P.M. at the end of a small wharf at Southeast Island. The salinity was computed from hydrometer readings made with an instrument having a base 15:4° C. and graduated in 0.0002. Prior to departure from Washington the hydrometer was tested and certified by the U. S. Bureau of Standards which supplied the necessary correction table. Samples of water collected at other stations were kept in magnesia-citrate bottles and upon return of the expedition to Honolulu were titrated with silver nitrate solution with use of standard sea water for comparison. Several samples taken at Southeast Island were also titrated. The difference between the salinity figures computed from the hydrometer readings and obtained by chlorine titration did not exceed ± 0.02 parts per thousand.

Plankton samples were collected by means of qualitative plankton nets, one foot in diameter made of bolting silk No. 20 and No. 12.

On account of the character of the bottom the attempts to use a dredge were not successful. Samples of mud, bottom animals, and plants were collected almost exclusively by the Filipino divers who were able to dive to a depth of 40 feet. Other members of the expedition could not descend below 20 feet. The diving helmet was of little service on account of the steepness of the reefs and fragility of corals. High transparency of the water facilitated the examination of the bottom from the surface. Thus, at every station a large area was carefully explored by the author either by observing it through a glass-bottom box suspended from a slow-going skiff or by swimming over it and examining it through water-tight goggles firmly adjusted to the eyes.

The method employed in determining the abundance of pearl oysters is described on pages 36-40.

Acknowledgments

It is the author's privilege to express his appreciation to Lieut. M. M. Nelson, U.S.N., for his cooperation and valuable assistance rendered during the expedition and especially for his work in hydrographic surveying, astronomical observations, and determination of the location of stations.

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PEARL AND HERMES REEF

History

Pearl and Hermes Reef derives its name from two English whalers which on the night of April 26, 1822, were wrecked within 10 miles of each other near the eastern end of the atoll. According to the account of this disaster found in the Hawaiian magazine "The Friend" (October, 1876, vol. 25, no. 10, p. 86) the *Pearl* was first to run aground, and the *Hermes,* which was cruising in her company, met a similar fate in attempting to help her consort. The crews of both ships reached a small island located inside the lagoon and established a camp. After much labor and many hardships they built out of the wreckage a small, 30-ton vessel, named *Deliverance,* which they navigated safely to Honolulu.

In 1858 Capt. N. C. Brooks cruising on the U.S.S. *Gambia* visited Pearl and Hermes Reef and gave a brief description of the lagoon. The following is the excerpt of his report published in Honolulu by the "Advertiser" (August 18, 1859):

> This group is in lat. 27° 42′ N, long. 175° 48′ W. . . . . The group consists of 12 islands, surrounded by a reef 50 miles in circumference, on which the sea breaks heavily. It is open from the W. There is a lagoon inside, where I found from 5 to 15 fathoms, within 2 miles of the land. A vessel may approach from any point. The largest island, which bears E. by S. ½ S. from the entrance, may be approached within 2 miles safely. There is good anchorage outside from 8 to 12 fathoms on the N. W. side. Currents set to the N. and S. at the rate of 2 knots. Tide rises 24 inches—the prevailing winds being from the E.S.E.
>
> The largest islands are covered with coarse grass and trees. I saw the remains of the two wrecks, the keel, stem and stern post, with three iron tanks, still standing. I brought away a wooden mortar used by the party on shore. The remains of the camp still exist on the large island. I took possession of this group. A bank makes off the E. and N. for about a mile, and to the W. for several miles, with from 8 to 16 fathoms, with no dangers outside the breakers.
>
> Plenty of fish and turtle.

In 1867 Pearl and Hermes Reef was surveyed by the U.S.S. *Lackawanna* and in the following year a small chart drawn in natural scale 1:100,269 was published by the Hydrographic Office of the Navy. This chart gives the general configuration of the lagoon and shows the location of two islands (North and Southeast).

In 1912 chemical engineer Carl Elschner accompanied the cruise of the U. S. Cutter *Thetis* and visited Pearl and Hermes Reef. His attempt to reach Southeast Island (7)* was unsuccessful because "the shoal water in the lagoon to southwestward of this island made passage even in a boat impossible." He succeeded, however, in reaching North Island and was able to make several geological observations which led him to the conclusion that sand islands in the lagoon are undergoing continuous changes in their number, structure, and location. According to Elschner the elevation of North Island above sea level was 12 feet.

In April, 1923, Dr. Alexander Wetmore, in charge of the Tanager Expedition,† visited the lagoon for observation of bird life and collection of other material. A few soundings were made inside the lagoon by the hydrographic party of the expedition and two small islands, hitherto uncharted, were given the names of Grass and Seal Islands. The data were incorporated in the new edition of the charts of Pearl and Hermes Reef issued by the Hydrographic Office of the Navy.

Since 1927 Pearl and Hermes Reef has been the scene of intensive fishing activity carried on almost exclusively by the schooner *Lanikai* which was first owned by the Hawaii Tuna Packers Co. and later acquired by the Hawaiian Sea Products Co.

During the period of 105 years which elapsed between the discovery of Pearl and Hermes Reef in 1822 and the beginning of fishing for pearls in 1927, this remote and uninhabited lagoon attracted but little interest. A study of the Archives of the Government of Hawaii failed to disclose any reference to it in the official documents in which on several occasions the Government listed all its possessions. Thus, on May 16, 1854, Kamehameha III, King of the Hawaiian Islands, issued a manifesto proclaiming his neutrality in the war "now impending between the Great Maritime Powers of Europe." The manifesto gives a list of islands under the Hawaiian Crown but fails to mention Pearl and Hermes Reef. In 1856 the Hawaiian Government issued a circular addressed to the U. S. Commissioner, David L. Gregg, and to the representatives of the governments of Great Britain and France, which also lists the islands within the domain of the Hawaiian Crown. The name of Pearl and Hermes Reef does not appear on this list. It has been omitted in

* Numbers in parentheses refer to Bibliography, page 49.

† For an account of the itinerary and activities of the Tanager Expedition, see Report of the Director for 1923: B. P. Bishop Mus., Bull. 10, 1924.

the official report of the Hawaiian Commission (1898) appointed by President McKinley in pursuance of the "Joint resolution to provide for annexing the Hawaiian islands to the United States." The report includes, however, Kuré [Ocean Island], which constitutes the extreme western end of the Hawaiian archipelago.

On February 3, 1909, by Executive Order No. 1019, Pearl and Hermes Reef, together with many other outlying islands of the Hawaiian group, was included in a bird reserve which was placed under the control of the U. S. Department of Agriculture. On May 9, 1930, in response to the applications made by several parties, the following order regulating the use of the land in Pearl and Hermes Reef was issued by the Secretary of Agriculture:

Use and Occupation of Pearl and Hermes Reef, Hawaiian Islands Reservation, Under Permit of Governor of Hawaii. Order.

By virtue of authority vested in the Secretary of Agriculture by Section 10 of the Act approved February 18, 1929 (Pub. No. 770—70th Congress) entitled "An Act to more effectively meet the obligations of the United States under the Migratory Bird Treaty with Great Britain by lessening the dangers threatening migratory game birds from drainage and other causes, by the acquisition of areas of land and water to furnish in perpetuity reservations for the adequate protection of such birds; and authorizing appropriations for the establishment of such areas, their maintenance and improvement, and for other purposes," and otherwise, the following rule and regulation to permit the use and occupancy of Pearl and Hermes Reef within the Hawaiian Islands Reservation is hereby adopted, effective May 15, 1929.

Any person holding a permit from the Governor of the Territory of Hawaii to use or occupy any part of the land or formation protruding above the normal water level at said Pearl and Hermes Reef is hereby permitted to occupy or use such area so long as the conditions of this order, the law protecting wild animals and birds on national refuges, and the above-mentioned permit are faithfully observed.

Any building or buildings to be constructed under this authority or any operations conducted thereunder shall be located or confined to such area or areas as shall constitute the least possible necessary disturbance of the wild life frequenting or using the said Reef.

No dog or cat shall be maintained or harbored on the Reef by any permittee, nor shall any reptile, rabbit, wild animal, or bird, be introduced or liberated thereon, and it shall be cause for revocation of any permit granted hereunder for the permittee or his agent or employee to violate any of the provisions of Section 145 of Title 18 of the United States Code making it unlawful to hunt, trap, capture, willfully disturb or kill any bird or wild animal of any kind whatever or take or destroy eggs of any such bird on any lands of the United States which have been set apart or reserved as refuges or breeding grounds for such birds or animals by any law, proclamation, or Executive Order, except under authority of the Secretary of Agriculture, or to cut, burn, or destroy any grass or other natural growth on said area or any property of the United States thereon, in violation of law.

Upon the revocation of any permit hereunder the permittee shall abandon his operations and remove his equipment, buildings, or other property from the Reef, and failure to remove such property or buildings from the Reef within a period of six months after notification of the revocation of the permit by the Governor of Hawaii or the Secretary of Agriculture, or within such time as may be determined by the said Governor or Secretary, such equipment, buildings, or other property shall be deemed to have been abandoned by the permittee and shall become the property of the United States to be disposed of as it may determine.

The conditions of this order shall be deemed to be a part of every permit issued by the Governor of Hawaii authorizing any use or occupancy of Pearl and Hermes Reef.—Signed by R. W. Dunlap, Acting Secretary.

It will be observed that this order refers exclusively to the land and concerns itself only with the protection of vegetation and birds. The fisheries are entirely under the jurisdiction of the Hawaiian Government.

DESCRIPTION

GEOGRAPHY

According to the chart of the Hydrographic Office of the Navy, Pearl and Hermes Reef is located between the latitudes 27° 46′ 30″-27° 56′ 30″ N., and longitudes 175° 45′-176° 01′ W. Observations made during the present survey give the position of the reef between the latitudes 27° 44′ 30″-27° 58′ 00″ N. and longitudes 175° 42′-175° 59′ W. One can notice from the chart (fig. 1) that the reef is a typical atoll of irregular oval shape, the long axis of which extends in a northeasterly direction. The atoll is 17 miles long, 10 miles wide, and measures about 43 miles along the circumference. There are in the lagoon four islands (North, Southeast, Grass, and Seal), covered with scanty vegetation represented mainly by a grass, *Eragrostis variabilis* (Gaudichaud) Steudel, and a number of low and barren sand islets and bars. Nearly all the islands and bars are found in the eastern and southern sections of the lagoon just inside the encircling outer reef.

Southeast Island, located close to the boat channel, can be easily reached by shallow draft craft. Other islands, surrounded by extensive shoals and numerous reefs, are more difficult to approach.

According to determinations made by Lieutenant Nelson, Southeast Island is in latitude 27° 46′ 58″ N., longitude 175° 47′ 56,7″ W. North Island is in latitude 27° 55′ 24,5″ N., longitude 175° 43′ 33,4″ W. At both places the observations refer to spots where signals were erected (fig. 1).

Southeast Island is about half a mile long and less than a quarter of a mile wide. There is a slight depression in the eastern section of the island which after a rain retains some fresh water. However, on account of the porosity of the ground the water disappears very quickly. Several attempts to dig the ground with the hope of finding a water-bearing stratum were fruitless, for sea water of the salinity equal to that of the lagoon appears even at a depth of 3 feet below the surface. Those who stay on the island are therefore entirely dependent on rain water or on the supply which was brought along from the ship.

The islands are nearly completely devoid of trees or shrubbery with the exception of a few ironwood (*Casuarina* sp.) trees which were planted here in

1928 and are growing quite well. Attempts to introduce the coconut palm were unsuccessful and all small trees planted in 1928-29 were in 1930 either dead or dying.

The lagoon is separated from the ocean by a strip of coral reefs about 250 yards wide over which the sea breaks very heavily (pls. 1, *B*, 2, *A*). The reefs form a nearly continuous line which embraces approximately two-thirds of the lagoon, leaving its northwestern side open. Here one finds several scattered groups of corals with the depth of water between them ranging from 1 to 15 fathoms. At the southern side there are two entrances with a minimum depth in the channel ranging from 1.5 to 3 fathoms. The depth inside the lagoon ranges from 1 to 104 feet. The greatest lagoon depth was found in the northeastern section of the lagoon near station 78.

The bottom of the lagoon is densely covered with numerous coral reefs, some narrow and long, extending for 2 or 3 miles in a general meridional direction, and others forming miniature atolls which in configuration resemble the main lagoon. The presence of the reefs inside the lagoon can be noticed by the discoloration of the water which in the areas surrounded by coral growth appears to be of much lighter color than in the channels and over the bars. Some idea of the abundance of small reefs can be gained from the observation made on an exceptionally clear and calm day near the signal "Neg" (pl. 3, *A*) where from the bow of the anchored motor boat 35 different reefs were counted. Assuming that the visibility from an elevation of 5 feet (the position of the eye above the level of the sea) was 2.5 miles, the area in question was not greater than 19.6 square miles. It is probable that many reefs were overlooked and that the actual visibility was less than it has been assumed here. Some of the small atolls were of perfect circular shape measuring from 200 to 350 feet in diameter.

All the reefs inside the lagoon had a shallow central portion surrounded by a fringe of living corals. In their central parts the depth varies from 3 to 8 feet and the bottom is covered with a thick layer of soft coral sand. The outer slopes of the reefs, made of living corals, extend very steeply to the depth of 50 and sometimes 60 feet. At 60 feet and below the bottom is covered with a very fine and sticky mud which smothers the corals. With the exception of Foraminifera very few bottom organisms were found in it.

According to the prevailing character of the bottom the entire lagoon can be divided roughly into two sections. The central and northern parts of it are occupied by coral reefs. Along the eastern and southern portions sandy bottoms extend. This distribution in general coincides with the distribution of pearl oyster banks shown in figure 8 in which all the reefs where pearl oysters were found are represented by circles containing black areas.

Sand bars shown on the chart (fig. 1) are subject to considerable changes depending on the action of wind and waves. After the two days of moderate storm which blew on August 7 and 8, there were noticeable changes in the configuration of some of them and several new bars appeared near the southern entrance to the lagoon. The fact that most of the islands and bars follow the southern arch of the encircling reef is apparently due to the action of waves and the prevailing northeastern winds. Under their pressure loose coral sand which forms the bars and the islands shifts very easily.

There are in the northeastern section of the lagoon several rocks which stood up approximately 5 feet above the water (fig. 1, station 42 near North Island; pl. 2, *B*). The determination of their elevation was made at 2:00 P.M. on August 18, 1930. According to the tide table high water (+ 1.9 feet) and low water (+ 0.1 feet) occurred on this day at 9:32 A.M. and 1:24 A.M. respectively. At 2 P.M. the water was probably at + 1.4 feet level. Inasmuch as the highest tide does not exceed 2.4 feet one can conclude that the top of the rocks is about 4 feet above the highest tide mark.

In their shape and general configuration these rocks, made of coral limestone, greatly resemble the present encircling reef, from which they are separated by a few hundred yards of shallow water. The presence of such rocks, which in the literature on coral reefs have received the name of "horses," has been recorded in many atolls of the Pacific and Indian oceans (see Gardiner, 10). Since there is no evidence of present-day formation to account for their position it is necessary to postulate either the elevation of the reef or small changes in the level of the surrounding ocean. On account of the destruction of limestone by weathering and wave action an accurate determination of the emergence of coral land is impossible. However, the lowering of the ocean has been recognized in numerous localities, as, for instance, Tutuila, Samoa, Society Islands, Mauritius, the Seychelles, and many other places. These and similar observations were used by Daly (3-6) in support of his well-known glacial control theory of coral reef formation.

CORALS

The outer reef of Pearl and Hermes lagoon consists of large colonies of corals which form a strong barrier (pls. 1, *B*, 2, *A*) reinforced by lime deposited by coralline algæ. The latter fill up the spaces between the interlocking branches of the corals and cover the whole structure with a thick layer of lime. In the middle of the barrier one finds solidified limestone rocks standing up a few inches above the sea level. Their surface is greatly eroded by constant pounding of the surf and in many places is densely covered by large barnacles. On account of heavy seas that break over the reef an examination of its outer rim is a dangerous and difficult undertaking which could be carried out only on exceptionally calm days. Even under the most favorable weather conditions it was difficult to approach the outer reef from the outside. Hence, with a few exceptions our observations were confined to a study of the inside and middle portions of the barrier. The barrier is intersected with a maze of narrow passages through which the water runs with great velocity, but there are numerous caves and sheltered places which afford an opportunity for collecting and examination.

Of several species of corals found in the lagoon, the most important reef builders are undoubtedly *Porites lobata* Dana, *P. lobata* forma *Centralis* subforma *Alpha* Vaughan, *P. compressa* Dana, and *Pocillopora ligulata* Dana. These species were found in great abundance both on the outer reef and on numerous small reefs growing inside the lagoon. Other common forms found in the lagoon comprise the following species: *Pocillopora damicornis* variety *cespitosa* Dana, *P. meandrina* variety *nobilis* Verrill, *Montipora verrucosa* Lamarck, *M. verrilli* Vaughan, *M. tenuicaulis* Vaughan, *Pavona varians* Verrill, *Cyphastrea ocellina* Dana. Beautiful red-colored *Dendrophyllia manni* Verrill, quite common on the reefs of Oahu, was found only at two stations. Mushroom coral, *Fungia scutaria* Lamarck, occurred at nearly all the reefs which were examined.

ALGAE

With the exception of Corallinaceae, whose rôle in reef building is equal to if not greater than that of the corals, the algæ are not abundant. Single specimens of *Halimeda* were found very often, but they never formed large colonies. In several places rocks and dead corals were covered with a green blanket of *Codium*. Large amounts of this alga were also discovered in the stomachs of turtles, *Chelonia mydas,* which apparently subsisted on it.

SPONGE

Large colonies of black horny sponge *Euspongia,* the fibers of which are of a soft texture rendering them useless for practical purposes, were present on every reef.

MOLLUSKS

Although mollusks were abundant they did not form large communities, and therefore failed to contribute to the building up of the reefs. The following were the most common species occurring at nearly every reef: *Conus litteratus* variety *millepunctatus* Lamarck, *Conus ebraeus* Linnaeus, *Spondylus tenebrosus* Reeve, *Arca ventricosa* Lamarck, *Pedalion costellatum* Conrad, and *Tonna melanostoma* Jay.

In August the cones were depositing their eggs in large white capsules, about 1 inch long, which they attached to the reefs and shells. In deeper water in the northern section of the lagoon we succeeded in obtaining a few live specimens of a large conch, *Cymation tritonis* Linnaeus. Dead shells of this large gastropod, more than 1 foot long, are often found on the beaches inside the lagoon, but the live animal is rather scarce. The stomachs of these snails contained the remnants of large starfishes.

A few specimens of cowrie shells, *Cytherea sulcidentata* Gray, an endemic Hawaiian species, were collected only at one station inside the lagoon.

The Pearl oyster *Pinctada galtsoffi* Bartsch, was found growing attached to the slopes of the coral reefs. Observations on distribution and life history of this species are described in a separate chapter.

The pencil shell *Terebra maculata* Linnaeus is one of the few large bottom organisms that inhabit sandy bottoms. Large numbers of this mollusk were collected on the shoals in the southern section of the lagoon. The animal is always found buried in the sand at one of the ends of a long burrow which marks his progress over the bottom. Only dead shells are found lying on the surface of the sand.

CRUSTACEANS

The crustaceans are very abundant. Innumerable crabs inhabit the coral reefs, finding shelter in coral rocks and between the branches of the corals. The collection brought by the author and identified by Dr. Mary J. Rathbun and W. L. Schmitt comprised over 50 species. Mention should be made here of large hermit crabs, *Dardanus deformis* M. Edwards, *D. gemmatus* M. Edwards and *D. sanguinilentus* Quoy and Gaimard, which were collected at night from the wharf at Southeast Island. All these crabs were found in the shells of *Tonna*.

Every night the beaches on the island are invaded by millions of ghost crabs, *Ocypode laevis* Dana, which disappear with the approaching dawn. Under old coral rocks and in other well-protected places large lobsters, *Panulirus japonocum,* are very abundant.

HOLOTHURIANS

The dimensions and shape of the atoll are to a great extent determined by the balance maintained between the constructive reef-building organisms and the several agents which tend to destroy the reef. Limestone rocks formed by corals and other reef builders are constantly being broken by the pounding and grinding action of the waves (pl. 2, *A*). Lime is gradually dissolved by the chemical action of the sea water. Small fragments of corals and limestone are reduced to sand and mud by the activity of numerous organisms that ingest them. Mechanical destruction caused by the waves is greatly facilitated by various boring animals that live in the rocks and weaken their structure.

In Pearl and Hermes Reef the principal biological factors responsible for the reduction of coral fragments into sand and mud are undoubtedly holothurians. Millions of these large and sluggish animals are found everywhere, on the inside reefs as well as in the middle of small lagoons and on sandy bottoms. Out of eight species collected in the lagoon the most abundant was *Holothuria atra* Jaeger, which was observed at nearly every station but was especially conspicuous on the white background of sandy bottom. These black and large animals, nearly 2 pounds each in weight and about 1 foot long, are continuously passing sand through their digestive tracts reducing it into fine mud which is deposited on the bottom. Enormous quantities of extruded masses of this sandy mud still having the shape of the intestine through which they had passed were found everywhere on the bottom and could easily be recognized.

Observations of Gardiner (10) on the holothurians of Hulule, Maldives Islands, show that the gut of an average specimen contains about 88 grams of sand and that half of this amount is passed daily, the intestines always being refilled during the night. The result of the activity of millions of animals which triturate sand and coarse fragments in mud cannot be overemphasized. Fine coral mud discharged by them is either deposited in deep water between the coral reefs or is carried away by the outgoing tide and settles on the bottom of the open ocean. Besides *Holothuria atra* the following species were rather common: *Holothuria difficilis* Semper, *H. paradoxa* Selenka, *H. pervicax* Selenka, *H. pardalis* Selenka, *H. fiscorubra* Theel, *H. monacaria* Lesson, *H. impatiens* Forskål. Edible bêche-de-mer, *Holothuria edulis* Lesson, which occurs on Oahu and is an important fishery product in the Orient, has not been found in Pearl and Hermes Reef.

SEA URCHINS, STARFISH, AND BRITTLE STARS

Feeding habits of sea urchins are similar to those of the holothurians. They also ingest sand, but their rôle in the formation of coral mud is undoubtedly of less importance. The following species were recorded in Pearl and Hermes Reef: *Heterocentrotus mammilatus* Brandt, *Brissus latecarinatus* Leske, and *Echinometra mathaei* de Blainville. The latter species with very long black spines is very common in shallow water and along the shores of the islands inside the lagoon. The animal is decidedly nocturnal in its habits; with the onset of darkness thousands appear along the shores, in places nearly completely hiding the bottom with their bodies. During daytime only a few could be found under the rocks and in small caves. The slate-pencil sea urchin, *Heterocentrotus mammilatus*, was very common in Pearl and Hermes Reef. It was found exclusively on live colonies of corals, where its red-colored body sitting in a small cave had the appearance of a fantastic tropical flower.

Starfish were represented by small *Lynkia multipora* Lamarck, very common on nearly every reef, and *Acanthaster planci* Linnaeus. One large specimen of *Luidia magnifica* Fisher, measuring 33 inches in diameter, was collected from the bottom at a depth of 25 feet.

The most common brittle star found in the lagoon belonged to the species *Ophiocoma insularia* Lyman.

JELLYFISH

No jellyfish were found in the daily collections made inside the lagoon, with the exception of *Charybdea alata* Reynaud, which on August 18 appeared in great numbers near Southeast Island and caused considerable discomfort to our divers. According to Dr. H. B. Bigelow, who identified the specimens, they agree very closely with the medusæ that Meyer (14) described as variety *Moseri*.

BIRDS

The islands inside the lagoon serve as nesting places for large and noisy colonies of birds (pl. 1, *A*.) During our stay on Southeast Island the following species were seen in large numbers: *Sterna fuliginosa* Gmelin (sooty tern); *Puffinus cuneatus* Salvin (wedge-tailed shearwater), *Sula sala* (Linnaeus) (booby), *Sula cyanops* Sund (blue-faced booby), *Fregata aquila* Linnaeus (man-o'-war bird), and *Diomedea immutabilis* Rothschild (Laysan albatross). On the day of our arrival at Southeast Island, July 23, we saw several hundred young albatross which had apparently been abandoned by their parents. In spite of their large size the youngsters were unable to provide themselves with food and were dying at an appalling rate. In about four weeks all of them were dead. Our attempts to feed them mullet were entirely unsuccessful; the birds refused to accept this food which they were unable to digest. Apparently they subsist entirely on young squid which is brought by their parents (see Fisher, 8).

SEALS

On every island and sand bar was a small herd of seals, *Monachus shauinslandi*. Altogether we counted 68 seals living in the lagoon.

FISH

Lack of time did not permit obtaining a full collection of the fishes that abound in the lagoon. A few most common species were, however, preserved. According to I. Ginsburg, who identified them, the collection comprised the following species: *Lycodontis meleagris* (Shaw and Nodder), *L. kidako* (Schlegel), *Jenkinsiella mcgregori* (Jenkins), *Ophichthus poly-*

ophthalmus Bleeker, *Belone platyura* Bennett, *Platophrys pantherinus* (Rüppell), *Atherina insularum* Jordan and Evermann, *Mugil cephalus* Linnaeus, *Priacanthus hamrus* (Forskål), *Kyphosus fuscus* (Lacépède), *Cirrhites marmoratus* Gill, *Caranx cheilio* (Snyder), *Thalassoma umbrostigma* (Rüppell), *Thalassoma purpureum* (Forskål), *Thalassoma ballieui* (Vaillant and Sauvage), *Coris flavovittata* (Bennett), *Coris lepomis* Jenkins, *Lepidaplois bilunulatus* (Lacépède), *Hepatus triostegus* (Linnaeus), *Zebrasoma veliferum* (Bloch), *Chaetodon fremblii* Bennett, *Chaetodon miliaris* Quoy and Gaimard, *Caracanthus maculatus* (Gray), *Calliurichthys decoratus* Gilbert, *Gobiichthys lonchotus* (Jenkins), *Salarias marmoratus* (Bennett), *Spheroides hypselogenion* (Bleeker), *Diodon holocanthus* Linnaeus, *Ostracion fornasini* Bianconi, *Antennarius commersonii* (Shaw), *Sebastapistes* species.

TEMPERATURE OF THE WATER

The temperature data obtained during the work at Pearl and Hermes Reef comprise the records of surface temperature taken twice a day at 7:00 A.M. and 7:00 P.M. at Southeast Island and the readings made at various times at

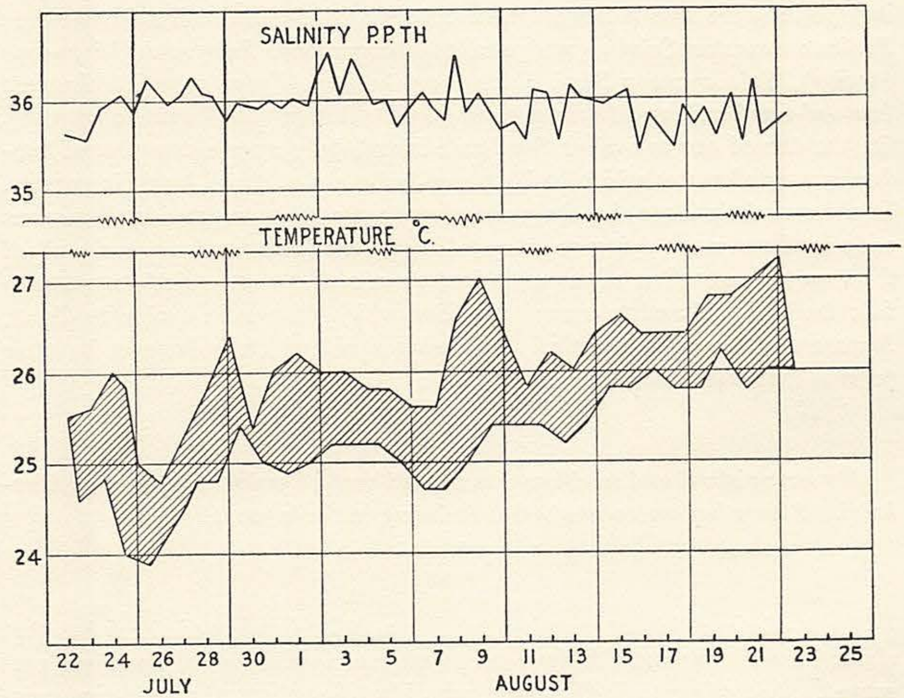

FIGURE 2.—Graph showing daily temperature and salinity of surface water at Southeast Island: upper line of the cross-hatched area represents readings made at 7 A.M; lower line, at 7 P.M.

every station in the lagoon. Daily observations were continued during a 31-day period from July 23 until August 22. The results of the observations, presented in figure 2, show that there was a gradual upward trend of water temperature which increased from about 25° C. in July to about 26.5° by the end of August. Morning readings were always lower than those taken in the evening, the difference, represented in the figure by a cross-hatched area, remaining with slight fluctuation nearly constant throughout the period of observations. It is quite possible that daily fluctuations exceeded those shown in figure 2, because in a shallow body of water the maximum daily temperature is usually reached early in the afternoon. The temperature observed at various stations (fig. 4, Table 1) varied from 22.7 to 27.9° C. It is of interest to note that temperatures below 24° C. were recorded only five times —on August 14, stations 74, 75, and August 16, stations 84, 85, and 88.

Table 1. Temperature and Salinity of the Water at Pearl and Hermes Reef, 1930.

(Location of stations indicated on the chart, fig. 1.)

Station Number	Depth in Feet	Bottom	Date July	Time	Level in Feet	Temperature Degrees C.	Salinity, Parts per Thousand
28	67	Coral, sand	July 20	1:33 P.M.	0	26.2	
					67	25.2	34.83
31	23	Coral, sand	July 23	10:45 A.M.	0	25.5	35.12
					20	25.2	34.49
32	6	Coral	July 23	1:00 P.M.	0	24.9	35.25
33	31	Sand	July 23	2:00 P.M.	0	25.6	35.07
					31	24.7	35.08
34	12	Coral reef	July 24	9:55 A.M.	0	26.5	35.00
35	19½	Coral, sand	July 24	11:02 A.M.	0	25.0	35.96
					19½	24.9	34.63
36	21	Coral	July 24	1:03 P.M.	0	25.6	35.61
					21	25.3	34.54
37	9	Coral, sand	July 24	2:47 P.M.	0	26.5	34.76
					9	26.2	34.87
38	6	Coral, sand	July 25	9:40 P.M.	0	24.8	35.61
39	2	Sand	July 25	10:15 A.M.	0	26.5	
40	1-2	Coral	July 25	2:00 P.M.	0	25.2	35.44
41	5	Broken coral	July 26	10:20 A.M.	0	25.2	35.20
42	2-4	Coral rocks	July 26	3:40 P.M.	0	24.8	
43	1-5	Reef	July 26	12:30 P.M.	0	25.7	35.30
44	16	Coral	July 28	10:20 A.M.	0	25.7	34.70
					15	25.2	36.43
45	15	Coral	July 28	11:30 A.M.	0	25.8	35.70
					15	25.8	35.20
46	16½	Coral	July 28	1:30 P.M.	0	26.2	35.55
					15	26.1	35.78
47	31	Coral rocks	July 28	2:05 P.M.	0	26.0	35.70
					31	25.4	35.44
48	12	Coral, sand	July 28	2:51 P.M.	0	25.6	35.70
					12	25.4	35.30
49	4	Sand	July 29	8:48 A.M.	0	25.2	35.28
50	5	Sand	July 29	10:05 A.M.	0	26.2	35.75

(Table 1—Continued)

Station Number	Depth in Feet	Bottom	Date July, Aug.	Time	Level in Feet	Temperature Degrees C.	Salinity, Parts per Thousand
51	7	Sand	July 29	11:05 A.M.	0	25.5	35.07
52	2	Sand	July 29	12:05 P.M.	0	25.9	35.92
53	6	Sand	July 29	2:07 P.M.	0	26.5	35.81
54	6	Coral	July 30	10:50 A.M.	0	26.1	34.51
55	18	Coral	July 30	11:57 A.M.	0	26.4	35.39
					16	25.6	35.39
56	8	Coral, sand	July 30	1:37 P.M.	0	27.6	35.12
57	6	Coral, sand	July 30	2:31 P.M.	0	26.7	
58	44	Fine sand	July 31	9:13 A.M.	0	25.8	35.17
					42	25.6	35.17
59	14½	Coral, sand	July 31	10:10 A.M.	0	26.4	35.17
					14	26.3	35.21
60	24½	Coral, sand	July 31	11:22 A.M.	0	26.6	34.99
					24	26.2	35.12
61	33	Coral	July 31	1:15 P.M.	0	26.6	35.34
					30	26.4	35.44
62	22½	Coral rocks	Aug. 1	9:05 A.M.	0	25.8	35.21
					23	25.6	35.50
63	18	Sand, few corals	Aug. 1	9:53 A.M.	0	26.4	35.03
64	15	Coral	Aug. 1	11:08 A.M.	0	25.8	34.97
					14	25.6	35.34
65	8	Sand, coral	Aug. 1	12:56 P.M.	0	26.1	
66	22	Sand, coral	Aug. 2	9:55 A.M.	0	26.3	34.90
					22	26.2	35.26
67	51	Sand	Aug. 2	11:19 A.M.	0	26.6	34.88
					50	25.8	35.34
68	10	Sand, coral	Aug. 2	1:17 P.M.	0	26.4	35.64
70	7	Sand, coral	Aug. 4	12:00 M.	0	25.2	34.92
71	28	Coral	Aug. 5	10:02 A.M.	0	26.2	35.17
					28	26.0	
72	15	Sand, coral	Aug. 5	11:37 A.M.	0	25.9	35.64
73	19	Sand, coral	Aug. 9	9:40 A.M.	0	26.0	35.48
					19	25.2	35.62
74	5	Coral	Aug. 14	10:47 A.M.	0	23.0	35.12
75	15	Coral, sand	Aug. 14	11:49 A.M.	0	23.4	
76	?	Coral	Aug. 14	2:20 P.M.	0	25.3	
77	15	Coral	Aug. 14	3:29 P.M.	0	25.4	
64	64	Soft mud	Aug. 15	9:30 A.M.	0	25.0	
					64	24.1	
78	98	Soft mud	Aug. 15	11:00 A.M.	0	27.5	
					97	25.9	
79	?	Coral	Aug. 15	11:32 A.M.	0	27.3	
80	7½	Coral, sand	Aug. 15	1:29 P.M.	0	27.6	
81	12	Coral	Aug. 15	2:55 P.M.	0	27.6	
82	4	Coral	Aug. 15	3:48 P.M.	0	27.9	
83	15	Coral	Aug. 16	12:36 P.M.	0	25.3	
84	?	Sand, coral	Aug. 16	1:06 P.M.	0	22.7	
85	?	Sand, few corals	Aug. 16	1:43 P.M.	0	23.2	
86	?	Coral, sand	Aug. 18	9:56 A.M.			
88	?	Coral, sand	Aug. 18	11:53 A.M.	0	23.5	
89	?	Sand	Aug. 18	12:15 P.M.	0	27.1	
90	5	Coral, sand	Aug. 21	10:11 A.M.	0	26.5	
91	24	Sand, coral	Aug. 21	11:00 A.M.	0	26.8	
92	10	Sand	Aug. 21	11:55 A.M.	0	26.7	

The temperature at the bottom of the lagoon differs but slightly from that in the surface layer of water, with the exception of one deepest place (station 78, 98 feet) where a difference of 1.6° C. was recorded; at all other stations the water at the bottom was only a fraction of a degree C. cooler than at the surface.

From a biological point of view it is of interest to know the extent of annual fluctuations in the temperature of the water. According to the statement made by Captain Anderson, who had spent several winter months at Pearl and Hermes Reef, the temperature of the water drops to 50° F. (10° C). It was, however, impossible to ascertain the accuracy of this observation. Some idea of the average monthly temperatures in the vicinity of Pearl and Hermes Reef can be obtained from the figures published by K. Tsukuda (21), and based on observations made during a 10-year period by Japanese vessels plying between Japan and the United States. They refer, of course, to the high seas. The Japanese data (fig. 3) show that in the area near Midway Island, lying between latitudes 26°-30° N, and longitudes 175°-179° W. the average monthly temperature varied from 18° in March to 25.1° in September. The corresponding fluctuations near Honolulu are from 22.5°

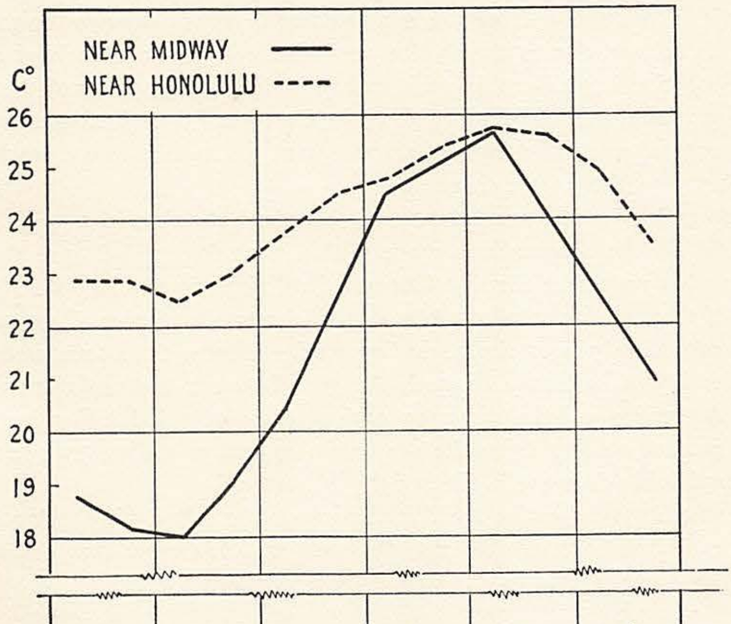

FIGURE 3.—Graph showing mean monthly temperature of the surface water of the ocean near Midway Island and Honolulu, based on observations made by Japanese steamers.

to 25.2°. Of course the minimum temperature in shallow lagoons can be considerably lower than the monthly average.

SALINITY

Daily observations of surface salinity were recorded at the Southeast Island simultaneously with the temperature readings, and at every station where biological observations were made samples of surface and bottom water were obtained and reserved for titration. From an examination of figure 2 (upper line), representing the results of daily salinity observations made at 12-hour intervals, one can notice that there was no definite trend in the salinity curve which fluctuated between 35.6 and 36.6 parts per thousand. For a greater part of the period of observations it remained close to 36 parts per thousand. There was no definite correlation between the salinity of the water and the time the sample was taken. The fluctuations shown in figure 2 were undoubtedly due to local showers, evaporation of water in the lagoon, and greater or smaller influx of ocean water.

The distribution of salinities at the surface of the lagoon is shown in figure 4. It will be noticed that high salinity figures almost invariably occur at the stations located far from the entrances or in places close to the sand bars and reefs, where, due to the shallowness of the bottom and lack of currents the evaporation is presumably greater than in the open sections of the lagoon. The distribution of salinities presented in the chart (fig. 4) suggests that the ocean waters enter the lagoon primarily at its northwestern corner and through the southern boat channel.

It must be borne in mind, however, that the isohalsines drawn in figure 4 are based on the observations made within a 31-day period and, therefore, only roughly represent the distribution of salinities in the lagoon. There is no doubt that salinity is affected by winds, currents, and size of waves which break continuously over the encircling reef. Hence, the ocean waters may enter the lagoon not only through the gaps between the reefs but at other points depending on the direction and velocity of wind. For instance, a strong current coming from the sea was observed at station 70 where there was a noticeable decrease in the salinity of water.

Present observations on the distribution of the salinity in the lagoon confirm the observations of Captain Anderson and his crew that ocean water enters the lagoon primarily through its northwestern corner.

TIDES

The tidal range at Pearl and Hermes Reef is about 2 feet. According to the chart of the Hydrographic office of the Navy the tides set north and south and have a velocity of 2 knots. It has been observed that inside the lagoon the direction of tidal currents is rather complex depending on the configuration of the reefs. On account of lack of time no current meter readings were made.

THE HAWAIIAN PEARL OYSTER

Description

The Hawaiian pearl oyster belongs to the group of subgenus *Margaritifera* (*Pinctada*) which according to Jameson (12) is characterized by the absence of hinge teeth. This large and not well defined group of pearl oysters comprises two species, *Margaritifera margaritifera* Linnaeus and *Margaritifera maxima* Jameson. The former species is distinguished from *M. maxima* by its greater convexity and shortness of the hinge, which measures but little more than half the length of the nacreous surface of the valve, from the anterior to the posterior margin. Jameson divides the Linnean species *M. margaritifera* into six different "geographical races" recognized in the trade under the names of Fiji shell (variety *typica*), Bombay shell (variety *persica*), so called because it is shipped via Bombay from the Persian Gulf, Zanzibar or Madagascar shell (variety *zanzibarensis*), Egyptian shell (variety *erythrensis*), Tahiti shell (variety *cumingi*), and Panama shell (variety *mazatlanica*). He states that pearl oysters from Hawaii, together with exceptional individuals of variety *typica* in the collection of the British Museum, are intermediate between the *M. margaritifera mazatlanica* and the Linnean type. The geographical races or varieties described by Jameson differ markedly from one another and are easily recognizable even by an inexperienced observer. There is but little doubt that they represent distinct species.

Two principal species of pearl oysters occurring in North Australia and the Philippine Islands are commonly known as the "black-lip" oyster, *Margaritifera* (*Pinctada*) *margaritifera*, and the "gold" or "silver-lip" oyster, *Pinctada maxima*. The two species are easily distinguished by the color of the outer margin of their nacre and by the difference in their size, *Pinctada maxima* being the largest and weighing as much as 7 pounds. The pearl oyster from Hawaii (pls. 4, 5, *A*), although slightly resembling *Pinctada maxima* by the yellow edge of the shell and its large size, can at once be distinguished from it by the short and more oblique hinge. Its deeply folded byssal notch and short hinge bear some resemblance to *Pinctada margaritifera*, from which it is distinguished by its greater size and the lighter color of the outer margin of the nacre. On the basis of these differences Dr. Paul Bartsch (1) of the U. S. National Museum regarded the Hawaiian pearl oyster as a distinct species which he named *Pinctada galtsoffi*. His complete description of this species follows:

Shell large, varying in shape from irregularly ovate to subquadrate, rather compressed. Hinge oblique, rather short and deep; byssal notch of the right valve deeply infolded. The outside of the shell is much laminated. In old shells, like the type, these laminations do not show the fimbriations at the free border present in young individuals. The outside is covered by a yellowish-olive periostracum. The nacre of the inside is lustrous silvery pearly gray, with a bluish tinge sometimes bordering on purple near the edge in old shells, as in the type. The outer margin in the type is yellowish horn-colored. In young specimens a band near the edge of the nacreous portion may be gold green with a greenish tinge or smoky with a greenish suffusion and decidedly iridescent. The marginal border in young individuals may be brown, variegated with radiating bands of darker brown or the edge may be quite deeply smoke gray or almost sooty black. Adductor muscle scar large, a little paler than the rest.

In the collection of more than 200 shells from Pearl and Hermes Reef, Midway Island, and Kaneohe Bay, Oahu, the color of the marginal border of the nacre changes from dark brown and sometimes almost sooty black in the young specimens to greenish purple and yellowish in the adults.

Distribution

Pinctada galtsoffi is apparently widely distributed in the Hawaiian archipelago. Collections of the National Museum in Washington and Bernice P. Bishop Museum in Honolulu contain specimens from the islands of Oahu, Molokai, Kauai, Hawaii, Maui, and Niihau. Some of these shells are listed under the names of *Meleagrina pallida* Conrad, or *Pinctada cumingi* Reeve. The latter species is a synonym of *Margaritifera margaritifera* variety *cumingi*. A comparison between the Tahitian shell (variety *cumingi*) and Hawaiian species leaves no doubt that they are two different species. *Pinctada cumingi* is characterized by its deep glossy color of the shell and a nacre steely in lustre with a very broad, dark, metallic green border. The brief description of *P. pallida* and absence of the type makes it impossible to compare this species. According to Jameson (12), "Species of this kind [as *M. pallida*] based upon unlocalized, immature and scanty material, can have no scientific value, and only a historic interest."

Although the Hawaiian pearl oyster was found on several islands between Hawaii and Midway it occurs in large numbers only on Pearl and Hermes Reef. So far no other locality has been discovered where it could be fished on a commercial scale.

Size and Weight of Shells

The Hawaiian pearl oyster reaches a large size and its shells are heavy. According to verbal statement made to the author by Captain Anderson, many oysters weighing about 10 pounds were taken in 1928-1929 from Pearl and Hermes lagoon, the largest shell found by the fishermen weighing as much as

15 pounds. Unfortunately its length and width have not been recorded. During the survey of the lagoon in 1930 the author collected 164 adult (sexually mature) oysters and 33 small ones (seed) attached to the shells of the adults (pl. 4). The adult oysters varied in size from 10 to 29 cm.; the small ones measured from 0.03 to 5.9 cm. In the following discussion, which refers only to the oysters collected in Pearl and Hermes Reef, the length (L) is regarded as the greatest dorso-ventral distance measured at right angles to the hinge. The width (W) is the greatest antero-posterior distance across the shell measured at right angles to the length. Both length and width were measured to the nearest half centimeter. The weights of the shells were read to the nearest gram. Before weighing, the shells were scraped and all foreign material was removed. Then the shells were allowed to dry for several days at room temperature. In measuring and weighing small oysters the second decimals of centimeter and gram were read. The figures of weight refer to the total weight of both valves.

For a biometrical study the data were grouped in classes of 2-centimeter intervals. It will be noticed from an examination of frequency polygon (fig. 5) that specimens measuring from 18 to 22 centimeters were predominant, that small oysters from 6 to 9.9 centimeters were absent, and young

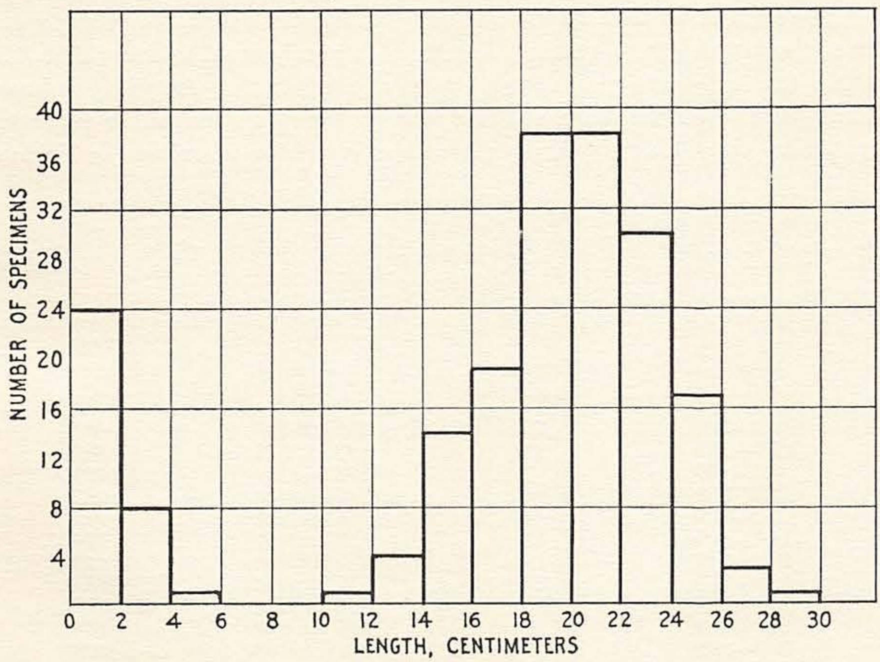

FIGURE 5.—Graph showing frequency distribution of the length of shells of *Pinctada galtsoffi* collected in Pearl and Hermes Reef.

oysters between 10 and 14 cm. long were scarce. Absence of small oysters (from 6 to 9.9 cm. long) and a relative abundance of the smallest specimens (less than 2 cm. long) can be explained by assuming that spawning and setting at Pearl and Hermes Reef takes place in July and August, at which time the material was collected. By this time 1-year-old oysters, those that were spawned in the summer of 1929, were already over 10 cm. long. This conclusion is corroborated by our observations that in July and August, 1930, all the adult oysters (over 10 cm. long) had ripe gonads and could be induced to spawn in the laboratory, and that a number of small oysters (spat) only several millimeters in length were found attached to the shells of the adults. Thus, the bimodal curve of frequency distribution can be interpreted as representing seasonal conditions when the young oysters have just attached themselves and the older ones have already reached 10-centimeter size.

The conclusion that 1-year-old oysters are more than 10 cm. long is supported by the measurement of one specimen which was planted in the summer of 1929 by one of the divers at station 64. According to the testimony of the diver, the oyster was about 1 inch long when planted. When it was recovered in August, 1930, it was 12 cm. long and 8.5 cm. wide, and its shell weighed 108 grams. Upon dissecting the animal it was found that it had fully developed reproductive glands which contained a large number of spermatozoa.

The shell of the Hawaiian pearl oyster is flat and round. In young specimens the length (dorso-ventral dimension) is nearly equal to the width. The adults (more than 12 cm. long) are relatively longer than the young animals. The difference in the shape of the oysters of various sizes can be expressed by the length-width ratios or by percental width $\frac{(100\ W)}{L}$ shown in Table 2.

Table 2. Length-Width Ratios and Percental Width of the Shells of *Pinctada galtsoffi*.

Length in centimeters	Number of Specimens	$\frac{L}{W}$	$100\frac{W}{L}$
0.0— 1.9	22	1.015 ± 0.02	98.5
2.0— 3.9	10	1.02 ± 0.03	98.0
4.0— 5.9	1	(1.05)	(95.2)
10.0—11.9	1	(1.05)	(95.2)
12.0—13.9	4	1.16 ± 0.02	86.2
14.0—15.9	14	1.17 ± 0.02	85.5
16.0—17.9	19	1.10 ± 0.01	91.2
18.0—19.9	38	1.17 ± 0.02	85.5
20.0—21.9	38	1.13 ± 0.02	88.5
22.0—23.9	29	1.19 ± 0.02	84.0
24.0—25.9	17	1.22 ± 0.03	82.0
26.0—27.9	3	(1.15)	(87.0)
28.0—29.9	1	(1.28)	(78.1)

Two facts will be noticed by examining this table. First, that no significant changes in the shape of the shells occur in the adult oysters (classes from 12 to 25.9 cm.) and that small immature oysters less than 6 cm. long are decidedly shorter than the adults. The small number of observations in classes 10-11.9, 26-27.9, and 28-29.9 does not permit a decision as to the significance of the variation in the ratios computed for these sizes.

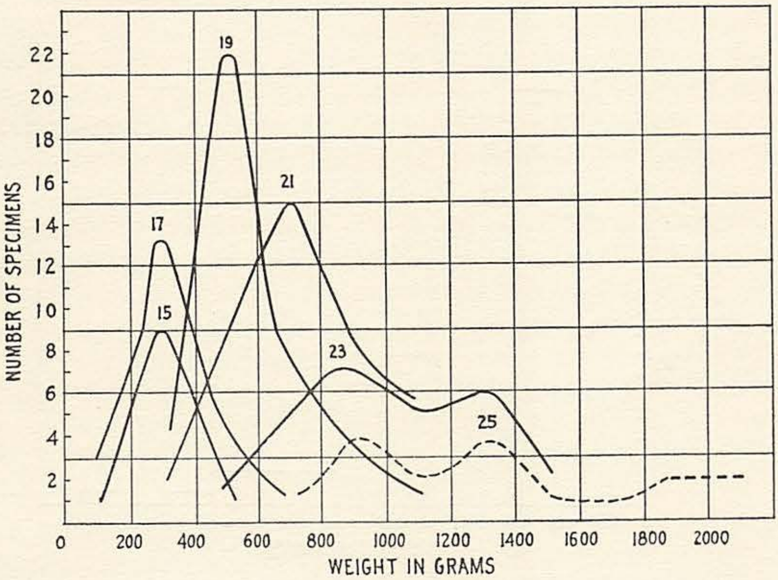

FIGURE 6.—Chart showing frequency distribution of the weight of shells in six classes of *Pinctada galtsoffi* collected at Pearl and Hermes Reef; figures in the body of the graph indicate the length of shells in centimeters.

The weight of shells varies according to their length. A general idea of the variations in weight in six classes of adult oysters can be obtained from an examination of figure 6, which shows that the skewness of the variation curves increases with the increase of length (compare the classes marked 21, 23, and 25 with those of 15, 17, and 19). This fact, coupled with the observation that the frequency curve of the weight of the oysters (fig. 7) is less symmetrical than the frequency curve of their length, suggests that the thickness of the shell continues to increase in spite of the retardation or even cessation of its growth in length.

In computing the mean for the class of oysters 14-15.9 cm. long, one measure of 697 grams was rejected because its deviation from the mean was 10.3 times the standard error. The probable error of the mean of the class of 12-13.9 cm. was corrected (19) for the small number of observations. An examination of the columns of standard deviations and of the Pearsonian coefficient of variation (Table 3) reveals the extent of variation in weight within each class. The coefficient of variation of small oysters (first two classes) is much higher than in the adult ones, but the differences in the coefficients of variation of larger oysters cannot be regarded as significant. The

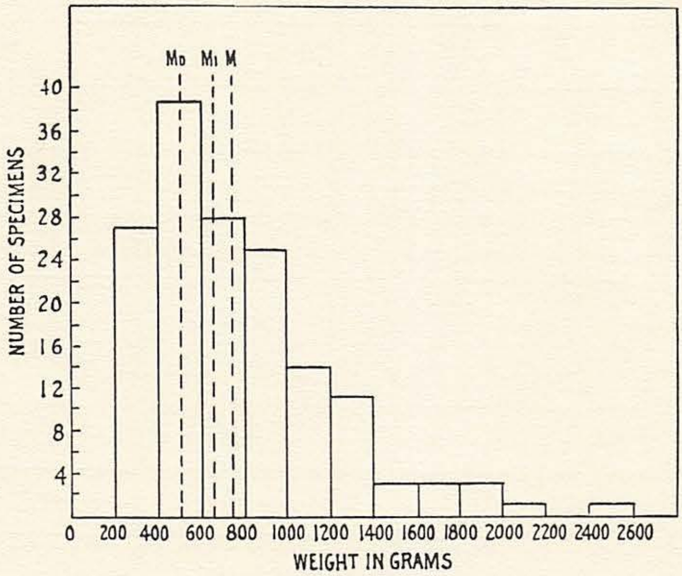

FIGURE 7.—Frequency distribution of the weight of shells of the adult *Pinctada galtsoffi*.

highest variability probably corresponds to the period of most rapid growth (22), which, judging from our knowledge of the growth of the edible oyster (*Ostrea*), occurs immediately after the attachment of the larvae. In spite of a great variability of weight within each class the mean weight of the oysters increases at a definite rate with the increase in length. Excepting the first class (oysters less than 2 cm. long) and the two largest classes (from 26 to 29.9 cm. long), which are represented by a very small number of observations, the relation between the weight and the length can be represented by the following equation: $W = 0.04209\ L^{3.21529}$ in which W is weight in grams and L is length in centimeters. For a detailed discussion of this subject the reader is referred to the paper of Galtsoff (9).

Table 3.

Biometrical Constants for the Weight of Various Classes of *Pinctada galtsoffi.*

Length in centimeters	Number of specimens	Mean, grams	Probable error	Standard deviation	Median	Mode	Coefficient of variation
0- 1.9	22	0.21	± 0.02	0.15 ± 0.02	0.20 ± 0.03	0.20	66.1
2.0- 3.9	10	1.33	± 0.14	0.61 ± 0.09	1.17 ± 0.17	0.85	45.9
4.0- 5.9	1	(3.5)	....	....	....	....	.....
10.0-11.9	1	(68)	....	....	....	....	.....
12.0-13.9	4	163	± 17.5	37.5 ± 8.9	....	....	23.0
14.0-15.9	14	262	± 15.9	81.4 ± 10.8	258 ± 19.9	250	31.1
16.0-17.9	19	375	± 17.3	109 ± 11.9	356 ± 21.7	318	29.1
18.0-19.9	38	570	± 23.3	201.5 ± 15.6	522 ± 27.6	426	35.4
20.0-21.9	38	738	± 23.1	208 ± 16.1	729 ± 28.5	711	28.9
22.0-23.9	29	998	± 36.8	289 ± 15.6	925 ± 46.2	779	29.0
24.0-25.9	17	1,265	± 60.8	361 ± 41.8	1,275 ± 76.1	1,295	28.8
26.0-27.9	3	(1,849)	....	....	....	....	.....
28.0-29.9	1	(2,509)	....	....	....	....	.....

The biometrical constants for the length and weight of an unselected sample of adult oysters from Pearl and Hermes Reef are given in Table 4, which shows that in 1930 the mean length of shells was 20.2 cm. and the mean weight was equal to 734 grams. The respective values for the mode was 20.5 and 492.6.

Table 4. Biometrical Constants for the Length and Weight of the Shells of Adult *Pinctada galtsoffi.*

	Mean	Probable error	St. deviation	Median	Mode
Length in centimeters..........	20.2	± 0.17	3.24 ± 0.12	20.3 ± 0.21	20.5
Weight in grams..................	734	± 22.6	418 ± 15.6	650 ± 28.2	492.6

The commercial value of the pearl oyster shell is primarily determined by its size and weight. Oysters less than 18 cm. long are of little value because they cannot be profitably used by the manufacturers of pearl buttons and mother-of-pearl articles. Of course other factors, as, for instance, flatness of the shell and absence of defects in the nacreous layer, affect the value of the pearl shell, but the main character which should be considered in the problem of conservation of pearl oyster resources is the size and weight of the marketable oyster. Unfortunately little is known about the rate of growth of this organism. Saville Kent (13) is inclined to think that the Australian oyster, *Pinctada margaritifera,* under favorable conditions reaches a marketable size of 8 or 9 inches in 3 years and that oysters weighing 5 or 6 pounds may be the product of 5 years of growth. Unfortunately Kent's opinion is not corroborated by accurate measurements and observations.

According to Seale (1910, 1917) the gold-lip oyster of the Philippine Islands, *Pinctada maxima*, is supposed to reach marketable size and become most valuable commercially in 4 or 5 years. He believes that specimens weighing 11 pounds are from 10 to 12 years old. Seale also fails to support his statements by direct measurements.

Talavera (20) states that *P. maxima* is sexually mature in 2 years and that it attains the "present legal size," that is, 14 cm. nacre measurement, in about 3 or 4 years. From a study of the correlation between nacre measurement and external dimensions he concludes that the total length of a marketable oyster should be not less than 19 cm.

Observations made by A. G. Nicholls (15) during the Great Barrier Reef Expedition in 1928-1929 show that small *Pinctada margaritifera* during a 9-month period increased in length from 27 to 42.6 millimeters (average figures). If our explanation of the absence of small oysters in Pearl and Hermes Reef is correct, the rate of growth of the Hawaiian species must be much greater than that of its Australian relative. Unfortunately no conclusion as to the age of the Hawaiian oysters could be drawn from the analysis of the length-weight relationship of its shells. This important problem can be solved only by long continued observations on a stock of oysters kept under known conditions.

Sex and Spawning

The sexes of the Hawaiian pearl oysters are separate. Out of 160 adult oysters the gonads of which were examined, 65 or 40.6 per cent were males and 95 or 59.4 per cent females. Thus the ratio between the males and females was 1:1.46. The inequality of sex ratios has been noticed also in the Ceylon oyster (*Margaritifera vulgaris*). Kelaart (2, p. 153) found only four or five males per hundred of females and believes that this is a normal sex ratio for that species.

In July and August, 1930, all the adult oysters (10 cm. or longer) were ripe; their gonads were swollen, soft, and contained fully developed eggs or spermatozoa. Some of the oysters had already spawned but still retained a small amount of sex cells.

The author's observations show that spawning of males and females is similar to the spawning of the American edible oyster, *Ostrea virginica*. The female discharges its eggs as a milky cloud which is effectively dispersed through the water by snapping of the valves. The male ejects the sperm as a continuous stream issued through the cloaca. The fertilization takes place outside the organism. Experiments performed on oysters obtained from Kaneohe

Bay, Oahu, and from Pearl and Hermes Reef indicate that the discharge of eggs or sperm can be stimulated either by a rise in temperature or by the addition of the sexual products of the opposite sex.

The males were found to be the first to respond to the increase in temperature and began to spawn as soon as the latter rose from 23-25° to 27° C. The presence of sperm in the water initiates spawning of the females, while discharged eggs in turn stimulate the emission of sperm by the males. This observation confirms the previous finding of Howell, who noticed that the males of Ceylon pearl oysters can be stimulated to discharge their sperm by the addition of sea water charged with freshly laid eggs.

According to the author's observations an increase in temperature to 27° is essential for the initiation of spawning in the males. It has been observed that as soon as at least one individual has responded and discharged some sperm, spawning spreads by mutual stimulation throughout the whole group of oysters kept together. This happened several times with oysters collected from the reefs and kept in tanks. On account of these conditions and high air temperature it was extremely difficult to prevent spawning of oysters which were transported to the laboratory.

In 1930 spawning of the Hawaiian oyster in Pearl and Hermes Reef occurred at the time when the water temperature varied between 25 and 27° C. and was approaching its annual maximum. It is very probable that there is only one spawning season which coincides with the temperature maximum of the water. This inference can be made from a study of the monthly average temperature curve, based on Japanese observations (fig. 3), and from the absence in the lagoon of any oysters of intermediate size (from 6 to 9.9 cm. long).

The absence of oysters of intermediate size can be explained either by the supposition that oysters failed to spawn during the summer of 1929 or by the more probable assumption that by August 1-year-old oysters had already reached 10 cm. in length. As has been shown above, this is in agreement with the measurements of the 1-year-old oyster which was planted at Pearl and Hermes Reef.

With regard to spawning seasons the Hawaiian species differs from the Australian pearl oyster, *Pinctada margaritifera,* which at Low Isles, according to Nicholls (15), spawned twice a year, in November and again in May. During these periods the temperature of the water varied between 26.2° and 28.4° C. in November and 27° and 25° C. in May. From Nicholls' observations one can notice that spawning of the Australian species takes place both when the water temperature is rising (November) and after it begins to drop (May). Similar observations were made by Herdman (11) on the Ceylon oyster, which also spawns once in May and again in November. It is quite possible that differences in the occurrence and number of spawning seasons of various species of oysters would be correlated with the temperature régime in various localities. In the temperate zone where the winter temperature drops below 18° C. and highest summer temperature rarely exceeds 27° C. oysters spawn once a year when the temperature is near the maximum, whereas near the equator where the annual range of temperature is smaller and the maximum approaches 30° C. there are two spawning seasons, one when the water is warming (November) and second one when it begins to cool (May).

Development of Eggs and Attachment of the Larvae

Eggs of the Hawaiian pearl oyster can be artificially fertilized in a small glass dish by adding to them a few drops of freshly obtained sperm. In a few hours typical free-swimming larvae develop. Our attempts to rear them until they reached setting stage were, however, unsuccessful. Similar failure has been recorded by Herdman (11), who succeeded in obtaining free swimming larvae of the Ceylon pearl oyster but was unable to keep them alive in his tanks. It is believed, however, that our failure to rear the larvae of the Hawaiian oyster was primarily due to the primitive conditions of the temporary laboratory at Southeast Island. The duration of the free swimming stage of the Hawaiian oyster remains, therefore, undetermined. Herdman estimates that the attachment of Ceylon oyster may be made within five days following fertilization, but his conclusion lacks corroboration.

Although the author was unable to keep the larvae alive and determine the duration of their free living stage, the fact that the setting of young oysters at Pearl and Hermes Reef takes place in August is evidenced by a number of spat found attached to the shells of the adult oysters. The smallest specimen in the collection was 0.6 mm. long. All the young seed oysters collected during the survey were found attached to the shells of live adult oysters. In several instances small specimens were found in a precarious position, just between the lips of the large oyster (pl. 4). It is obvious that they could not continue to grow in the selected place and would be either killed by snapping of the shells of the adult oyster or forced to change their place of attachment.

Careful examination of reefs, algae, pieces of broken corals, and other submerged objects failed to disclose the spat of pearl oysters. It is, of course, possible that the presence of nearly microscopic spat on the reefs and dead corals was overlooked and that our failure to find it except on the shells of the adult oysters should be attributed to the difficulty of observing such small objects when working in the diving helmet. On the other hand it is possible that the surface of the old oyster shell presents the most favorable conditions for the attachment of the larvae. On account of its inclined position and vigorous snapping of the valves its surface remains clean, whereas the rocks and pieces of dead corals are covered with fine sediment which may prevent setting of the larvae.

Although as many as 10 or 12 small oysters may be found attached to one large shell, the adult oysters do not grow in clusters. This is due to the fact that the attachment of the pearl oyster is not permanent, the organism being able to change the place to which it first cemented itself. The process of detachment of the Hawaiian pearl oyster has not been observed by the author, but it has been noticed that small oysters left overnight in the tank changed their places of attachment. According to S. Thomas in 1886 (11, p. 130) young Ceylon pearl oysters about one-half inch in diameter moved up 4 inches along the smooth side of a glass in 8 or 9 minutes. Herdman (11) states that a number of small oysters placed on the bottom of a narrow vertical aquarium started at once to climb up the glass sides and traveled on the average at the rate of about 1 inch per minute. Apparently the locomotory power of the young oyster decreases with age, though it is not entirely lost by the adult organism. Herdman (11) observed the reattachment of a two-and-a-half-year-old oyster which traveled three and a quarter inches during the night. There is no doubt that an adult oyster, after being separated from its place of attachment, can anchor itself in a new environment, provided its byssus gland has not been injured. In 1929 at Pearl and Hermes Reef a number of adult oysters which were too small to be of commercial value were transplanted in the lagoon from one reef to another. In 1930 the majority of them were found attached to the corals. Likewise, oysters brought by the author from Pearl and Hermes Reef and planted in Kaneohe Bay, Oahu, attached themselves and grew well.

The ability of young and adult oysters to shift their place of attachment supplies explanation of the absence of cluster formation and is undoubtedly responsible for the single occurrence of adult oysters in spite of the fact that several seed oysters may be found on one large shell. It is interesting to add that the detachment and locomotion of oysters very seldom occur during daylight, but take place mostly at night. Herdman (11, p. 133) observed that Ceylon oysters are extremely sensitive to light when preparing to attach themselves and that flashing a bright light when oysters are moving in the tank always causes the withdrawal of the foot and cessation of activities.

All the adult oysters examined by the author contained one or several specimens of decapod crustacean *Conchodytes meleagrina* Peters living in their mantle cavities.

THE OYSTER BEDS OF PEARL AND HERMES REEF

Observations in 1930

Observations made at 70 stations more or less uniformly scattered over the whole area of the lagoon show that pearl oysters are confined exclusively to those sections where the bottom is covered with corals. Thus the distribution of oysters, shown on the chart (fig. 8) by black sectors in the circles, in general coincides with the distribution of the reefs which are found chiefly in the northern half of the lagoon. Outside of this area the bottom consists of shifting sand unsuitable for the attachment and growth of the oyster. There is a consensus among pearl fishermen that the oysters thrive on reefs which are swept by strong tidal currents. Present observations corroborate this view.

In Pearl and Hermes Reef pearl oysters were found standing vertically or in slightly inclined position attached to the corals on the outside slopes of the reefs. Only a few specimens were found lying flat on sandy bottom in the centers of small lagoons. No oysters were found on either side of the main encircling reef. Oysters were found at any depth between 8 and 45 feet, but were most abundant at a depth of from 15 to 25 feet. According to Captain Anderson, at the time the pearl banks were discovered oysters were very abundant in shallow water, from 3 to 10 feet deep. Their present scarcity at these levels is apparently the result of three years of unrestricted fishing.

Because of their peculiar habitat the Hawaiian pearl oysters cannot be dredged or gathered by means of other gear employed in the fishing industry. For commercial fishing it is therefore necessary to employ divers who pick the shells with their hands and bring them to the surface (pl. 5, *B*). Experienced Filipino divers employed during the survey were able to swim continuously for several hours and dive to a depth ranging from 25 to 50 feet. They resented the use of the diving helmet or scaphander, preferring naked or "skin" diving, and never used any weights or sinkers that would facilitate their descent to the bottom. The only protection employed consisted of a pair of tightly fitting goggles, the glass of which was rubbed with tobacco juice to prevent condensation of vapor. Heavy cotton gloves served as precaution against cuts and scratches. In search for oysters the divers would swim in a zigzag line along the reef observing the bottom with their heads in the water. Due to high transparency of the water the bottom is usually visible to a depth of 45 or 50 feet. On exceptionally calm and clear days the visibility exceeds 60 feet.

For scientific investigation the following method of searching and fishing was adopted. Upon arrival at the station and completion of hydrographical observations the divers at a given signal would jump into the water and begin swimming and diving. Oysters brought from the bottom were immediately thrown in the skiff which followed the divers as closely as possible. A complete record was kept of the time spent in diving and of the number of oysters collected by each diver. Personal examination of the reefs has convinced the author of the high efficiency of this method of collecting. The divers never missed an oyster that happened to be within the range of their vision and were able to explore large areas of the bottom. Conversely, the use of the diving helmet was of little value and involved a great deal of labor and loss of time.

Because of the scarcity of the oysters, large areas of bottom had to be examined. The fragility of corals, which would not support the weight of a human body, and the steepness of the slopes of the reefs on which the oysters grew made walking over them very difficult.

The method of collecting by skin diving precluded the possibility of estimating the absolute abundance of oysters on various reefs. It was, however, possible to determine their relative abundance by computing the number of oysters caught at a given station in a unit of time per unit of effort. In fishing with various gear the problem is relatively simple and depends on the type of gear used and its efficacy. In dealing with human beings whose efficiency as divers cannot be estimated in advance but should be determined by trial, it presents certain difficulties. The three divers employed in this work differed from each other in their ability to swim and dive. One was able to dive to a depth of over 50 feet and apparently enjoyed deep diving; the second diver rarely went below 35 feet; 25 feet was the limit of operation of the third one. The ability to reach the greatest possible depth did not constitute, however, the most important qualification of a successful diver in Pearl and Hermes Reef. This would have been a deciding factor in other localities, as for instance in Ceylon, where pearl oysters form extensive banks similar to the beds of edible oysters along the Atlantic Coast and extending to a depth of 13 fathoms and more. In Pearl and Hermes Reef success in pearl fishing is primarily dependent on the ability of the diver to discern from the surface the objects on the bottom and on his endurance in swimming. After comparing the records of the three divers employed by the author it has been found that their efficiency, determined by the number of oysters brought in a unit time was the same, in spite of the fact that each of them was unconsciously covering that section of the reef the depth of which was within the range of his ability. It has been therefore assumed that their diving efforts were equal. To avoid the possible effect of fatigue which may cause a considerable decrease in the rate of swimming and loss of visual acuity the divers were invited to rest as often as they desired. However, even after an hour and a half of continuous swimming they were apparently untired by their efforts and refused to come aboard.

In order to obtain some idea of the area covered by the divers in their search for oysters it was necessary to determine the rate of their swimming and diving. This was accomplished in the following manner. The divers were ordered to swim and search for oysters along a small circular atoll (near signal "Neg"), the two diameters of which were accurately measured. The results of the two tests made on August 18 are presented in Table 5. They show that the rate of the resulting forward motion averaged 42.7 feet per minute. The reader must bear in mind that this figure does not represent the actual velocity of swimming, which of course is much greater, but shows the rate at which the divers proceed along the periphery of the atoll. Their actual path is a complex zigzag line fluctuating from 30 to 50 feet to the right and left from the circumference of the atoll and occasionally going to the depth of 35 feet and possibly deeper. At this rate one diver in one hour would complete fishing over an area having a circumference of 2,562 feet.

Table 5. Velocity of Collection by Two Skin Divers.

(Both divers started and finished diving at the same time.)

	Temperature of water, degrees C.	Circumference of lagoon in feet	Area of lagoon, acres	Depth inside in feet	Depth outside in feet	Duration in minutes	Velocity, feet per minute	Average velocity, feet per minute
1	23.5	1,036	1.96	7	35	24	43.2	42.7
2	23.5	634	0.74	8	30	15	42.3	

Test 1, small lagoon southeast of signal "Neg," 9:58 to 10:22 A.M.; August 18, 1930; Test 2, small lagoon south of signal "Neg," 10:44 to 10.59 A.M., August 18, 1930.

A complete record of diving operations showing the total number of oysters obtained at each station, time spent in diving, and the relative abundance of oysters (number of oysters per diver per hour) is shown in Table 6.

The relative abundance of oysters is also shown graphically on the chart (fig. 8). Oysters are most abundant on the reefs located in the central part of the lagoon and their distribution coincides in general with the distribution of the reefs. No oysters were found on sandy bottoms in the southern section of the lagoon and only a few were observed in the central sections of the inside reefs. The majority of the oysters were found attached to the outer slopes of the reefs where the conditions were apparently most favorable for their propagation and growth.

Table 6. Distribution and Relative Abundance of Pearl Oysters in Pearl and Hermes Reef

Station number	Diver's number	Time of diving, minutes	Number of oysters	Relative Abundance of oysters	Oysters with pearls	Number of pearls
31	2	30	1	1	....	....
32	3	30	10	6.6	....	....
33	3	40	2	1	....	....
34	2	30	6	6	....	....
35	2	30	19	19	....	....
36	2	40	4	3	....	....
37	2	20	8	12	....	....
41	2	30	4	4	....	....
44	2	30	11	11	1	1
55	3	15	5	6.6	....	....
56	3	30	10	6.6	....	....
59	3	40	38	19	1	3
60	2	50	34	20.4	7	15
61	3	20	5	5	....	....
64	3	45	75	33.3	....	....
65	3	40	5	2.5	....	....
66	3	30	13	8.6	....	....
67	3	35	17	9.7	1	3
71	4	40	29	10.9	....	....
72	3	30	1	0.7	....	....
74	2	30	1	1	....	....
75	2	20	4	6	....	....
76	2	35	17	14.6	4	7
77	2	20	17	25.5	....	....
79	2	30	13	13	....	....
81	2	15	9	18	3	6
82	2	25	3	3.6	....	....
83	2	15	4	8	1	1
86	2	24	4	5	....	....
87	2	15	2	4	....	....
88	3	20	5	5	....	....

The data presented on the chart (fig. 8) and in Table 6 show the scarcity of oysters. The maximum yield on the best reef was only 33 oysters per hour per diver, while on a great number of them only one or two specimens were found after a continuous search for nearly two hours. These observations indicate that the pearl oyster population of Pearl and Hermes Reef has reached a low limit. That these conditions are not due to natural causes but are the result of fishing operations is clear from the statements made to the author by several fishermen who were fishing the lagoon in 1927 and 1928. They all agree that oysters were very abundant and that during the most intensive fishing operations as many as 1,000 large shells were taken daily from the reefs.

Although official records are wanting, it was possible by inquiring of different parties engaged in pearling to estimate the minimum number of oysters taken from Pearl and Hermes Reef since the discovery of pearl oyster bottoms in 1927. A very conservative analysis of this information shows that during this period not less than 100 tons of shells (about 100,000 oysters) were exported from Pearl and Hermes Reef to Honolulu. How many defective shells were discarded or how many small oysters were sacrificed in searching for pearls it is impossible to estimate.

Commercial concerns consider that diving can profitably be carried out if the bottom yields not less than 50 oysters a day per diver. At present this minimum cannot be attained at Pearl and Hermes Reef, for the oyster population has reached a dangerously low limit and is threatened with complete extinction. Studies on the physiology of reproduction of edible oysters and experiments performed by the author during the present survey show that for successful propagation the oysters must grow in a close proximity to one another. A few specimens scattered over a large territory are unable to stimulate the discharge of sexual products and, under these conditions, should spawning be stimulated by the temperature, the eggs would have a very remote chance of being fertilized by the sperm. At present the pearl oyster community at Pearl and Hermes Reef is still able to propagate and if left undisturbed will probably reëstablish itself in a period of several years. On the other hand, if fishing is continued the number of adult oysters will be quickly reduced to such a minimum that no further propagation would be possible. In connection with this discussion it is interesting to add that no spat were found on a few oysters collected at Midway Islands, although the oysters showed indications of having spawned. All the oysters collected at Midway were old and apparently the remnants of a former larger colony which had almost ceased to exist.

The present survey has shown that at 60 feet and deeper the bottom of the lagoon is covered with soft coral mud in which no oyster can live. A comparatively small number of oysters was observed at a depth between 40 and 55 feet. The greatest number was confined to the stratum between 15 and 30 feet. Inasmuch as present fishing operations cover the whole zone inhabited by the oysters, hopes or expectations that there still remains in deep water a stock of breeders which may supply spat is entirely unjustified. The maintenance of the oyster colony and its growth is entirely dependent on the propagation of its members which inhabit the reefs within the reach of skin divers. Should the number of the oysters be further reduced, the propagation of this colony would cease and in a short time only a few adult specimens which had escaped the divers' attention would remain.

Commercial Values

Because of the small number of oysters examined by the author and the impossibility of inspecting the pearls accumulated by various persons who were engaged in fishing operations in the lagoon it is impossible to give an accurate estimate of the potential value of Pearl and Hermes Reef as a pearl-producing area. Out of 164 oysters examined by the author 18 contained pearls (pl. 5, *A*). Altogether 36 irregular pearls of various sizes and quality were obtained. None of the pearls were perfect. The value of the whole lot was less than 50 dollars.

According to information obtained by the author, about one quart of pearls was obtained from the lagoon during the 2-year period of fishing operations, but only a small number of good pearls were found. According to the statement made by an official of the company engaged in pearling, the best pearls were sold in Paris. On one occasion the company refused to accept $5,000 for one of the best pearls found in the lagoon. Several Hawaiian pearls could be seen in local jewelry stores in Honolulu. The best were offered in 1930 for $1,500 and $2,500 each.

Because of the scarcity of pearl oysters and the relatively small area of Pearl and Hermes Reef it is doubtful that the lagoon will ever become an important source of supply of pearls. On the other hand the large shell of the Hawaiian oyster represents a valuable product for which there is a steady demand on the market. Pearl and Hermes Reef should be regarded, therefore, as a valuable source of supply of mother-of-pearl shells. Unfortunately a large percentage of shells at Pearl and Hermes Reef is damaged by the boring sponge that honeycombs the shell substance, rendering it useless for commercial purposes.

During the past years good shells were shipped to San Francisco and New York and sold to the manufacturers of mother-of-pearl articles and pearl buttons. The shells were usually graded into five classes according to their shape, weight, size, and quality of the nacre. The highest grade shells were sold in 1929-1930 at about 20 cents a pound (wholesale). Those of the lowest grade brought only 10 cents. Although the nacre of the Hawaiian oyster has a beautiful silvery lustre its value is decreased by a greenish-olive or pink color along the margin. On account of this discoloration the Hawaiian shells are less desirable to the trade than the Australian shell, which in 1929-1930 was sold in New York for about 45 cents a pound.

CULTIVATION OF PEARL OYSTERS

Two years of fishing operations carried out by one company have resulted in a noticeable depletion of pearl oyster resources of Pearl and Hermes Reef and rendered this locality unsuitable for further commercial exploitation. There is no doubt that if left unprotected the pearl oyster colony would be completely destroyed by the fishermen attracted to the place by the possibility of obtaining a few valuable pearls. Because of the remoteness of the place no efficient patrolling and enforcement of the restrictive regulations seem to be possible. On the other hand, the survey of Pearl and Hermes Reef has demonstrated the presence of a fairly large number of young oysters (spat) which if left undisturbed would grow and reach maturity. From these observations it can be inferred that should the oyster community of Pearl and Hermes Reef be protected from further depredations it will increase in size and in the course of several years may reach its former state. Inasmuch as there are no other known pearl oyster bottoms within the Hawaiian archipelago, Pearl and Hermes Reef seems to be the only place from which a large number of oysters can be obtained. It has been estimated that since 1927 about 100 tons of oysters were exported; 50 tons were taken out of water but discarded as defective, and probably not more than 100 tons remain at present on the reefs. (The author is convinced that less than 100 tons of oysters remained on the reefs in 1930, but intentionally considers the greater figure.) Thus, the total oyster population of the lagoon for the period of 1927-1930 was about 250 tons or 250,000 adult oysters.

This source of supply is too small for the development of an industry, and present experience teaches that it could easily be wiped out by a few years of fishing operations. The best possible utilization of the place can be made by considering it as a source of supply of live stock that could be used for transplantation and propagation in other waters. The suitability of various sections of the Hawaiian islands for propagation of this species is evidenced by the findings of pearl oysters in several islands of the archipelago. There are reasons to believe that by exercising proper care and precautions the transplanted oysters could be propagated in these localities on a large commercial scale. To test this possibility the author made an investigation of the inshore waters of Oahu and selected one section of Kaneohe Bay as a place which appears suitable for the establishment of an experimental oyster farm.

Kaneohe Bay (fig. 9; pl. 3, *B*) is located on the northeastern shore of Oahu. It is about 8½ miles long and 2½ miles wide. It is separated from the ocean by a series of reefs and sand bars forming an outer boundary marked by a white line of breakers. The bottom is covered with coral reefs made primarily by *Porites lobata* Dana, *Pocillopora damicornis* Dana, *P. lingulata* Dana, *Montipora verrilli* Vaughan, *M. verrucosa* Lamarck, *Pavona duerdeni* Vaughan, *Dendrophyllia manni* Verrill, and *Fungia scutaria* Lamarck.

Between the reefs the bottom is covered with soft mud. Extensive sand flats and bars are found near the outer edge of the bay, around some of the islands (Ahuolaka, Kapapa islands) and along the western and southern shores of Mokapu Peninsula. The salinity of the water during June, 1930, varied between 34.29 and 36.08 parts per thousand. (For distribution of salinity see fig. 9.) It is said that after heavy rains the eastern corner of the bay adjacent to Mokapu Peninsula may be affected by floods of fresh water which considerably reduce its salinity.

The place selected for oyster planting is situated west and south of the southern end of Mokuoloe Island. Here the bottom is covered with a dense growth of corals standing up abruptly from a depth of about 35 feet. There is a strong current which brings the water from the open ocean. The place is sufficiently protected from heavy seas.

The transportation of live pearl oysters presents certain difficulties which

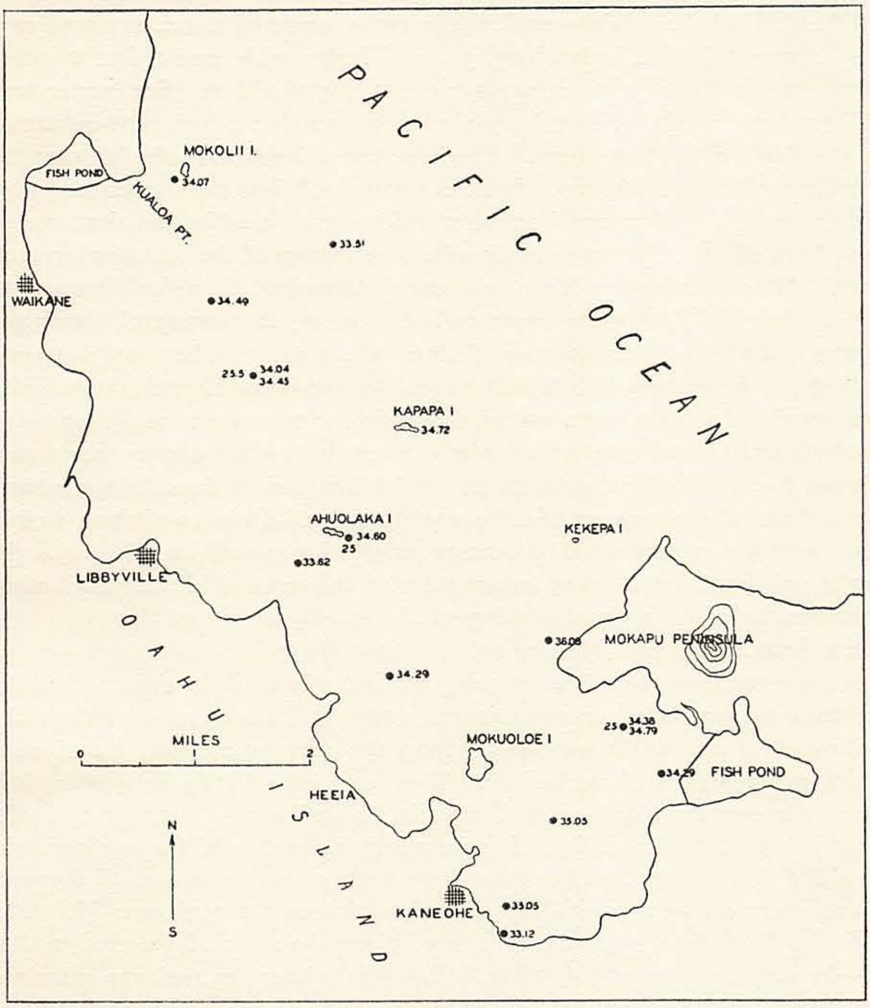

FIGURE 9.—Sketch chart of Kaneohe Bay, Oahu.

one does not encounter in dealing with the edible oyster. Laboratory experiments made by the author at the Marine Laboratory in Honolulu have demonstrated that, unlike the edible oyster, the Hawaiian pearl oyster lacks ability to keep its valves tightly closed when taken out of the water. In a few minutes after being exposed to air it relaxes its adductor muscle, opens the valves, and loses all the water that fills the shell cavity. Within three or four hours the oyster dies. Obviously it must be kept fully submerged during transportation. This requires the construction of special tanks and arrangements for pumping sea water. In order to test the feasibility of transporting oysters from Pearl and Hermes Reef to Honolulu two tanks were installed on the deck of the *Whippoorwill.* The tanks, made of 2-inch surfaced redwood, were 5 feet 10 inches long, 3 feet 6 inches wide, and 2 feet 2 inches deep. Their inside measurements were $5 \times 3 \times 2$ feet. Sea water was delivered at the rate of 10 gallons a minute through a 2-inch pipe connected to the ship's circulating pump. The inlet was 1 inch above the bottom; the overflow spilled over the top. Each box contained four wooden frames, with bottom made of galvanized iron wire, which were placed in two tiers one on top of the other. Oysters were placed on the bottom of the boxes and in each tray. Altogether the two boxes held 320 oysters of medium size (from 14 to 17 cm. long). The oysters were collected during the survey of Pearl and Hermes Reef and were kept in shallow water at the wharf at Southeast Island. A few hours before departure they were transferred to the ship. Previously, the tanks were soaked in water for two weeks and thoroughly washed, and several tests were made to ascertain that the oysters would survive in them. During the return trip which lasted eight days the tanks were cleaned and the oysters examined every other day. Only 10 of them died in transportation, a very small percentage considering crowded conditions in the tanks and rough weather encountered during the voyage. It happened often that because of rolling and pitching of the ship oysters from the upper tiers were thrown on the deck, though they apparently suffered no injury.

The circulating pump was working continuously until the ship reached the entrance to Pearl Harbor, when it was stopped. Two hours later the tanks with oysters and water were lifted from the deck by a crane, placed on a truck, and rushed to Kaneohe Bay. They were immediately dumped in shallow water near the wharf of the Territorial Game Farm. On account of softness of bottom and the influx of fresh water this section of the bay is unsuitable for pearl oysters. They were kept there only five days until arrangements were completed for their transplantation to the reef near Mokuoloe Island. Here the oysters were scattered along the slope of the coral reef at depths varying from 15 to 35 feet. Two weeks later the reef was examined by the author. The oysters were found to be in good condition, and some of them had already attached themselves to the corals.

In December, 1930, at the request of the Chief Territorial Warden, Mr. Castle examined the reef and was able to count 121 oysters, of which four were dead. The last report of the chief warden states that the reef was examined again on April 17, 1931, by one of the Filipino divers employed during the expedition, who reported finding 150 oysters only two of which were dead. Six oysters taken out of water and examined by the chief warden were found to be in good condition and nearly doubled in size.

The success in bringing live oysters from Pearl and Hermes Reef to Kaneohe Bay shows the feasibility of restocking the waters of the main islands of the Territory of Hawaii with this valuable species. One can not expect that 300 specimens brought by the expedition will suffice; systematic transplantation would require a much larger number of oysters. The purpose of the present work was, however, to demonstrate the feasibility of transplantation of this mollusk and to determine the best method.

CONCLUSIONS AND RECOMMENDATIONS

The investigations of Pearl and Hermes Reef demonstrated the depleted state of pearl oyster bottoms which were discovered only three years before. From the scarcity of 1-year-old oysters an inference can be drawn that the normal propagation of the oyster community was affected by some adverse factor the true nature of which cannot as yet be definitely determined.

It is possible to suppose that the failure of oysters to spawn in 1929 was responsible for the scarcity of young oysters in 1930. There is no evidence, however, to corroborate this supposition. On the other hand, a suspicion that fishing operations carried on in 1927-1929 interfered with the propagation of the oyster seems to be well justified. The adverse effect of intensive fishing should be attributed not so much to the decrease in number of breeders (spawners) as to the inevitable destruction of spat which, as we have seen, attaches itself to the shells of the adult oysters. Even if the oysters are carefully culled before being taken ashore and all the spat returned to the reefs, it is doubtful that many can survive. All seed oysters examined by the author had very delicate shells which were easily injured when the oyster was detached. Moreover, the chances are that when thrown in the water they will fall on soft or sandy bottom and perish before being able to reattach themselves. The introduction of a cull law will therefore be useless. The restriction of the fishing season and closing of the fishing bottoms during the time of spawning may have a beneficial effect. However, because of our ignorance of the rate of growth of young oysters and their habits it is impossible intelligently to formulate such regulations.

The presence of a relatively large number of spat attached to the shells of the adult oysters indicates that the pearl oyster colony has not yet lost its vitality. If it is left undisturbed for several years there is no doubt that it will reach its former size.

The experience with newly discovered banks of pearl or edible oysters in various parts of the world teaches that the apparent richness of virgin bottoms is often misleading and is not indicative of their natural productivity. Many newly discovered oyster banks have remained undisturbed for possibly thousands of years, so that dense populations represent the accumulated heritage of many generations. Many oyster banks which to their discoverers appeared to be inexhaustible were depleted in a very short time after the beginning of intensive fishing. Destroyed oyster banks along the coast of Maine and New Hampshire are the best examples of these conditions. The true productivity of any oyster bottom is determined by the rate of propagation and growth of its population, not by the abundance of individuals at the time of discovery. An understanding of these factors enables one to determine what portion of the population may be taken without depleting the whole community. Unfortunately, our present knowledge of the biology of the pearl oyster is entirely inadequate to provide a scientific basis for the solution of this problem.

It has been stated above that probably no more than 100 tons of oysters remain at present at Pearl and Hermes Reef. Considering that $250.00 a ton is probably the highest market value of shells, the total value of pearl shells left on the bottom is only $25,000. To this figure the value of pearls should be added. It is, of course, impossible to state how many pearls and of what quality could be obtained from the reef. On the basis of information received from parties engaged in pearling in this locality and from the data referring to pearling at Thursday Island (23) we can estimate about $150 worth of pearls to every ton of pearl shell. Thus, the combined value of pearl shells and pearls which are growing now on the bottom of Pearl and Hermes Reef does not exceed $40,000. The potential value of the bottoms, however, is much greater. There is no other place in the territory of the United States where a large number of pearl oysters can be found. Successful experiments in transporting live oysters from Pearl and Hermes Reef to Oahu and the presence of the same species in several islands of the archipelago show that cultivation of this oyster in the inshore waters of the Hawaiian islands is possible. It is desirable, therefore, to regard the pearl oyster bottoms of Pearl and Hermes Reef as a source of supply of breeders which could be used for restocking and cultivation.

The success of the experiment in transplanting pearl oysters from Pearl and Hermes Reef to Kaneohe Bay indicates the feasibility of developing pearl oyster farming in Hawaiian waters. The number of oysters which were planted in the bay is, however, too small for restocking the extensive reefs in that body of water or for establishing an oyster farm. For the latter purpose a greater number of oysters should be transplanted and more information should be obtained regarding the spawning, setting, and growth of this species. These biological observations should be carried on throughout the year by a trained biologist. It is recommended, therefore, that the Territorial Government appoint a qualified marine biologist to carry out the program of the investigations and continue the experimental work that was begun in 1930. At the same time private persons should be encouraged to undertake pearl oyster farming and develop a new industry in the territory. Because of a considerable demand for mother-of-pearl shells, market conditions appear to be favorable to the development of this valuable natural resource and pearl oyster farming may become an important industry of the Territory of Hawaii.

It is also recommended to set aside Pearl and Hermes Reef as a Government reservation from which no oysters should be taken except by the permission of the Government and exclusively for the purpose of transplantation and cultivations. Because of our lack of knowledge regarding the rate of propagation and growth of the oyster it is recommended to resurvey Pearl and Hermes Reef in 1935 in order to obtain a census of the oyster population and determine the number of oysters that could be taken for transplantation.

Upon completion of biological and hydrographical observations presented in this paper the following recommendations were made to the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii:

1. To forbid commercial fishing for pearl oysters in Pearl and Hermes Reef for a period of not less than 5 years.
2. To resurvey the bottom of Pearl and Hermes Reef in 1935.
3. To establish at Pearl and Hermes Reef a pearl oyster reserve from which oysters could be taken only by permission of the Government and exclusively for the purpose of transplantation and cultivation.
4. To continue biological observations on the rate of growth, spawning, and setting of this species.
5. To employ a marine biologist capable of carrying out these studies.
6. To encourage the cultivation of pearl oysters in the Territory of Hawaii by private citizens.

On September 15, 1930, the Governor approved regulations issued by the Board of Commissioners of Agriculture and Forestry; pearl oysters were placed under the protection of the Government, and to take oysters from waters under the jurisdiction of the Territory of Hawaii was prohibited. The full text of the order is as follows:

Under authority of Act 209, Session Laws of Hawaii, 1929, the Board of Commissioners of Agriculture and Forestry of the Territory of Hawaii hereby makes the following Rule and Regulation for the conservation of pearl oysters in the waters under the jurisdiction of the Territory of Hawaii.

Section 1. It shall be unlawful for any person, firm or corporation to take, molest, collect or destroy any kind of pearl oyster found in any of the waters under the jurisdiction of the Territory of Hawaii. Provided, however, the Governor on recommendation of the Board of Commissioners of Agriculture and Forestry may by proclamation declare an open season and permit the taking, etc., of any species of pearl oysters found within the waters under the jurisdiction of the Territory of Hawaii, for stated periods, and may at any time take either of said species of oysters for the purpose of propagating, experimenting and planting them in new localities and for scientific research work in connection with the propagation and cultivation of oysters.

Section 2. Any person, firm or corporation violating any of the provisions of this regulation shall be subject to a fine of not more than $500.00 or to imprisonment for not more than six months or to both such fine and imprisonment in the discretion of the court. One half of all moneys collected from any fine imposed under this Regulation shall be paid to the person or persons assisting in the arrest and conviction of the offender.

Section 3. This Regulation shall take effect upon its approval by the Governor of Hawaii.

Adopted by the Board of Commissioners of Agriculture and Forestry this 12th day of September, 1930.

Approved this 15th day of September, 1930, by Lawrence M. Judd, Governor of Hawaii.

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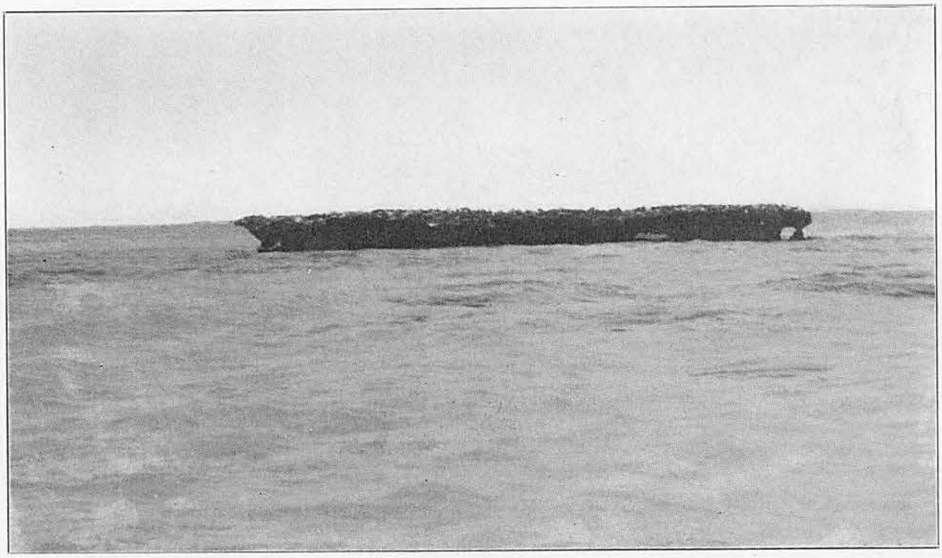
A

B

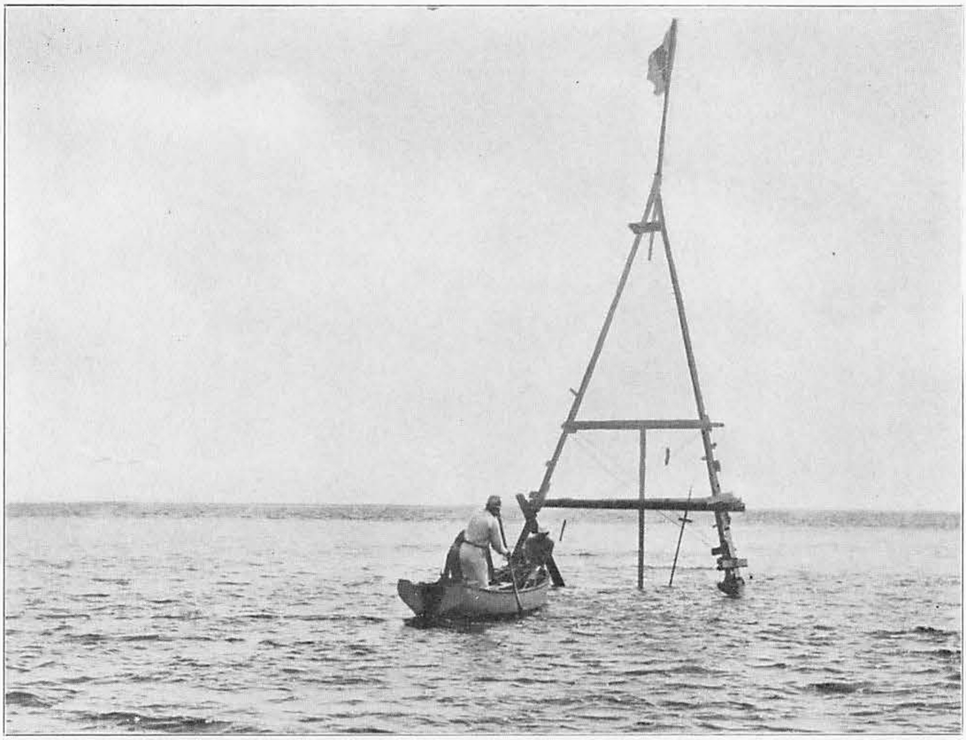
PEARL AND HERMES REEF: *A*, SOUTHEAST ISLAND, AUGUST, 1920; *B*, ENCIRCLING REEF, NEAR NORTH ISLAND.

A



B

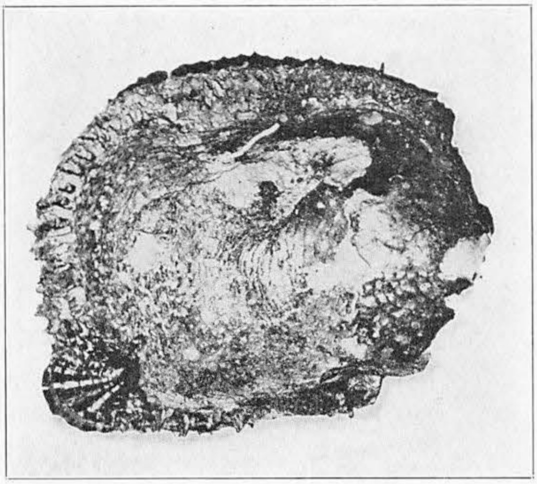
PEARL AND HERMES REEF: *A*, BREAKERS ON ENCIRCLING REEF NEAR NORTH ISLAND; *B*, LIMESTONE ROCKS (SO-CALLED "HORSE").



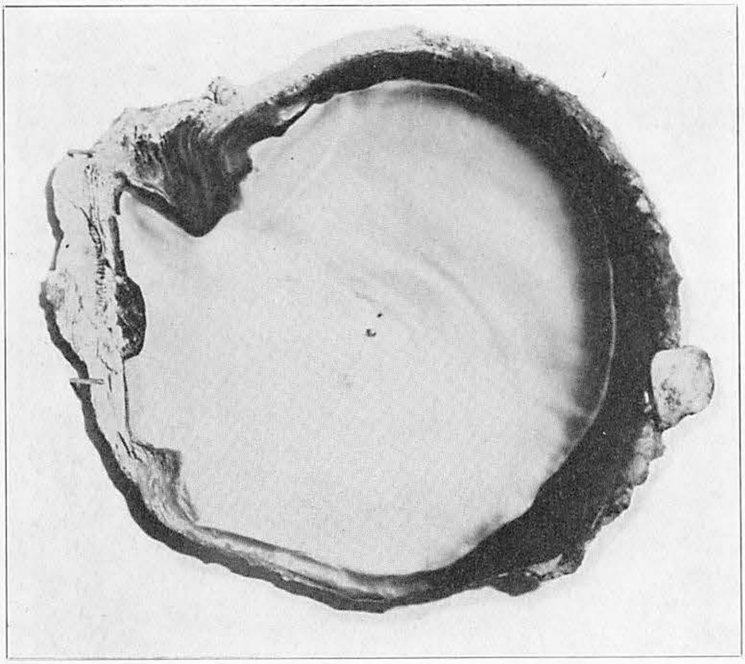
A

B

A, SIGNAL "NEG" ERECTED IN A SMALL ATOLL NEAR STATION 71, PEARL AND HERMES REEF; *B*, KANEOHE BAY, OAHU, MULLET POND IN FOREGROUND.

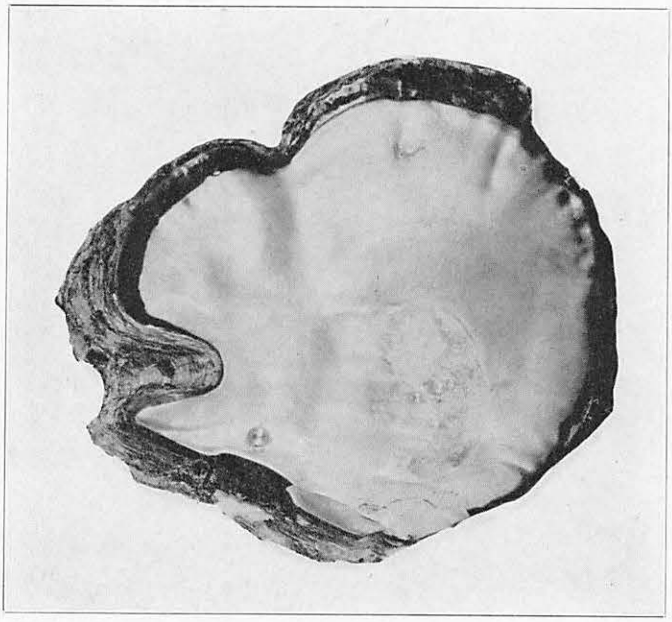


A

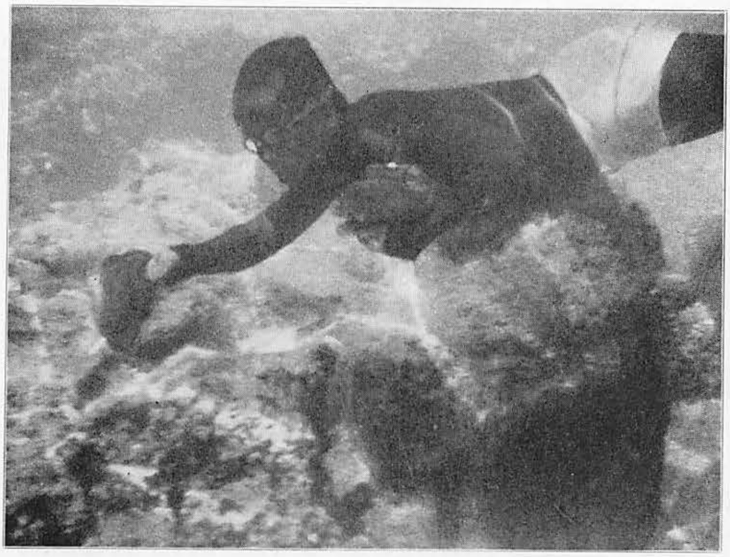


B

ADULT *PINCTADA GALTSTOFFI*: *A*, WITH YOUNG OYSTER ATTACHED TO OUTSIDE OF SHELL; *B*, WITH YOUNG OYSTER ATTACHED TO MARGIN OF SHELL.



A



B

A, ADULT PEARL OYSTER, *PINCTADA GALTSOFFI*, WITH PEARL; *B*, DIVER PICKING PEARL OYSTER FROM BOTTOM OF LAGOON, DEPTH 15 FEET (under-water photograph).