# POSSIBILITIES for OYSTER CULTURE in PUERTO RICO and the VIRGIN ISLANDS



SPECIAL SCIENTIFIC REPORT: FISHERIES No. 9

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

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# POSSIBILITIES FOR OYSTER CULTURE IN PUERTO RICO AND THE VIRGIN ISLANDS

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# INTRODUCTION

The oyster industry of Puerto Rico is virtually non-existent. Marketing of locally-produced oysters has changed little since the beginning of the century. Soon after the island was acquired by the United States, Wilcox (1900) reported that there was an abundance of small oysters growing on the aerial roots of mangrove trees bordering the lagoons and that occasionally a few of these were gathered and sent in the shell to the largest cities where they were peddled through the streets. Fishermen at the present time at Boqueron gather a few of the larger oysters by cutting them from the mangrove roots with their machets. After sacking the oysters and placing them outside in pure sea water for a few days, they are sold in the cities, almost exclusively in San Juan. Figures available at the office of the Division of Fisheries and Wildlife Conservation of the Puerto Rican Department of Agriculture and Commerce show a production of 50,000 oysters in 1940.

Very recently the territorial government considered it advisable to attempt development of an oyster industry in Puerto Rico and thought was given to the introduction of the foreign species, Ostrea gigas, which, it was hoped, would establish itself and give sizable yields of a good marketable oyster. Actual importation has been delayed, however, because of difficulties encountered in obtaining the seed oysters and because of the desire to investigate more fully the details of actual planting operations to be performed.

There is no marketing of locally produced oysters in the Virgin Islands. Some may be gathered and eaten by residents who live close to the few areas where oysters are found, but the majority of the people do not know the local oyster and do not eat it. This oyster is too small in size to be a valuable food oyster and it is not abundant. Frozen oysters are imported to meet the demand and sold at a high price to a limited number of consumers.

The Government of the Virgin Islands is interested in the promotion and development of small industries and agriculture in the islands. The development of the tourist trade requires the establishment of adequate hotel facilities, which in turn, poses the problem of supplying certain foods and delicacies. The development of an oyster industry would assist this program.

The governments of Puerto Rico and the Virgin Islands requested advice and assistance of the Fish and Wildlife Service in a study of their respective oyster resources and of possibilities for the development of an oyster industry through cultivation. The authors were detailed to the survey in March - April 1949 and have reported results and recommendations to officials of the two governments.

In each area, automobiles and small boats, with operators, were placed at the disposal of the investigators. Observations and collections of specimens were made, the nature of the bottom in each area was determined by probing with poles, and samples of water, from which temperature, salinity, and pH were ascertained, were taken just above the bottom. Salinity was calculated from hydrometer readings of the density of the water, corrected to 17.5°C., using Knudsen's hydrographic tables (Knudsen, 1901). The pH was measured colorimetrically (using Thymol Blue as an indicator), the results being expressed without correction for salt error. A bolting silk net of No. 20 mesh was towed at each station and samples examined for plankton forms, including molluscan larvae. Samples of oysters were examined for condition and for the presence of parasites; sections of the gills were examined in a fresh condition microscopically.

Acknowledgments are due to many Federal and insular Government officials for courtesies and helpful cooperation. Mr. Derrickson of the Department's Division of Territories and Island Possessions made the initial arrangements. In Puerto Rico Mr. Roberto Sanchez Villela, executive secretary to the Governor; Mr. Miguel Melendez Ortiz, chief, Division of Fisheries and Wildlife Conservation and Mr. Félix Iñigo of the same division; and Mr. Abdom Perez of the Puerto Rican Agricultural Development Corporation, arranged transportation and provided every facility for the work. In the Virgin Islands, Governor William H. Hastie; Mr. Morris DeCastro, Government Secretary; Messrs. George Simmons and Harry E. Taylor, administrators for St. John and St. Croix, respectively; and Mr. Valdemar A. Hill, former tax assessor, showed interested and effective cooperation in every part of the work. Colonel Axel Oxholm, then special agent for the U. S. Department of Commerce, and particularly interested in the development of new industries in the islands, gave us valuable information and assistance.

## Survey of Areas

### Puerto Rico

By use of a car furnished by the Government of Puerto Rico, the principal coastal areas of the island were visited. Examination of bay and lagoon waters was made by small boats and skiffs. The survey also included Vieques Island, the largest and most populated of the outlying islands of Puerto Rico, some 11 miles off the southeast coast. The places visited and considered are shown on the map of Puerto Rico in Figure 1. Results of observations on water conditions are grouped for convenience in Table 1.

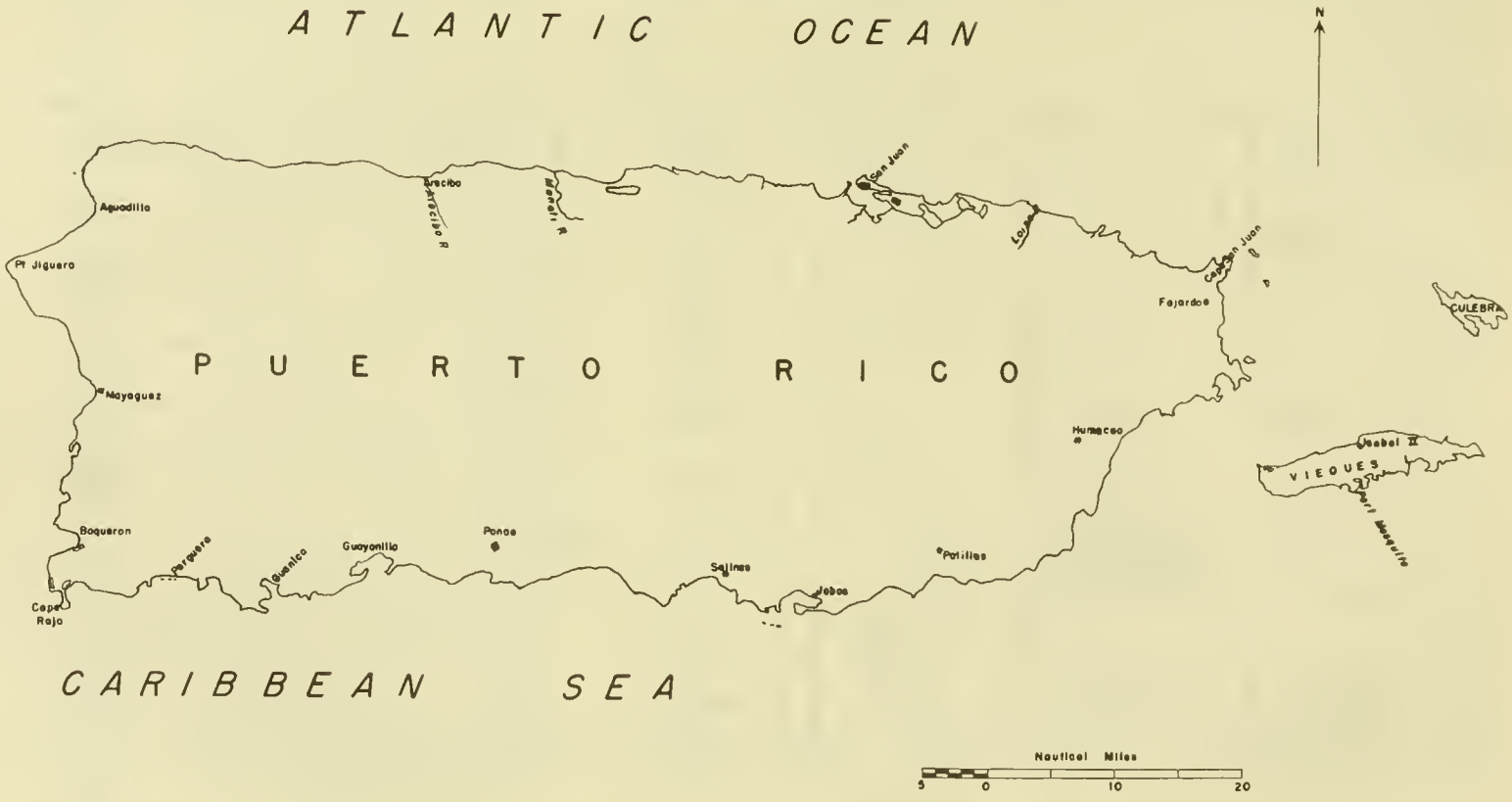
ATLANTIC OCEAN
N
Aguadilla
Pt Jiguero
Arecibo
Manati R
San Juan
Loiza
Cabo San Juan
Fajardos
CULEBRA
PUERTO RICO
Mayaguez
Humacao
Isabel II
VIEQUES
Boqueron
Parguera
Guanica
Guayanilla
Ponce
Salinas
Jobos
Patillas
Cape Rojo
CARIBBEAN SEA
Nautical Miles
5 0 10 20

FIGURE 1.

Table 1. Hydrographical conditions at Puerto Rican station

| Station No. | Location | Date | Time | Bottom water temp. | Bottom salinity | Bottom pH |
|---|---|---|---|---|---|---|
| | | 1949 | | °C. | Parts per thousand | |
| 04.01 | Jobos Bay, P. R. | 4/1 | 1755 | 27.5 | 36.33 | 8.3 |
| C4.02 | Jobos Bay, P. R. | 4/1 | 1830 | 27.0 | 36.56 | 8.3 |
| 04.03 | Off Parguera, P. R. | 4/2 | 1225 | 28.2 | 36.02 | 8.4 |
| 04.04 | Boqueron, P. R. | 4/2 | 1545 | 27.8 | 35.19 | 8.4 |
| 04.05 | Boqueron, P. R. | 4/2 | 1625 | 28.2 | 34.46 | 8.4 |
| 05.01 | Port Moscuito, Vieques, P. R. | 4/4 | 1545 | 29.0 | 36.11 | 8.4 |

The north coast of Puerto Rico is well exposed to the open Atlantic and is characteristically rugged and rocky with few sandy beaches. The water is rough the greater part of the time. Since the northern slope and the eastern section receive greater rainfall, the rivers entering the Atlantic are larger than those of the southern coast, which are virtually dry most of the year. The northern rivers are relatively short, however, flowing from the mountainous interior and emptying rather abruptly into the sea. Because of the steepness of the northern coast, the shore dropping off to considerable ocean depths only a short distance from the coast, the mouths of the rivers offer little in estuarine conditions. There are low areas and lagoons in the general vicinity of San Juan, and oysters are found in this area. Because of the great amount of pollution in the waters near San Juan, this area was considered as not being satisfactory for oyster-growing experiments. The lack of suitable estuarine waters and the rugged nature of the northern coast make it unsuited for oyster culture.

The southern coast of Puerto Rico, facing the Caribbean Sea, protected to some extent by small islands, points of land, and coral reefs, is not particularly estuarine in character. The rivers of the southern slope are small and have little flow except during the rainy season. This area of Puerto Rico has a much drier climate than others and the bays are highly saline. They have rocky or sandy bottoms and shores except for small areas where surface water enters at times. Here the bottoms are more muddy and are fringed with mangroves. In some places these low sections of the shore are more or less cut off from the bays and form lagoons. The waters of the lagoons also are salty much of the year.

The first area examined on the southern coast was Jobos Bay close to Central Aguirre. This bay is shallow except for deeper channels at the lower end close to the dock area. The bottom has a firm mud underlying a soft and sticky surface layer. Patches of grass grow on much of the bottom. The mangrove roots along the shore are well covered in the zone between low water and high water marks with great numbers of small oysters. A few of these have reached a fair size, the maximum between 2 and 2-1/4 inches. The greatest part of the young oyster spat is dead, although oysters of all ages are present. The water temperature close to the shore at the time of observation on April 1 was 27.5°C., and salinity was 36.33 parts per thousand. Nearer the center of the bay, in 8 feet of water, the bottom water temperature was 27.0°C., and the salinity 36.56 parts per thousand.

Guayanilla Bay is open and exposed but a small and very shallow area in the western part may have limited potentialities for shellfish production.

The upper end of Guanica Bay, known as Northwest Bay, or Sugar Mill Harbor, opposite the large sugar mill at Ensenada, has a low area near the mouth of the Loco River that is fringed with mangroves. Along this area are oysters, some of which were found attached to rocks between the tide levels. This area is very small and the greater part of Guanica Harbor is deep water with sandy and rocky shores.

A brief stop was made at the fishing village of Paraguera. The small islands along the shore are fringed with mangrove trees and oysters are present on the roots between tide marks. Most of the bottom here is coral, sand, and rocks, and the water is quite open. At the time of sampling on April 2, the water temperature was 28.2°C., and the salinity 36.02 parts per thousand. Shifting sand and open water limits the areas where oysters may grow. Starfish and other enemies of bivalve mollusks are present.

Boqueron Bay is on the western coast facing Mona passage in the Caribbean. This bay is an arm of the sea and is bordered by rocky and sandy shores. Connected to the bay by a very small and narrow shallow passage is a lagoon known as Cana de Boqueron or Laguna Rincon. The lagoon is about 2 miles long and somewhat less than 1/2 mile wide. It receives fresh water drainage from a considerable valley area inland. There is a project under way to construct dams and to utilize for irrigation purposes much of the water which now reaches Boqueron. This change may greatly influence Boqueron for it is within this lagoon that the greatest colony of oysters in Puerto Rico is found, one which is of some economic importance.

Only the lower half of the lagoon close to the connecting passage to Boqueron Bay was studied closely. The bottom is a firm shell sand with a thin layer of soft silt covering it. There are some patches of grass growing on the bottom. At the time of the last of ebb tide on April 2, the water had a yellow-brown appearance differing from sea water. This was apparently the result of fresh water from rains which had occurred two days before. Inside the opening to Boqueron Bay the temperature of the water was 27.8°C., and its salinity was 35.19 parts per thousand. Along the shore opposite the entrance and to the northeast where more fresh water drains in from surrounding areas, the water temperature was 28.2°C., and the salinity 34.46 parts per thousand.

The mangrove trees fringing this lagoon are very dense and their roots are heavily covered with oysters, many of large size compared with those of other areas of Puerto Rico. The largest collected measured 2-3/4 inches in its greatest dimension. There

were but few barnacles and few snails. A few tree oysters, probably Pedalion alata Gmelin, were observed attached in clusters on the mangrove roots below the attachment of the true oysters, usually close to the low water mark.

It was in this lagoon at Boqueron that Mattox made rather extensive observations on the biology and ecology of the oysters. His detailed observations have not been published, but they are summarized in a brief paper (Mattox, 1948). He gives the salinity range in this lagoon as being from 32.9 to 40.2 parts per thousand. The water temperature varies from 25°C., in January to 31°C., in August, while the pH ranges from 7.2 to 8.3.

The southern shore of Vieques Island has a number of bays and inlets: Salina del Sur, Ensenada Honda, Port Ferro, Port Mosquito, and Ensenada Sombe. On the western end of the island near Point Arenas are swampy areas completely cut off from the sea. A large salt water pond lies on the south shore near Playa Grande. Because of operations of the U. S. Navy, only the middle belt across the island is unrestricted.

To complete the survey in as short a time as possible, the different areas of Vieques Island were observed first from a small plane 1/ traveling at very low altitude and slowly circling the bodies of water. From the air it was possible to judge well the conditions in the bays. The swampy areas of the western end of the island were judged not suitable for oyster culture. The salt water pond of the southern shore is shallow with much area completely exposed as drying mud. A rocky bottom with considerable exposure to the open sea characterizes the remaining bays and inlets with the exception of Port Mosquito. In this inlet the bottom appears more suitable and the fringe of mangroves contains many oysters. A more detailed examination of this inlet by boat was arranged, for it is the only place on the island that appears promising for oyster culture.

Port Mosquito is a body of water, the shores of which are bordered with mangrove trees with many oysters growing on their roots. Near the entrance, which is a deep channel to the sea, the bottom is hard sand with little mud. Closer to the shores there is a firm mud bottom, often only a firm crust that can be penetrated by a pole with a little effort. Once through the crust, the pole can be pushed to

1/ Mr. Seth Plank of the Puerto Rican Agricultural Development Company piloted his personal plane for the survey.

Table 2. Hydrographical conditions at Virgin Island stations

| Station | | Date | Time | Bottom water temp. | Bottom salinity | Bottom pH |
|---|---|---|---|---|---|---|
| No. | Location | | | | | |
| | | 1949 | | °C. | Parts per thousand | |
| 01.01 | Benner Bay, St. Thomas | 3/24 | 1610 | 27.4 | 36.73 | 8.3 |
| 01.02 | Benner Bay, St. Thomas | 3/24 | 1725 | 27.3 | 37.09 | 8.3 |
| 01.03 | Mangrove Lagoon, St. Thomas | 3/25 | 0935 | 25.2 | 37.03 | 8.4 |
| 01.04 | Mangrove Lagoon, St. Thomas | 3/25 | 1040 | 25.8 | 36.02 | 8.4 |
| 02.01 | Hurricane Hole, St. John | 3/26 | 1255 | 25.2 | 36.04 | 8.4 |
| 02.03 | Coral Harbor, St. John | 3/26 | 1445 | 25.3 | 35.69 | 8.3 |
| 02.04 | Cruz Bay, St. John | 3/26 | 1610 | 26.5 | 36.95 | 8.3 |
| 03.01 | Altona Lagoon, St. Croix | 3/29 | 1650 | 24.3 | 33.01 | 8.2 |
| 03.02 | Altona Lagoon, St. Croix | 3/29 | 1735 | 24.3 | 34.42 | 8.2 |
| 03.03 | Christiansted Harbor, St. Croix | 3/29 | 1800 | 24.2 | 28.53 | 8.0 |
| 03.04 | Salt River, St. Croix | 3/30 | 0930 | 24.8 | 33.98 | 8.2 |
| 03.05 | Salt River, St. Croix | 3/30 | 1000 | 24.8 | 35.48 | 8.2 |
| 03.06 | Limetree Bay, St. Croix | 3/30 | 1500 | - | 27.93 | 8.3 |

considerable depth. The remainder of the bottom is patchy with areas of softer silt on hard sand and areas of hard sand. The end of the inlet farthest from the entrance is very shallow with grass growing on the bottom. Port Mosquito has many areas of hard bottom which could support oysters. The bottom water temperature at the time of observations on April 4 was 29.0°C., and the salinity was 36.11 parts per thousand.

## Virgin Islands

By use of cars and small boats furnished by the Government of the Virgin Islands, the coasts of the three major islands belonging to the United States, St. Thomas, St. John, and St. Croix, were visited and the small bays and lagoons thoroughly investigated as to their possibilities for oyster production. The results of the observations on water conditions are grouped in Table 2.

The island of St. Thomas is mountainous, with a precipitous and rocky coastline, and there is considerable wave action against the rugged shore. All the bays are rocky, with small sandy beaches, protected to some extent from the open ocean by coral reefs. None of these arms of the sea is suitable for the cultivation of oysters.

On the eastern end of the island is a well protected body of water known as Mangrove Lagoon. This lagoon, leading off from Jersey Bay through a channel from a small arm of Jersey Bay known as Benner Bay, is an extensive, shallow body of water completely fringed with mangrove trees. A moderately extensive population of oysters grows on the mangrove roots in Benner Bay and Mangrove Lagoon. These areas are the only ones of the island of St. Thomas suitable for the growth of oysters.

The bottom in Benner Bay is a firm shell-sand with a light silt layer covering it to a depth of 2 to 2-1/2 inches. At the time of examination on March 24 the bottom water temperature close to the shore was 27.4°C., and the salinity was 36.73 parts per thousand. The salinity was 37.09 parts per thousand closer to the sea.

Small oysters are attached to the mangrove roots between tide levels. These are characteristically deep cupped, with a purple-colored inner margin of the shell. Also attached to the roots of the mangroves at a point closer to the low tide level are clusters of the thin tree oyster, Pedalion alata Gmelin. Just below these are masses of bryozoans. Some enemies of oysters are present, including snail-like forms, and small mud crabs are abundant.

The mangrove trees bordering the channel leading into Mangrove Lagoon similarly have many oysters attached. Here the bottom is hard sand and broken shell, with few spots with silt or grass. The bottom water temperature was 25.2°C., and the salinity 37.03 parts per thousand on March 25.

Mangrove Lagoon is shallow and the bottom is mostly hard sand, with a few areas covered by grass. Fewer oysters are present on the mangrove roots in the lagoon proper than are found in the channel leading to the lagoon. The bottom water temperature was 25.8°C., and the salinity 36.02 parts per thousand.

The island of St. John is mountainous like St. Thomas. The coast is abrupt and rocky, particularly along the northern shore facing Drake's Channel, where the ocean beats against rocky cliffs. There are few inlets suitable for the growing of oysters. Cruz Bay on the western end of the island, and Coral Bay on the eastern end are protected bodies of water and offer the best locations for oysters in the waters of St. John. Coral Bay has three small tributary arms: Round Bay is open and has a rocky and sandy shore, while Hurricane Hole and Coral Harbor are protected and are fringed with mangrove trees. Hurricane Hole is a deep inlet with steep banks; the bottom is rocky and has considerable coral. The animal community of Hurricane Hole is typical for a coral reef and the clear and quiet water makes a study of the bottom and its marine life particularly interesting. The mangrove roots have a few tree oysters but no Ostrea rhizophorae. Specimens of Ostrea cristata are present. Sponges, varied echinoderms, and colorful reef fishes are abundant among the numerous different types of corals. At the time of observation on March 26, the bottom water temperature was 25.2°C., and the salinity 36.04 parts per thousand.

Coral Harbor, the innermost part of Coral Bay, has many oysters covering the roots of the mangroves bordering the shores. The concrete dock at Coral Harbor is well covered with oysters of all sizes, but the majority of the spat and young oysters are dead. The area receives considerable fresh water at times of heavy rains; this brings in a large amount of soil and makes the bottom in Coral Harbor a soft mud close to shore where the greatest amount of water enters. The salinity of the water was 35.69 parts per thousand. The bottom water temperature was 25.3°C., at the time of observation.

The southern coast of the island of St. John, although less abrupt than the northern coast, is still exposed and rocky. The few inlets have rocky or sandy shores and bottoms.

Cruz Bay on the west coast of St. John is well protected and is fringed with mangroves. The bottom here is muddy and soft and the roots of the mangroves are nearly free of marine life. A few small barnacles are attached to rocks along the shore, but no oysters were found. Clams,

probably Chione pubera Valenciennes, locally called cockles, are present in great abundance in the mud. These should be of value as a marketable shellfish, but few are eaten. The bottom water temperature here was 26.5°C., and the salinity 36.95 parts per thousand.

The island of St. Croix, larger than St. Thomas or St. John, is less mountainous and has more areas of level land. Agriculture and the cultivation of the soil is of greater importance. There are more small streams, although they have water in them only a small part of the time. In general the coast is rocky, but extensive offshore coral reefs make the water less rough on the beaches. The most promising areas for oysters appeared to be Altona Lagoon and Salt River and these were carefully investigated.

Altona Lagoon is a well-protected body of water almost completely cut off from Christiansted Harbor. It is connected to it only by a very narrow and shallow entrance. The lagoon itself is shallow, the lower central portion being deepest with a maximum of 7 to 8 feet. The bottom is soft mud and the shores are bordered by a heavy growth of mangrove trees.

No edible oysters were found in Altona Lagoon - only a few tree oysters, Pedalion alata, barnacles, and numerous sponges and bryozoan colonies. Clams are reported to be present in the mud, but were not collected. The bottom water temperature on March 29 was 24.3°C., and the salinity was 34.42 parts per thousand.

Salt River on the northern coast of St. Croix is more like an estuary than other places in the Virgin Islands. It was here that Columbus sent his men in search of fresh water, only to meet with disappointment. The small stream flowing into the inlet, which is primarily an arm of the sea, is dry most of the year. At the time of sampling there was a small flow of fresh water entering; it was raining and had been raining for two days. It was reported that 4.82 inches of rain had fallen in the 24 hours preceeding our visit. The flow of the stream was slight and little influence could be seen on the waters of the inlet.

The bottom in Salt River is mud, somewhat firm at the lower end and grading to sticky and soft in the upper reaches. The mangrove trees bordering the shore have many oysters attached to their roots. These are more abundant and of larger size in the upper portion of the inlet which receives the most fresh water. The largest are from 3 to 3-1/4 inches in length, the largest seen or collected either in the Virgin Islands or in Puerto Rico. The bottom water temperature was 24.8°C., and the salinity 35.48 parts per thousand on March 30.

Krause Lagoon and Limetree Bay on the southern coast were observed but Krause Lagoon was not examined in detail. It is nearly completely cut off from the sea and is reported as being shallow and having an extremely soft mud bottom. Limetree Bay has extensive mud flats which are covered in some areas with grass. The mangrove trees along the shore have no oysters, but crabs are abundant among the roots. On the flats there are numerous univalve mollusks and in the mud the clam Chione pubera is plentiful. Land crabs are present in abundance on shore.

## Discussion and Recommendations

### Oysters of Puerto Rico and the Virgin Islands

Oysters of one type or another are almost world wide in their distribution, being found along the coasts of nearly all the continents and islands. Although certain characteristics of the different oysters are sufficiently marked to allow a separation of oysters into major groups, there is considerable confusion as to the correct classification of oysters in the smaller groupings, particularly in the genus Ostrea.

Among the most important distinguishing characters of the members of the genus Ostrea are the dentition of the inner shell margin, the structure and shape of the beak, and the coloration and location of the scar of attachment of the posterior adductor muscle. The latter character has been shown to be of considerable importance by Nelson (1938) for it is related to the presence or absence of a promyal chamber. Space for the chamber results in a deeper valve with the muscle scar more distally located. It is known that oysters having a promyal chamber are dioecious and oviparous, while those without it are hermaphroditic and larviparous. Because of these differences, McLean (1941) has grouped the species of Ostrea into two subgenera, Ostrea and Crassostrea. His key to the species of Ostrea of the Western Atlantic is the best available at the present time. A revision of the classification of oysters is being made by Ranson, the French oyster specialist, but his work is not yet complete.

Dall and Simpson (1900) classified the common oyster of Puerto Rico as Ostrea virginica Gmelin. Mattox (1948) agreed with this classification, but as a result of a more recent study (Mattox, 1949), he considers it as Ostrea rhizophorae Guilding. The differences between the common oyster of Puerto Rico and the Virgin Islands and the Eastern oyster (O. virginica) of the United States strengthen the case for O. rhizophorae. It is small, not exceeding 2-3/4 inches in length, often ribbed radially, and flourishes in lagoons, attached to the vertical aerial roots of the red mangroves between low and high

water. Typically deep cupped, the cavity of the attached valve extends under and beyond the hinge; this left valve is larger than the free moving one. Inner margins of the valves are smooth and undenticulated and usually are purple in color. The posterior adductor muscle scar is non-pigmented and is distally located. There is a promyal chamber. The sexes are separate and the eggs and sperm are released in the water for fertilization.

One specimen of the larviparous oyster, Ostrea cristata Born, was collected in Hurricane Hole on St. John, Virgin Islands.

Some individuals were found with ripe gonads and there were oyster larvae in the plankton samples collected with the fine net. Mattox (1948) reports that individuals were found throughout the year with ripe gonads and that spawning takes place at all months of the year. A similar situation has been observed in the oysters of the Gulf of Mexico coast of the United States when, in an extremely mild winter, oyster larvae are present and setting takes place on cultch in abundant amounts through the year. There are slight peaks of spawning, but these are less marked than in years of colder winters. In warm years there is no period in which sexually mature and spawning oysters cannot be found. It would be interesting to know if there are any peaks in the spawning activity of the oysters of Puerto Rico and the Virgin Islands. Mattox did not report any for Puerto Rico, but his completed observations have not been published.

There was no evidence of shell damage from the marine worm, Polydora. This, of course, may be correlated with the method of oyster growth on the vertical roots of the mangrove and off the bottom. Examination of the mantle margin for the presence of the encysted spores of the gregarine, Nematopsis, showed that this parasite was absent in the oysters collected.

## Conditions affecting oyster production

Conditions favorable for the production of oysters in any great quantities are not present in the waters of the Virgin Islands and Puerto Rico. The rugged coastlines with rocky shores where there is considerable rough water and the few bays where the shore is either rocky or has sandy beaches are not oyster-growing areas. Estuarine waters, which are the most advantageous for oysters, are definitely lacking. The quiet lagoons offer the only areas where oysters grow to any extent and where culture is at all feasible. Here the bottoms are

soft and muddy. Oyster growth is limited to the roots of the mangrove trees that border the shores. The inlet known as Salt River on St. Croix island more closely approaches estuary conditions than other areas.

Besides having high temperatures, the waters of Puerto Rico and the Virgin Islands are very saline, perhaps too much so for the best growth and reproduction of oysters. Typical of this part of the world, the heat and excessive evaporation concentrates the shallow waters and increases their salt content. This is true even of the surface of the open ocean in this area, where salinity is greatly increased from evaporation and is only reduced by mixing by storms and currents. Salinities as high as 40 parts per thousand may be found even in the open sea. The range of salinity observed on this short survey was from 34 to 37 parts per thousand. Observations made by Mattox in Puerto Rico at intervals throughout a year showed a range of from 33 to 40 parts per thousand in the lagoon off Boqueron Bay. Although oysters will live and reproduce at high salinity, they do not do as well as in more brackish waters. As a matter of fact, in the lagoon areas of Puerto Rico and the Virgin Islands, the heaviest set and the greatest growth of oysters takes place at locations receiving the most abundant fresh water from run off of the surrounding area. It is possible that oysters may not thrive when the fresh water entering the lagoon at Boqueron is diverted. Construction of dams and use of the water for irrigation purposes, part of the project already underway, may have an adverse influence on the lagoon at Boqueron.

The fact that oysters are not found on the bottoms of the lagoons may be the result of several factors. In the first place the bottoms are muddy and soft and there is almost nothing for the attachment of oyster larvae. It may be possible that lack of suitable bottoms and cultch is important in limiting their location. On the other hand, the vertical aerial roots of the mangrove have oysters only in the area between tide levels. They are not found below the low water mark. There may be some characteristic of the movement of the larvae which keeps them close to the surface at the time of their attachment. Enemies of the oyster are present, including the various oyster-drilling mollusks, starfish, and fishes, which may prey on oysters that are not exposed at low water. Also, growth of bryozoans is rapid and the roots near the low water mark are often covered with them. Rapid fouling of available surfaces may limit the attachment of oyster spat.

Although the rate of growth of the oysters of Puerto Rico and the Virgin Islands is rapid, they do not reach a large size, the largest attaining a length of 2-1/2 to 3 inches, the great majority being much smaller. Indications are that continued high salinity is a factor in this, for the largest oysters are found in the areas of lagoons receiving the most fresh water. It is probable, however, that this species of oyster differs from Ostrea virginica of the mainland and the normal adult size is small.

## Possibilities for oyster culture

Possibilities for developing the oyster industry of Puerto Rico and the Virgin Islands through cultivation and improvements of the native oyster are slight. The introduction of a new oyster to the region, with good oyster-farming practices, may prove to be a solution. It should be borne in mind that the industry would not be a large one for the areas suited for the growing of oysters limit the opportunities for expansion. There is good possibility, however, that, with proper utilization of these few areas, there could be developed an industry that would more adequately supply the markets of Puerto Rico and the Virgin Islands.

Since Ostrea gigas was successfully introduced to the Pacific coast of the United States and a sizable industry has developed, consideration was given by the Puerto Rican Government to the introduction of this oyster to Puerto Rico. Although Ostrea gigas grows rapidly to large size, it is generally considered to be inferior in quality to other species. It is also better for marketing as shucked oysters than for the half-shell trade. In the Pacific Northwest it is grown in waters with salinities of 16 to 17 parts per thousand, or fresh as compared with those of the Caribbean islands. Excessive cost of importing seed oysters from the Pacific coast for planting also must be considered. For these reasons we believe that the introduction of the Japanese oyster, Ostrea gigas, into the Caribbean area would not be desirable.

Ostrea virginica as found along the eastern coast of the United States might be introduced in experimental plantings with reason to believe it might prove successful. Transportation costs would be much less, and this species is regarded as having meats of particularly high quality. Along the south Atlantic and Gulf coasts of the United States this oyster grows in waters that are not markedly different in temperature range from those of Puerto Rico and the Virgin Islands. In a few areas it is even grown in waters of very high salinity, although its best growth and reproduction takes place in more brackish water. Selection of seed for planting in the waters of the Caribbean should be carefully done with the thought of avoiding drastic changes in salinity for the planted stock. The seed should come from waters having as high a salinity as possible.

Methods of oyster culture are varied and the type used depends on the local situation to a great extent. In general it may be said that seed-producing grounds are not often good oyster-growing grounds and that transplanting of oysters is the general rule in cultivation. There are a variety of methods for catching the oyster set as well as methods for the growing and fattening of the oysters for market. They may be grown directly on the bottom or on specially constructed trays and racks.

In Europe the oyster spat or set is collected by allowing attachment of the free-swimming larvae on coated tiles. The attached spat are then removed from the tile and planted on growing beds in deep water, from which they are dredged for market, or allowed to grow on frames and trays in selected localities.

In the United States the methods are varied. For the most part the spat are allowed to attach themselves to old shell on the bottom. The seed oysters are then dredged or tonged and transplanted to growing beds. The adult oysters are taken for market from the bottom by dredging in deep water and by tongs in shallow water. In some instances they are gathered by hand when they are exposed along the shores at low tide. Wooden frames holding metal trays have been used in the United States with some success in sheltered waters. These have been described in detail by Nelson (1934) and by Evans (1943). The frames are expensive to construct and the handling of the seed oysters in the trays makes the cost of the oysters high.

Aocording to a Japanese method, large oyster shells with a hole drilled though each are placed in suitable locations to catch an oyster set. The shells bearing the young oysters are strung on wire separated from each other by bamboo spacers about 4 to 6 inches long. These are then suspended from a wooden float, some 20 by 40 feet, held up by drums or wooden barrels. After a period of growth, the oysters are taken up and marketed.

In Australia "stick" oultivation of oysters has become popular. The sticks are from the black mangrove, which proves very successful, as the bark does not deteriorate during the growing stages of the oysters. In some methods the sticks are placed on racks, rocks, shell beds, and in galvanized wire trays. These latter methods provide for the growth to a marketable size of the oyster spat caught in one place and transferred and placed on the trays. Some discussion of certain aspects of the stick methods are described by Thomson (1948).

In the waters of the islands of the Caribbean methods for the growing of oysters must be developed experimentally. Possibilities of growing market oysters from seed planted directly on the bottom are very limited and possible only in few locations. The growing of the seed on trays in the sheltered lagoons seems promising. This latter method seems particularly advantageous in the Virgin Islands where bottoms suitable for oyster culture are lacking.

From our survey of the waters of Puerto Rico, we believe that experimental oyster plantings can be made best in the lagoon of Boqueron Bay, known as Caña de Boqueron, and in the inlet on Vieques Island known as Port Mosquito.

Most of the bottom in the Caña de Boqueron is covered with a soft silt layer of mud which would interfere with oyster planting on the bottom. Soft bottom can be strengthened by the use of sand in areas which are sheltered. Experiments in Canada by Needler (1932) showed that the laying down of a sand layer of 4 to 5 inches thickness caused sufficient stiffening of a very soft bottom so that shells could be planted. These caught a good set of oysters and resulted in a good oyster bed with a firm bottom. There are excellent sandy areas close to Boqueron and the transport of sufficient sand to form an experimental oyster bed would not be difficult. With this in mind, it would be possible to plant an area with seed oysters directly on the bottom. Tray cultivation should be tried.

There is one difficulty that may be experienced in the experimental plantings of oysters in Boqueron. The area is visited by many people gathering oysters from the mangrove roots and fishing or boating in the Boqueron area. Protection of the planted oysters from poachers may be a problem, particularly when one realizes that the seed oysters planted may well be comparable in size to the oysters now taken in that lagoon.

On the southern shore of Vieques Island, Port Mosquito offers an excellent location for experimental oyster plantings. Here there are considerable areas of firm bottom, some of which may be a firm crust over a softer mud, sufficiently hard to support oysters planted directly on the bottom. Grassy areas must be avoided. Experimental plantings of oysters directly on the bottom are recommended. This body of water is isolated and completely owned by the Puerto Rican Agricultural Development Company and there is little danger that the experimental oysters would be disturbed.

Since starfish and other oyster enemies are present and may congregate at any planted bed, a watch should be made for early attacks by these oyster pests.

In the Virgin Islands, Salt River on St. Croix, Coral Harbor on St. John, and Mangrove Lagoon on St. Thomas offer possibilities for the cultivation of oysters. In these locations it seems that planting on racks or in trays will be necessary. Some experimental planting of seed oysters on the bottom in Mangrove Lagoon is possible and should be attempted. The shores of the channel leading from Benner Bay to Mangrove Lagoon appear to present the most satisfactory conditions for experimental oyster plantings on St. Thomas.

In connection with any experimental plantings and development of oyster beds in Puerto Rico and the Virgin Islands, it is suggested that examination and strict control of shellfish-bearing waters from a pollution standpoint be observed in order to avoid any hazard to the public health.

In addition, it is imperative to the establishment of experimental oyster plantings in the Virgin Islands that ownership and riparian rights be ascertained and that these plantings be made on Government-owned water bottoms with access to the plantings assured.

## CONCLUSION

Although it is impossible to predict in advance whether an introduced species will become sufficiently adapted to new conditions to assume commercial importance, there are several well-known examples of good adaptations where this has been the case - the Japanese oyster (Ostrea gigas), the shad, and the striped bass on the Pacific coast of the United States, and the smelt in the Great Lakes, for instance. Introduction of a new species of oyster rather than improvement in the native oyster now present seems to be the best solution for the development of an oyster industry in Puerto Rico and the Virgin Islands. The magnitude of the industry could never be large, but it would be adequate to meet the needs of the market in these islands.

Any attempt to develop Puerto Rican and Virgin Island oyster industries through the introduction of a new species of oyster must be started on an experimental basis and should be accompanied with a careful scientific study of the biology and ecology of oysters in the waters of the islands. The two Governments may well institute the planting of experimental oyster beds. These plantings and examination of the plantings at regular intervals should be under the supervision of biologists who can follow the chemical and physical conditions of the environment as well as the growth, survival, conditions of the oyster meats, and the spawning and setting cycles.

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