

SURVEY OF THE OYSTER

POTENTIAL OF HAWAII

by Albert K. Sparks

STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
DIVISION OF FISH AND GAME
HONOLULU, HAWAII

May 1963

ACKNOWLEDGEMENT

The author would like to acknowledge the splendid cooperation of all members of the Division of Fish and Game who aided in the survey.

CONTENTS

	<u>Page</u>
Introduction.....	1
History of Oyster Importations.....	2
<u>Crassostrea virginica</u>	2
<u>Ostrea lurida</u>	3
<u>Crassostrea gigas</u>	3
<u>Crassostrea commercialis</u>	3
<u>Crassostrea amasa</u>	3
Methods and Materials.....	4
Initial Surveys.....	4
Kaneohe Bay.....	6
Detailed Survey of West Loch, Pearl Harbor.....	6
Results.....	8
Major Beds of West Loch.....	12
Walker's Bay Bed.....	12
One Rock Bed.....	12
Three Rock Bed.....	14
Salt Bed.....	14
Gilbert's Bed.....	15
Gilbert's Little Bed.....	15
Honouliuli Station Bed.....	17
South Gate Bed.....	17
Matsuyama Fish Pond Bed.....	18
North Gate Bed.....	18
Matsuyama Little Bed.....	18
Matsuyama Submerged Bed.....	18
Laulaunui Bed.....	19
Honouliuli Channel Bed (Laulaunui Bed).....	19
Honouliuli Parallel Bed.....	19
Honouliuli Channel Middle Bed.....	20
Yoshida Bed.....	20
Hoaeae-Waikele Bed.....	21
Waikele Point Bed.....	21
Loch Point Bed (Called Kekona Bay Bed during Field work)..	23

CONTENTS (Continued)

	<u>Page</u>
Discussion.....	23
Oyster Population of West Loch.....	23
Bacteriological Examination.....	25
Histological Examination.....	27
Gonadal Development.....	27
Encysted Helminth.....	27
<u>Ostrea sandwichensis</u>	27
Associated Fauna.....	29
Salinity and Temperature.....	31
Site Search.....	33
Oahu.....	34
Kaneohe Bay.....	34
Keehi Lagoon.....	34
Kauai.....	34
Hanalei Bay.....	35
Kalihiwai Bay.....	35
Wailua Bay.....	35
Hanamaulu Bay.....	35
Nawiliwili Bay.....	35
Menehune Fish Pond.....	36
Port Allen.....	36
Hawaii.....	36
Maui.....	38
Molokai.....	39
Palaau Fish Pond.....	39
Kaunakakai Harbor.....	39
Kamalo.....	39
Keawe Nui Fish Pond or Yuen Fish Pond.....	39
Mystic Spring (Apo) or Ualapue Fish Pond.....	40
Kaopeahina (or Hustace) Fish Pond.....	40
Niaupala (or Jones) Fish Pond.....	40
Kupeke (Yoshimura) Fish Pond.....	40
Matayoshi Fish Pond.....	40

CONTENTS (Continued)

	<u>Page</u>
Recommendations.....	41
Pearl Harbor.....	41
Transplantation Experiments.....	41
Literature Cited.....	43

FIGURES

<u>No.</u>	<u>Page</u>
1. Oyster Beds in West Loch, Pearl Harbor.....	5
2. Walker's Bay Bed.....	13
3. One Rock Bed.....	13
4. Three Rock Bed.....	13
5. Salt Bed - Result of Poaching.....	16
6. Salt Bed.....	16
7. Honouliuli Channel Bed.....	16
8. Hoaeae-Waikele Bed.....	22
9. Hoaeae-Waikele Bed.....	22
10. Waikele Point Bed.....	22
11. Percent Length Composition of Oyster Beds, West Loch, Pearl Harbor.....	24
12. Encysted Tylocephalum.....	28

TABLES

<u>No.</u>	<u>Page</u>
1. Summary of Individual Oyster Bed Samples.....	9
2. Summary of Composite Samples From Each Bed.....	10
3. Estimated Area and Density of Oysters on Major Beds in West Loch.....	11
4. Results of Bacteriological Examination of Pearl Harbor Oyster Bed Waters and Oysters.....	26
5. Water Temperature and Salinity of West Loch.....	32

INTRODUCTION

In late June, 1960, Mr. Kenji Ego, Chief, Fisheries Branch, Division of Fish and Game of the State of Hawaii, visited the author at the College of Fisheries, University of Washington, Seattle, Washington. Mr. Ego informed the author that large beds of oysters were present in one or more bays on the Island of Oahu, Hawaii. Since no one on the staff of the Division of Fish and Game had had extensive experience with oysters, Mr. Ego was interested in suggestions for determination of the potentialities for oyster culture in Hawaii.

As a result of this conversation, a letter was written to Mr. Ego in July of 1960, outlining a preliminary program for an initial survey and some possible research needs that might arise from the survey.

After considerable correspondence, a contract between the State of Hawaii through the Board of Land and Natural Resources, with authorization granted by the First State Legislature of Hawaii as Act 125 of the Regular Session of 1961, and the author was signed and the preliminary survey was conducted during the period of March 12 through March 31, 1962.

The contract stated that extensive beds of oysters found in Pearl Harbor, Kaneohe Bay, and other areas in the State held promise for oyster propagation. These facts emphasized the need for investigation by a specialized professional to ascertain the feasibility of developing the oyster resource in the State of Hawaii and to formulate a program for the proper utilization of the resource. The primary phase of the work to be performed by the Contractor was to consist of a preliminary survey to determine the feasibility of developing the commercial and/or recreational utilization of the oyster resources found at Pearl Harbor and Kaneohe Bay. The investigation at Pearl Harbor and Kaneohe Bay was to include, but not be limited to, a survey of the extent and status of the oyster beds, analysis of the size and age composition of the oysters on the bed, box counts, examination of boxes for evidence of predation, study of associated fauna, study of condition index for marketability, species composition and consideration of problems associated with fecal contamination. Should findings of the preliminary survey appear favorable for the development of the oyster resource, the Contractor was to submit a detailed proposal, including cost estimates, for the conduct of a research program which will permit a study of the growth, condition and survival of the oyster. If indicated by the results of the preliminary survey, the Contractor was to also suggest a course of action or other management measures which should contribute toward the proper development and utilization of the oyster resource.

A secondary phase of the investigation was to consist of a cursory survey of selected shore areas around the islands of Oahu, Kauai, Hawaii, Maui, and Molokai to determine the suitability of these areas for the stocking of oysters and/or other shellfish such as clams.

History of Oyster Importations

Prior to the present survey, the history of oysters in Hawaii had been one of numerous importations of various species with, in many cases, initial encouraging survival but eventual loss of the stocks. Several publications have discussed these facts: Coleman (1923) reported on efforts to acclimatize both the eastern oyster, Crassostrea virginica, and the eastern soft shell clam, Mya arenaria, in Hawaii. Ostergaard (1936) discussed the introduction of edible species of shellfish and Edmondson and Wilson (1940), in a paper on the shellfish resources of Hawaii, discussed the importation of oysters as well as the presence of local species such as Ostrea sandwichensis, which is too insignificant for human food, and the fossil form, O. retusa. Finally, Brock (1952 and 1960) summarized the history of introduction of aquatic animals to Hawaii, with a detailed and presumably fairly complete list of importations of oysters.

According to Brock, five species of oysters have been introduced. These are Crassostrea virginica, the eastern oyster; Ostrea lurida, the Olympic oyster; Crassostrea gigas, the Japanese or Pacific oyster; Crassostrea commercialis, the Australian oyster; and Crassostrea amasa, the coral rock oyster. Ostrea (Crassostrea) cuculata, the Indian oyster, is listed by Edmondson and Wilson (1940) as an import and by Brock in his 1952 report as an Australian oyster import, but in the 1960 paper Brock lists C. commercialis and not C. cuculata. It is apparent that Brock accepted Edmondson and Wilson's specific name in his earlier paper but subsequently corrected the error.

The history and fate of importations of each of the above species will be summarized as background information for the present study.

Crassostrea virginica

There is some conflict in the statements of Edmondson and Wilson (1940) and Brock (1960) as to the planting which resulted in establishment of this species on Oahu. The first importations, in 1871 and 1873, apparently were unsuccessful. Brock says that plantings in Pearl Harbor by a private individual in 1893 and 1895 were both successful, while Edmondson and Wilson imply that the first successful transplants were by the initial Territorial Division of Fish and Game imports in 1921. The latter authors stated there was evidence that spawning and setting of this species had occurred in Pearl Harbor, but then stated further that, at the time of their writing (1940), the eastern oyster had not become a local commercial product.

Among the attempts to establish C. virginica in areas other than Pearl Harbor were plantings at Kalihi (1883), Aiea (1921), Coral Garden (Heeia) (1921), Kaneohe Bay (1923, 1924), Hanaloa Pond (1929), Mokapu (1929), Kaneohe Bay and Punaluu (1940) on the island of Oahu. Apparently none of these attempts were successful. Additionally, eastern oysters, both from the mainland and from the established beds in Pearl Harbor have been transplanted to various other islands, including Kauai (Nawiliwili Bay, 1949), Molokai, Maui, and Hawaii. Brock stated that some evidence indicated successful spawning in these transplants. In the present survey, however, no knowledge (among the wardens) exists of survival of plantings on other islands and no evidence was seen by the author in visiting potential transplant sites.

Ostrea lurida

There was, according to existing records, only one attempt to establish the Olympic oyster (called California oyster by Brock) in Hawaii, that being an importation of some 3,000 specimens to Manana, Oahu from San Francisco in 1893 by John P. Colburn, who successfully (according to Brock) established C. virginica in the same area at the same time. No records exist of the fate of the Ostrea lurida from this shipment, but it is presumed that they either failed to survive or to reproduce. Since the Olympic oyster is a cold water species, the latter case is most likely; certainly, the species failed to become established.

Crassostrea gigas

The first recorded importation of the Japanese or Pacific oyster was 1926, with a small planting made in Kalihi and Kaheohe on Oahu. Additional plantings of small numbers of this species took place in Pearl Harbor and at Mokapu on Oahu in 1938, then, in 1939, a large shipment of Japanese seed oysters was placed in two areas, Coconut Island and Mokapu, on Oahu. The actual size of this planting was, according to Edmondson and Wilson (1940), "more than one million seed", while Brock (1960) stated that 2,150,000 seed were planted. Edmondson and Wilson noted that, in the four months from that planting until their paper was written, exceptionally rapid growth had occurred and they advanced the hope that the species would become permanently established. Brock (1960) listed C. gigas as an introduced species which probably did not survive. As will be pointed out in a later section, large numbers of this species are present in Kaneohe Bay at the present time, but apparently the species failed to gain a foothold in Pearl Harbor despite the several attempts mentioned above and at least one importation of seed oysters by the Matsuyama family about three years ago (1959).

Crassostrea commercialis

Brock (1960) listed two importations of this Australian species, a very small shipment of three bushels in 1928 and a somewhat larger shipment of 24 bushels in 1929. Despite the small size of both importations, they were further divided into even smaller lots and planted in various locations on Oahu, including West Loch of Pearl Harbor, Sand Island, and various areas in Kaneohe Bay. Edmondson and Wilson and Brock reported that all the stock died within six months of planting.

Crassostrea amasa

A shipment, consisting of one 75-pound sack of rock oysters from Australia was brought to Coconut Island in Kaneohe Bay in 1956 and placed in enclosed ponds. These oysters survived well, some at least until 1959, but apparently no reproduction occurred and examination of the ponds during the present survey indicates the original population has died out.

Although the numerous attempts to establish commercial stocks of edible oysters have met with complete success only in West Loch of Pearl Harbor and with limited success in Kaneohe Bay, it is obvious that at least part of the past failures of species to establish themselves has been due to insufficient initial stocks, to planting in unfavorable environmental situations when more suitable locations existed nearby, to inadequate preparation of the areas where the plantings were to be made, and, in at least two cases, to unusual hydrographic and meteorological phenomena.

METHODS AND MATERIALS

Initial Surveys

A preliminary survey of West Loch, Pearl Harbor and Kaneohe Bay was made early in the first week of the investigation to establish the location, approximate number, and size of the major oyster beds and to develop a sampling program for the more intensive survey which was to follow. The initial survey of West Loch demonstrated that extensive beds of oysters existed in that area (fig. 1) and that an intensive effort by personnel of the Fisheries Branch of the Division of Fish and Game would be necessary to produce an intelligent estimate of the oyster stocks in West Loch.

After examining a number of beds exposed at low tide, it was decided to collect a series of oyster samples from the Three Rock Bed in order to arrive at the number of samples necessary to determine the density of oysters on each bed. To accomplish this, a one square yard sampling device of stiff wire was constructed and one square yard samples were taken from the center, from halfway between the center and the seaward edge, and halfway between the center and the landward edge of the Three Rock Bed. All oysters and dead shell in each sample were placed in sacks and returned to the laboratory for analysis, which included culling to remove all dead shell, determination of the volume of dead shell and oysters, and length measurements of all living oysters. Analysis of these samples revealed that considerable differences existed in the number of oysters per square yard at these different sites, with 529 oysters in the seaward sample, 383 in the middle, and 82 oysters in the square yard shoreward sample.

To determine if this relationship was characteristic of the bed, a similar series of samples was taken 50 yards from the first series. The ratios were the same in this series of samples with the greatest number of oysters on the outer side, next most in the middle, and the fewest in the shoreward sample; too, the numbers of oysters in this second series were similar to those in the first series, being 645, 378, and 102 from seaward to shoreward. Because of the relationship of one area of the bed to the other, it was decided to routinely sample each bed with three samples taken in the manner described.

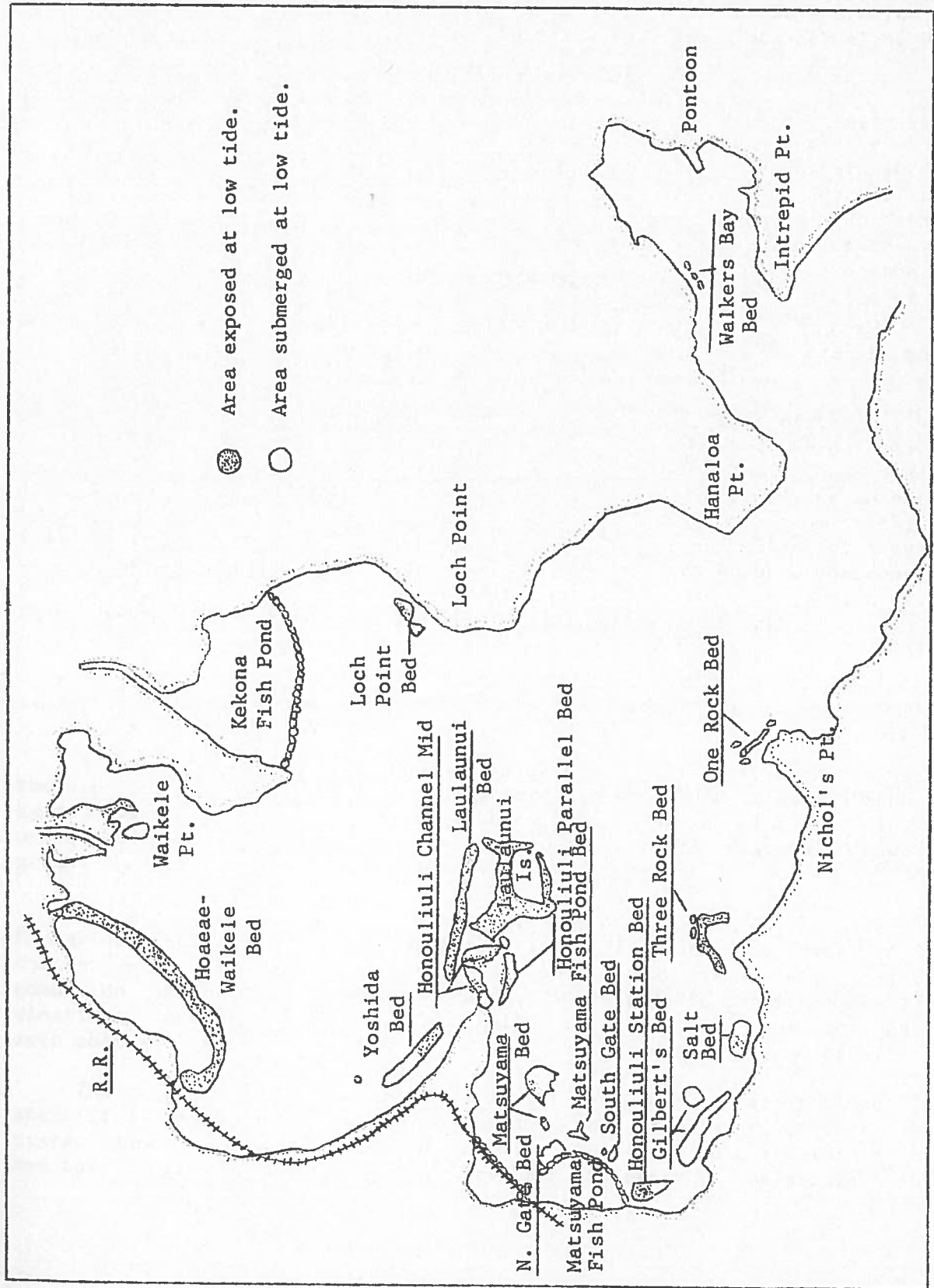


FIGURE 1. Oyster beds in West Loch, Pearl Harbor, Hawaii

Kaneohe Bay

A preliminary examination of Kaneohe Bay was first conducted on Tuesday, March 13. In this survey the shoreline and shallows along the shoreline from the Yacht Club Basin to Coconut Island to Matson's Point and back along Heeia fish pond were studied.

A very heavy set of both large and small Japanese oysters, Crassostrea gigas, was found on the pilings, coral bulkheads, cement bulkheads, rocks, and other objects providing suitable sites for setting over the entire eastern portion of the bay. Scattered oysters were observed on the south side of Coconut Island. None of the rock oysters, C. amasa, planted in fish ponds on Coconut Island were seen. A very few scattered oysters were seen along the bay side of the lava rock bulkheads of the Heeia fish pond and a very few live oysters on the inside wall of the fish pond. No oysters were found in the Matson's Point area despite a careful examination of the shoreline and the coral reefs in the vicinity. It appears that Coconut Island marks the westward terminus of Crassostrea gigas in Kaneohe Bay.

The shallow bottoms and coral reefs in the eastern part of the bay were carefully checked on this and a subsequent visit. No oysters were found on the bottom on either visit, nor were any evidences of past beds, such as dead shell, located. Warden Bowman of the Fish and Game Division informed the author that there were at one time numerous clusters of oysters on the bottom in this area. It is extremely interesting, if this is correct, that no remains of these oysters can now be found. No potential predators such as starfish or predaceous snails were noted in the bottom examination; the possibility still exists, however, that the absence of any oysters on the bottom is due to predation.

Detailed Survey of West Loch, Pearl Harbor

As mentioned previously, the preliminary survey in West Loch demonstrated the need for an intensive study in that area and the lack of such a need in Kaneohe Bay. Based on the initial studies, a plan of sampling the West Loch oyster beds was developed. In this survey, it was first planned to have three groups operating in the field each day.

One group, consisting of the author; Mr. Carl Nemoto, Chief, Marine Section, Fisheries Branch; Mr. James Yamashiro, District Fish and Game Warden of Oahu; and another warden as a boat operator was set up to locate beds, collect oysters for condition index, collect samples of water and oysters for coliform level determinations, determine temperature and salinity of the water over each bed, obtain such photographs as were judged to be needed, and coordinate the other groups.

The other two groups were initially set up to measure the beds, collect stratified random samples of oysters as described previously, collect the associated fauna, determine the amounts of live oyster and dead shell in each sample and take length measurements of live oysters collected in the samples. Due to

illness among the personnel of the Fisheries Branch, we were restricted to a surveying group and one sampling group for much of the period. The various phases of the study are described below.

- (1) As each major bed was located by the surveying party, its location was pointed out to a sampling party. The first function of this latter group was to determine the length and width of the bed by pacing. In some instances, stakes were driven to outline the submerged beds. From knowledge of the length and width of a specific bed, it was possible to calculate its approximate area.
- (2) In addition to determination of the dimensions of each bed, certain other physical and chemical data were obtained. These included the character of the bottom within the bed and immediately adjacent to it, the approximate depth of the bed, the amount of submergence or exposure at low tide, the salinity, and the temperature of the water covering the bed at the time of sampling.
- (3) At each bed, and at some additional locations, water samples were collected for fecal type coliform level determination by the Hawaii State Department of Health. Additionally, from each bed a sample of oysters was collected for fecal type coliform level determination.
- (4) On most of the beds, because of the experiences described in the preliminary studies, a series of three stratified random samples, including seaward, middle and landward samples of one square yard of live oysters and dead shell, were collected. These samples were placed in gunny sacks containing identifying labels at the time of collection and were transported to the Fish and Game Division's laboratory at Kewalo Basin for processing. There the samples were washed to remove the mud, so the smaller oysters would not be overlooked, and carefully culled to separate all live oysters from dead shell. The volume of dead shell in each sample was measured and recorded in parts of bushels.

The lengths of all live oysters were then measured to the nearest millimeter with vernier calipers, the length measurement being of the right valve from the umbo to the furthest extension of the shell. As each oyster was measured it was placed in a wire basket and its length recorded.

The culling and measuring of each sample was done by a crew of three to five men. In measuring, one man recorded the lengths of oysters as the two to four men measuring called out the lengths. The oysters were broken down into three sizes for recording; those under 26 millimeters (one inch), between 26 millimeters and 76 millimeters (one to three inches), and those over 76 millimeters. Thus, when all the live oysters in a one-square yard sample had been measured, the volume, the number and size distribution of all live oysters in that sample were known.

Additionally, the number of oysters in the 26-76 millimeter and over 76 millimeter size groups necessary to fill a one-bushel container was determined so that an eventual estimate of the number of bushels as well as the number of individuals in each size group could be made.

During the washing, culling, and measuring, as well as in the collection of oysters in the field, all associated fauna was removed and placed in jars of 10% formalin. The author, in searching for beds, etc., made notes of the fauna associated with the oysters and collected such forms as could be readily captured. The preserved associated fauna was shipped to the College of Fisheries, University of Washington for subsequent identification, largely with the use of Edmondson's "Reef and Shore Fauna of Hawaii."

From each oyster bed studied in the intensive survey, a random sample of 10 oysters was taken for determination of Condition Index (C.I.). This value is a measure of fatness or of marketability and is a standard tool of both the oyster biologist and the commercial oyster grower. It consists of the determination of the ratio of the dry weight of the oyster meat divided by the volume between the two shells multiplied by 100. The condition indices were, with the initial help of the author, determined by Mr. Carl Nemoto, Chief of the Marine Section of the Fisheries Branch of the Division of Fish and Game.

A small sample of oysters was randomly selected from West Loch for histological examination and was fixed in Zenkers, washed in tap water, stored in 50% isopropyl alcohol, and shipped to the College of Fisheries where they were dehydrated and blocked in paraffin by standard methods, then sectioned and stained in Harris Hematoxylin and Eosin. From these slides, information on the stage of sexual development and, thus, on the spawning season of the oysters in West Loch was obtained. Examination of these slides for parasites or disease producing microorganisms was also made.

Samples of the water over each bed and at certain selected points in mid-harbor and the channel connecting West Loch with Middle Loch were collected and taken to the State Health Department for analysis of the fecal coliform level of the water. Oyster samples were also collected from most of the major beds for fecal coliform determination.

Salinities of the water over each bed and in certain other selected sites in West Loch and approaches were obtained by means of a hydrometer.

RESULTS

A description of each bed, including the area and bottom composition of the bed, density, size distribution, and condition of the oysters on each bed will be presented. The data on numbers of oysters of each size category, mean length in each category, mean number per square yard, and mean length of all oysters in each sample are summarized in table 1. In table 2, the data on sample position, number and mean length in each size category, average number per square yard in each size category, and average number per square yard for each bed is presented. The fecal coliform levels of the water and oysters and the associated fauna of the entire area will be discussed later as a unit.

TABLE 1. Summary of Individual Oyster Bed Samples

Name of Oyster Bed	Sample	25 mm. & below No. $\bar{x}$ mm.		26-76 mm. No. $\bar{x}$ mm.		77 mm. & up No. $\bar{x}$ mm.		Total No. Oysters	Total $\bar{x}$ mm.
One Rock	Seaward	29	20	131	40	44	101	204	51
" "	Middle	114	20	347	48	168	94	629	55
" "	Landward	6	21	58	48	105	109	169	85
Walker's Bay	Middle	16	21	71	49	90	106	177	76
Matsuyama									
Fish Pond	1	15	23	249	51	133	116	397	72
" "	2	53	22	183	46	74	105	310	56
" "	3	34	18	226	42	101	123	361	67
Three Rock	Seaward	133	22	425	37	87	116	645	44
" "	Landward	9	22	87	39	16	123	112	50
" "	Middle	32	21	216	49	135	96	383	63
" "	Seaward	66	22	371	36	95	115	532	48
" "	Landward	1	22	37	45	44	118	82	84
" "	Middle	26	22	206	47	148	102	380	67
Gilbert's		27	19	97	37	61	116	185	60
Honouliuli	Seaward	24	22	187	36	85	113	296	57
"	Middle	57	30	323	37	135	124	515	59
Bed at south gate of fish pond	1	130	20	271	38	175	124	576	60
South Gate	2	4	22	55	48	63	119	122	84
" "	3	14	18	87	49	100	120	201	82
Laulaunui	Seaward	27	21	147	38	57	105	231	52
"	Middle	96	20	309	54	104	93	509	56
"	Landward	17	20	174	36	27	105	218	43
Waialeale	Seaward	105	20	249	43	151	125	505	63
"	Middle	24	20	62	41	57	124	143	70
"	Landward	55	20	106	43	59	118	220	57
Matsuyama									
Little	Landward	23	22	273	44	85	124	381	61
" "	Middle	19	20	312	51	97	104	428	62
" "	Seaward	31	22	233	46	66	116	330	57
Salt	Seaward	199	21	331	35	70	110	600	39
"	Middle	67	21	209	39	66	93	342	46
"	Landward	8	19	65	40	32	121	105	63
Honouliuli									
Parallel	Seaward	4	23	75	39	13	146	92	53
" "	Middle	5	23	212	52	55	94	272	60
" "	Landward	16	22	87	38	10	121	113	43
Matsuyama									
Submerged	Middle	0	--	101	--	38	--	139	65
" "	Seaward	0	--	5	44	4	92	9	65
" "	Landward	0	--	40	46	13	--	53	62

TABLE 2. Summary of Composite Samples From Each Bed

Name of Oyster Bed	No. Samples	25 mm. & below No. $\bar{x}$ mm.		26-76 mm. No. $\bar{x}$ mm.		77 mm. & up No. $\bar{x}$ mm.		Average Number			Per Square Yard Aggregate
		No. $\bar{x}$ mm.	No. $\bar{x}$ mm.	No. $\bar{x}$ mm.	No. $\bar{x}$ mm.	<25 mm.	26-77 mm.	>77 mm.			
Walker's Bay	1	16	21	71	49	90	106	16	71	90	177
One Rock	3	149	20	536	44	317	100	50	179	106	335
Three Rock	6	267	22	1342	40	525	107	45	224	88	357
Salt	3	274	21	605	37	168	105	91	202	56	349
Gilbert's	1	27	19	97	37	61	116	27	97	61	185
Honouliuli	2	81	28	510	37	220	120	41	255	110	406
Bed at South gate of fish pond	3	148	20	413	41	338	122	49	138	113	300
Matsuyama fish pond	3	102	21	658	49	308	116	34	219	103	356
Matsuyama little	3	73	21	818	47	248	114	24	273	83	380
Matsuyama submerged	3	0	--	146	53	55	95	--	49	18	67
Laulaunui	3	140	20	630	45	188	98	47	210	63	320
Honouliuli	3	25	22	374	46	78	106	8	125	26	159
Parallel Hoaeae-	3	184	20	417	42	267	123	61	139	89	289

TABLE 3. Estimated Area and Density of Oysters on the Major Beds in West Loch, Pearl Harbor

Bed	Area in Sq. Yd.	Ave. No. per Sq. Yd.	Estimated No. on Bed	Ave. No. Bushel per Sq. Yd.	Estimated No. Bushels
Walker's Bay	500	177	88,500	0.4	200
One Rock	2,500	335	837,500	0.5	1,250
Three Rock	7,500	357	2,677,500	0.7	5,250
Salt	4,700	349	1,640,300	0.6	2,820
Gilbert's	9,300	185	1,720,500	0.4	3,720
Gilbert's Little	4,400	185*	814,000	0.4*	1,760
Honouliuli Station	7,300	406	2,963,800	0.7	5,110
South Gate	1,100	300	330,000	0.6	660
Matsuyama Fish Pond	1,100	356	391,600	0.6	660
North Gate	3,100	368	1,140,800	0.5*	1,550
Matsuyama Little	1,300	380	494,000	0.6*	780
Matsuyama Submerged	7,200	67	482,400	0.1	720
Laulaunui (Honouliuli Channel)	15,300	320	4,896,000	0.5	7,650
Honouliuli Parallel	3,300	159	524,700	0.2	660
Honouliuli Channel Mid.	18,000	159*	2,862,000	0.2	3,600
Yoshida	12,900	67*	864,300	0.1*	1,290
Hoeaeae- Waikele	43,000	289	12,427,000	0.4	17,200
Waikele Point	3,400	67*	227,800	0.1*	340
Loch Point	4,100	67*	274,700	0.1*	410
	150,000		35,657,400		55,630

* Estimated.

Major Beds of West Loch

Walker's Bay Bed

This bed, which did not exist three years ago when the first oyster survey was made by the Division of Fish and Game, actually consists of three small distinct clumps separated by several yards of soft mud, (fig. 2). It is likely that the three areas, which are exposed at low tide, will be joined into one continuous bed within a short time. The entire bed has a length, discounting the intervening unproductive spaces, of 190 feet and is approximately 24 feet wide, thus having an area of approximately 500 square yards. Virtually all wrecked ships (which are common in the area), pilings, rocks, and other suitable objects in Walker's Bay are covered with a heavy set of oysters, further indicating that this area will increase in importance in oyster production.

Visual inspection of the oyster producing areas on this bed led to the decision that a single square yard sample would be representative of the entire area. Analysis of the sample revealed that the oysters on this reef were less crowded (fewer per square yard) and were larger (greater mean length) than those found anywhere in West Loch except the shoreward samples on the Three Rock and Southgate Beds.

The sample showed that the density of the bed was an average of 177 oysters per square yard. An estimated 88,500 live oysters are present on this bed. Of these 16 x 500 (8,000) should be less than 26 millimeters, 71 x 500 (35,500) should be between 26 and 76 millimeters in length, and 90 x 500 (45,000) should be greater than 76 millimeters.

The sample contained 1.3 bushel of dead shell and 0.4 bushel of live oysters, indicating a total of 200 bushels of oysters on the bed. Condition of oysters from Walker's Bay Bed was determined, revealing a C.I. of 7.2. This is considerably below the figure of 10.0 which is considered the lowest limit for commercial utilization.

One Rock Bed

The first major oyster bed found inside West Loch proper is the One Rock Reef, located just off Nichols Point on the southern shoreline of West Loch, approximately 1,000 yards west of the Navy Small Boat Pier. This bed is named for a large rock protruding above water at high tide, marking the westward end of the major part of the reef, though a small separated clump of oysters is located a few yards due west of the rock (fig. 3).

One Rock Bed is a large reef, consisting of three portions, a long reef 220 feet in length and 80 feet wide running from the rock southwest parallel to the shoreline of Nichols Point, the small clump west of the rock which is 64 by 40 feet, and another small clump measuring 64 by 36 feet lying directly off the tip of the main reef, but a short distance from it. Large portions of all three areas are above water at low tide, exposing a dense population of oysters. Here, as in most other areas, the greatest number of oysters per square yard was located on the center (exposed) part of the reef, while the fewest, but largest

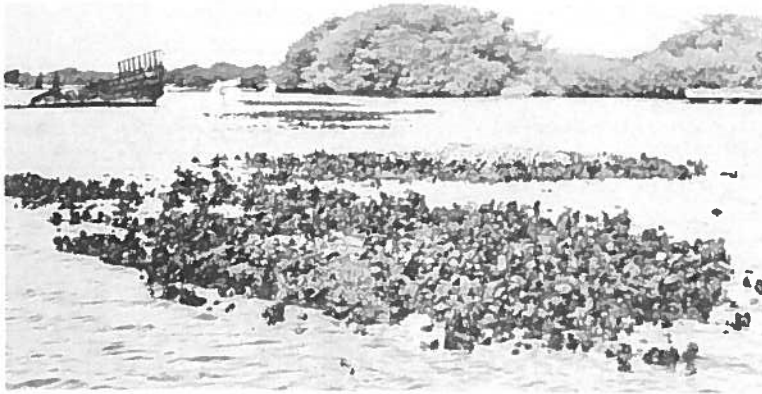


FIGURE 2. Walker's Bay Bed



FIGURE 3. One Rock Bed



FIGURE 4. Three Rock Bed

oysters, were located on the shoreward side of the bed. The samples taken from the shoreward, center, and seaward areas of the bed were combined to form a composite sample representing the bed. This resulted in an estimate of 335 oysters per square yard, of which 50 should be less than 26 millimeters in length, 179 should lie between 26 and 76 millimeters and 106 oysters per square yard should be larger than 76 millimeters in length. By multiplying the average number (335) per square yard by the number of square yards on the bed (2,500), we can estimate that 837,500 oysters are present on the entire bed. Measurement of the amounts of live oysters and dead shell from each sample shows an average of 0.5 bushel of live oysters per square yard, indicating a total volume of 1,250 bushels of oysters on the bed. The oysters on One Rock Bed were not fat, determination of condition revealing a C.I. of 7.2.

Three Rock Bed

A large bed lying 650 yards due west of One Rock Bed and just off a point on the southern shore of West Loch, this bed was estimated to be approximately 7,500 square yards in total area, being 790 feet in length by 86 feet wide. It is named for a large rock (fig. 4) having three points protruding above the water at high tide. This rock is located approximately in the middle of the bed.

As mentioned in the Methods Section of this report, six square-yard samples were taken from the Three Rock Bed. These six samples, two each from the middle, seaward and landward sides of the bed were combined to obtain an estimated average number of 357 oysters per square yard, of which 45, 224, and 88 were estimated to lie within the less than 26 millimeter, 26-76 millimeter, and over 76 millimeter size ranges respectively. From the calculations derived from the six samples, an estimated 2,677,500 oysters are present on this bed. An average of 0.7 bushel of oysters per square yard was found which indicates a volume of 5,250 bushels of live oysters on the bed. Portions of the top of this reef have been cleaned bare of oysters by poachers. The Condition Index of a sample of oysters from Three Rock Bed was 7.1, indicating the oysters on this bed are not fat enough for utilization.

Salt Bed

Salt Bed is located in the slight embayment west and a bit south of Three Rock Reef and is separated from the latter bed by about 275 yards. Because of its convenient proximity to the shoreline, Salt Bed is heavily poached. During the present investigation, two poachers were apprehended taking oysters from this reef. As a result of poaching, parts of the exposed portion of Salt Bed are bare (fig. 5).

The outer portion of the bed has a density of 600 oysters per square yard, exceeded only by the outer portion of the Three Rock Bed and the middle sample from One Rock Bed. Analysis of mean lengths of oysters from the combined sample of this bed again shows it to be one of the best beds in West Loch. There are more potential seed oysters per square yard, i.e., under 26 millimeters on this bed, than any other in the bay and also significant numbers in the intermediate size range of 1-3 inches. It is likely that the reduced numbers of oysters in the larger size categories, particularly in the inner samples is at least partially due to poaching.

Salt Bed is an extensive bed, 260 by 164 feet in size, encompassing approximately 4,700 square yards of firm bottom. Most of the bed is submerged with only a narrow inner reef and several small clumps of oysters exposed at low tide (fig. 6). The combined sample from this bed indicate an estimated mean of 349 oysters per square yard, or 1,640,300 oysters on the entire bed of which 427,700 are estimated to be less than 26 millimeters in length, 949,400 between 26 and 76 millimeters in length, and the remaining 263,200 oysters more than 76 millimeters in length. Condition Index of a random sample of oysters from Salt Bed revealed a C.I. of 8.0, again a figure considered by mainland oystermen as too low for commercial utilization. From calculations of the volumes of oysters from each sample, 2,820 bushels of live oysters are estimated to be present on Salt Bed.

Gilbert's Bed

Lying 150 yards west of Salt Bed and just off the next point of land, is a submerged bed about twice the size of Salt Bed, approximately 840 feet long and 100 feet wide and having an area of about 9,300 square yards. This bed was named for Mr. Georges Gilbert, skipper of the Hawaii Division of Fish and Game's research vessel M.V. Makua, who located it. Approximately one-half of the bed has a dense growth of oysters while the other half is composed of scattered clumps. Because this bed was found near the end of the survey, only a single oyster sample was taken for size analysis and the estimate of the number and size distribution for the entire bed will be based on it. In this one square yard sample a total of 0.9 bushel of live oysters and dead shell was collected, of which 0.4 bushel was composed of live oysters. Assuming this to be representative of the bed, an estimated 3,720 bushels of oysters are present on this bed. Since the sample included 185 oysters an estimate of 1,720,500 oysters are located on this bed, of which 251,100, 902,100, and 567,300 respectively are in the three size categories of under one inch, one to three inches, and over three inches.

Gilbert's Little Bed

Lying just off the northeast corner of Gilbert's Bed and almost connected with it is another submerged bed, designated Gilbert's Little Bed, that is roughly oval in outline and approximately 244 by 164 feet and has an area of approximately 4,400 square yards. Since the density of oysters on this bed appeared to be about the same as on the adjacent Gilbert's Bed and because of the limitation of time, no samples were taken. If we assume the density to be the same as on the adjacent Gilbert's Bed we can estimate 814,000 oysters or 1,760 bushels of oysters on this bed.

A sample of oysters was taken for Condition Index from Gilbert's Little Bed, the results revealing the C.I. to be 11.33, one of the higher levels in West Loch and sufficiently high for commercial utilization.



FIGURE 5. Salt Bed -
Result of Poaching



FIGURE 6. Salt Bed



FIGURE 7. Honouliuli
Channel Bed

Honouliuli Station Bed

This bed, another large, mostly submerged reef, lies just north of Gilbert's Bed and just off the Matsuyama family's house and east of the Honouliuli railroad station. The total dimensions of the bed are 476 feet long by 152 feet wide through most of its length, narrowing down to a tongue 40 feet wide for the last 60 feet of the bed. The area of the bed is calculated to be approximately 7,300 square yards. Only two narrow, parallel strips of this bed are exposed at low tide, the rest of the bed being permanently submerged. The area included in the bed is of firm mud and heavy shell. The entire western side of this embayment has a firm bottom with scattered clumps of oysters present between the numerous dense beds.

The oyster population on Honouliuli Station Bed was studied on the basis of two samples, from the middle and outer portions of the reef; the landward station was eliminated because of the press of time. Based on the two square yard samples, we find that an estimated average of 406 oysters per square yard are present, the greatest density estimated for any bed in West Loch. It should be pointed out, however, that on certain beds the seaward sample and the middle sample contained larger numbers of oysters than the comparable sample from Honouliuli Station Bed, but the lesser densities in the shoreward samples lowered the average density for the entire bed. Since the shoreward sample was omitted from the Honouliuli Station Bed sampling, it is quite likely that a slightly exaggerated estimate of the population of this bed has been obtained. The 406 oysters per square yard consist of 41 below 25 millimeters in length, 255 between 26 and 76 millimeters, and 110 greater than 76 millimeters in length; the estimated total number of live oysters on the bed is 2,963,800.

After culling the samples, the middle sample was found to contain 1.0 bushel of live oysters and 0.6 bushel of dead shell, while the outer sample contained 0.4 bushel of live oysters and 1.1 bushel of dead shell and trash. If the average volume of 0.7 bushel of live oysters per square yard is accurate, the Honouliuli Station Bed contains 5,110 bushels of oysters. The Condition Index of a sample from this bed was determined to be 8.0, indicating that fattening of the oysters should occur prior to utilization.

South Gate Bed

This bed, actually consisting of two reefs separated by a narrow strip of mud, is located 100 yards northeast of the previous bed and due east of the southern gate of the Matsuyama fish pond for which it is named. The South Gate Bed is a fairly large bed consisting of large numbers of large oysters. The mean number and mean volume of each sample are shown in table 3. The combined samples show 49, 138, and 113 to be the average numbers of each of the three size categories for a combined estimate of 300 oysters per square yard. Since the bed contains an estimated 1,100 square yards, the total estimate of the bed is 330,000 oysters. Each square yard of the bed was estimated to contain 0.6 bushel of live oysters, providing an estimate of 660 bushels of oysters present on the bed.

The oysters found on South Gate Bed are fatter and in better condition than in any of the beds previously discussed, with a C.I. of 12.5 which is considerably above the C.I. of 10.0 considered to be the point at which oysters are suitable for commercial utilization.

Matsuyama Fish Pond Bed

Lying just north and slightly east of the South Gate Bed is a T-shaped bed of moderate size, 1,100 square yards and containing a dense growth of oysters. Only one series of three samples was taken because the density seemed to be the same over the entire bed and because of the limitation of time. The samples contained an average of 356 live oysters, giving an estimate of 391,600 oysters present on the bed. The three samples contained an average of 0.6 bushel of oysters per square yard, indicating 660 bushels of oysters present on the bed.

North Gate Bed

This bed consists of three prongs emerging from the rock wall of the north side of Matsuyama Fish Pond near the gate opening to the West Loch for which the bed was named. No samples were taken from North Gate Bed because of time limitations, instead the densities of the two adjacent beds, Matsuyama Fish Pond Bed and Matsuyama Little Bed, were averaged to obtain an estimated density of 368 live oysters. On this basis the number of oyster on this bed was estimated to be 1,140,800.

A sample of oysters from North Gate Bed revealed a C.I. of 9.16.

Matsuyama Little Bed

A small bed, 150 by 80 feet, lies east of the previously discussed bed and a short distance north of Matsuyama Fish Pond Bed and is almost completely exposed at low tide. Though small in size, this bed is densely populated, particularly with oysters of medium size. There was an average of 273 oysters in this size category per square yard. The average number of oysters of all categories per square yard for the bed is estimated to be 380, resulting in an estimate of 494,000 oysters totaling 780 bushels on the bed.

Matsuyama Submerged Bed

This is a large submerged bed located due east of the previous bed. Although completely submerged the bed is almost shallow enough to be exposed at low tide, since a water depth of only two or three feet occurs over the bed at low tide. The oysters on this bed tend to be much more scattered than on any of the other major beds in West Loch. Of particular interest was the complete absence of small oysters (less than one inch) in the three samples. Quantities of dead shell forming a reef are present over most of the area, but there are areas of mud bottom with only scattered dead shell and few live oysters found on the bed.

The perimeter of the bed was outlined by sticking poles in the mud along the edges of the bed and dimensions obtained by pacing off the length and breadth. The bed was determined to be oval in shape, 260 by 250 feet, with an area of approximately 7,200 square yards. An average of only 0.1 bushel of live oysters per square yard was obtained from the three samples collected on this bed, leading to an estimate of 720 bushels containing 482,400 oysters on the entire bed. Thus, although the present bed has 5 times the area of the adjacent Matsuyama Little Bed, the volume and number of oysters are approximately equal on the two beds. Of particular interest was the fact that no oysters below 26 millimeters were found

in any of the samples indicating, perhaps, that a successful spatfall did not occur in the past year on this bed. This bed was sampled in the previous survey (Unpublished manuscript, Division of Fish and Game, Hawaii) and a large number, 964, oysters per square yard reported, suggesting that this bed has been subjected to heavy poaching in recent years.

Laulaunui Beds

The next group of beds connect Laulaunui Island to the point of land projecting finger-like towards the island. It is extremely difficult to ascertain where one bed ends and another begins in this area, because most of the bottom between the island and the point as well as from the western tip of Laulaunui Island supports an almost continuous heavy growth of oysters, with extensive reefs developed which are exposed at low tide. Despite the difficulty in separating the various beds and the necessity for somewhat arbitrary decisions as to where one bed begins and ends, this complex of oyster beds was measured and sampled and will be considered as a group of beds rather than one bed.

Honouliuli Channel Bed (Laulaunui Bed)

This large bed, stretching from the western tip of the northern side of Laulaunui Island to the level of Honouliuli Point, is approximately 1,500 feet in length and from 100 to 175 feet in width (fig. 7). Because a portion of the reef, at about the western end of Laulaunui Island is usually submerged at low tide, this bed was originally considered to be two beds and was sampled accordingly. When the measurements of the supposed two beds were paced off, it was discovered that they actually were continuous and will be considered as a single bed in this report. As mentioned previously, this is an extremely large bed, with an area of 137,500 square feet or approximately 15,300 square yards. The usual three samples were taken from this bed, showing it to contain an average of 320 live oysters per square yard and an estimated total of 4,896,000 oysters on the entire bed, averaging 0.5 bushel per square yard which would amount to 7,650 bushels of oysters. The oysters on this bed are somewhat smaller than on most of the beds discussed previously, with a mean size of only 52.0 millimeters per oyster. Since the number per square yard, while relatively great, is less than found on several other beds it is assumed that this has resulted from larger numbers of small oysters rather than from stunting due to overcrowding.

Honouliuli Parallel Bed

This bed runs from the southern tip of Honouliuli Point to the adjacent tip of Laulaunui Island and is another large bed exposed at low tide and containing large amounts of live oysters and dead shell. It is 600 feet long and 50 feet wide with an area of 30,000 square feet or 3,300 square yards. Sampling of this bed led to a mean of 159 oysters per square yard or an estimated total of 524,700 oysters on the bed, most of which lie within the 26-76 millimeter size range. This bed contained large amounts of dead shell in comparison to the volume of live oysters, with an average of only 0.2 bushel of live oysters per square yard. From these calculations a total of 660 bushels of oysters are present on the bed.

Condition of the oysters on this bed was ascertained, indicating that oysters on this bed were the fattest of any oysters studied in the present survey, with a Condition Index of 14.36 which is far above the figure considered suitable for commercial utilization.

Honouliuli Channel Middle Bed

This bed lies between the two beds just discussed. It is composed of four segments either connected to one another or separated by very short intervals and the bottom is composed of hard rock. Because of the lack of time, this bed was not sampled for an estimate of number and size distribution of its oyster population. From a reconnaissance of the reef, it was decided that the density and size distribution of oysters was approximately equivalent to that of the adjacent Honouliuli Parallel Bed. The bed was, however, paced off to determine its dimensions; all the above mentioned segments total approximately 161,800 square feet (18,000 square yards). Assuming that the density is approximately the same on this bed as on the adjacent Honouliuli Parallel Bed, an estimate of the number and volume of oysters on Honouliuli Middle Bed can be made. Since the density of oysters on the Parallel Bed was 159 oysters per square yard, the estimate for total number of oysters on Middle Bed is 2,862,000, which would be a volume of 3,600 bushels of live oysters.

It is believed that any error in the estimate of numbers of oysters on this bed would tend to be conservative.

Yoshida Bed

Lying parallel to the shore on the north side of Laulaunui Point is a rather large bed of oysters, measuring 896 feet in length and 130 feet in width, thus consisting of an area of 12,900 square yards. This bed lies directly offshore from the Yoshida family house and piers and has been given the name Yoshida Bed to locate it. Only a small portion near the eastern end of the bed is exposed at low tide, most of the oysters remaining submerged at all times. The bottom in the region surrounding Yoshida bed is soft mud as is the bottom on the bed itself where oysters and dead shell have not firmed it.

Due to the press of time, oyster samples were not taken from this bed. For an estimate of the amount of oysters present on the bed, the densities obtained on Matsuyama Submerged Bed have been utilized, both because the two beds are similar in depth, exposure, and location, being on opposite sides of Laulaunui Point and because Matsuyama Submerged Bed had the lowest density of any bed sampled, thus causing any error on Yoshida Bed estimates to be in the direction of conservatism. With these data, then, the estimate of oysters on Yoshida Bed is 864,300 live oysters totaling 1,290 bushels.

Hoaeae-Waikele Bed

Although small concentrations of oysters, and perhaps larger undiscovered beds, undoubtedly occur along the western shoreline from Laulaunui Point to Hoaeae Point, the next bed of consequence located in this survey was in the Hoaeae-Waikele portion of the bay. This bed was shown as two beds in the original survey and appeared to be separated on visual inspection. During the preliminary part of the survey it was considered, therefore, to be two beds, termed the Hoaeae Bed and Waikele Bed. During the measurement of the dimensions of the beds, however, it was ascertained that the two beds have been joined to form one bed, which has been given the name Hoaeae-Waikele Bed. This reef is by far the largest oyster bed in West Loch, extending in two long half-moons for more than 3,000 feet along the shoreline in the northwest corner of West Loch. (figs. 8 and 9). The reef is surrounded by very soft mud and, while the center of the reef is solid oysters and dead shell, toward the outer and inner margins of the bed, where the reef has not been consolidated, the bottom is of soft mud between the clumps. This bed is subject to possible damage from a nearby sugar cane processing plant. During a part of this survey, large amounts of shredded sugar cane was observed to be stranded on the reef, which could conceivably lead to smothering of oysters or perhaps an oxygen depletion during decomposition.

Samples taken from this bed revealed a peculiar distribution of sizes and numbers of live oysters in comparison to the other beds in West Loch, with the greatest density (505/square yard) on the outside of the reef, followed by the inside (220/square yard), and the fewest in the middle (143/square yard). The mean size distribution was also peculiar, with the middle of the bed containing the largest oysters (70 millimeters), the shore side supporting the smallest (57 millimeters), and the outside portion of the bed containing oysters of intermediate size. Thus, while the outside portion of the bed supported the greatest density of oysters, the center of the bed contained fewer oysters than the inside (shoreside). Despite these peculiarities in distribution, this bed is an extremely important, productive bed, with large numbers of oysters of all three size categories present per unit area and a large mean number (289) of oysters per square yard.

Because of the large size of this bed, uneven outline and some variations in the width at various locations, it was divided into four sections, each section was measured and the four combined to obtain the number of square yards (43,000) included in the bed. From these data, an estimate of 12,427,000 live oysters or 17,200 bushels of culled live oysters are present on Hoaeae-Waikele Bed.

The Condition Index of a sample of oysters from this bed was determined to be 4.0, the lowest C.I. of any sample in the survey.

Waikele Point Bed

This is a relatively small bed (206 feet by 150 feet) lying directly off a delta-like point in the northernmost portion of West Loch. Only parts of this bed (fig. 10) are exposed at low tide. The bottom is of soft mud, most of the bed is not dense reef, but soft mud containing clumps of large oysters. It was not possible to obtain a sample of oysters from this bed for study of density and size distribution, but utilizing the lowest densities found in the survey, 67 oysters per square yard, a conservative estimate of 227,800 oysters totaling 340 bushels are on this bed.

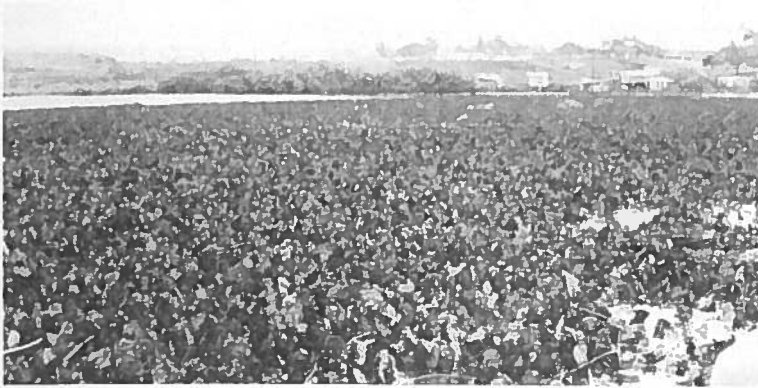


FIGURE 8. Hoaeae-Waikele Bed



FIGURE 9. Hoaeae-Waikele Bed

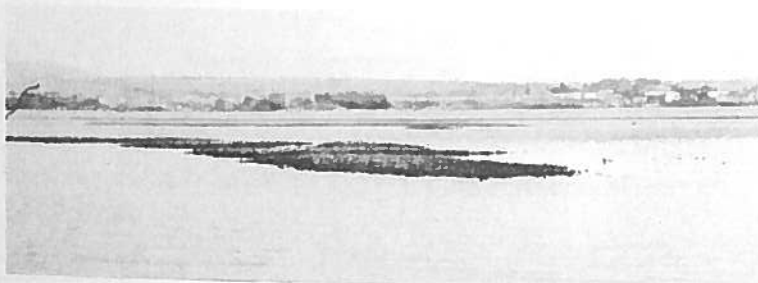


FIGURE 10. Waikele Point Bed

Loch Point Bed (Called Kekona Bay Bed During Field Work)

The last major bed to be discussed is a large one, 4,100 square yards, lying parallel to the western side of the bay, called Kekona Bay because of the Kekona family home location and the Kekona fish pond which occupies approximately one-third of the bay. The bed runs from the point (Loch Point) north to the back of the bay. There is not a solid reef present, instead fairly thick clumps of large oysters are lying on a soft mud bottom. There are numerous wrecked landing crafts and other partly submerged structures in this area, all of which are covered by a dense growth of oysters.

No sample was taken of this bed, but, using the lowest encountered density figures, 274,700 oysters or 410 bushels were estimated to be present on the bed.

DISCUSSION

Oyster Population of Pearl Harbor

Estimate of total area, numbers of oysters and number of bushels of oysters on the major beds of West Loch is possible by combining these data from all the beds discussed (table 3), revealing an estimated 35,657,400 live oysters, totaling 55,630 bushels on the estimated 150,000 square yards of major oyster beds located in the present survey. It is quite possible that additional large submerged beds exist but were not found. This does not include those oysters along the shorelines, attached to the numerous pilings and sunken vessels throughout West Loch and the approach to the Loch. Throughout the entire area virtually all such surfaces suitable for attachment were covered by a dense set of oysters. Although these oysters would be largely unavailable as either seed or commercial oysters, they will continue to contribute to the set of spat on more suitable clutch.

Our data demonstrates that the southwest portion of West Loch, from Laulaunui Island south to Three Rock Bed contains most of the major beds and the bulk of the oysters, without including the largest bed (Hoaeae-Waikele Bed). Also, these beds generally support a denser population of oysters per unit area than other areas in West Loch.

Length frequency distributions of oysters on several beds were plotted in an effort to learn something of year classes, survival and growth of oysters in West Loch. These are presented in figure 11.

Since no studies of growth rates of Crassostrea virginica have been made in Hawaii, the assumption must be made that growth of the species in Hawaii does not greatly exceed the maximum growth recorded for C. virginica. As pointed out by Menzel (1950), Ingle and Dawson (1952), and summarized by Mackin and Sparks (1962), maximum growth of C. virginica is approximately 55 millimeters in the first year, from 55 to 85 millimeters in the second year, and 85 to 100 millimeters in the third year.

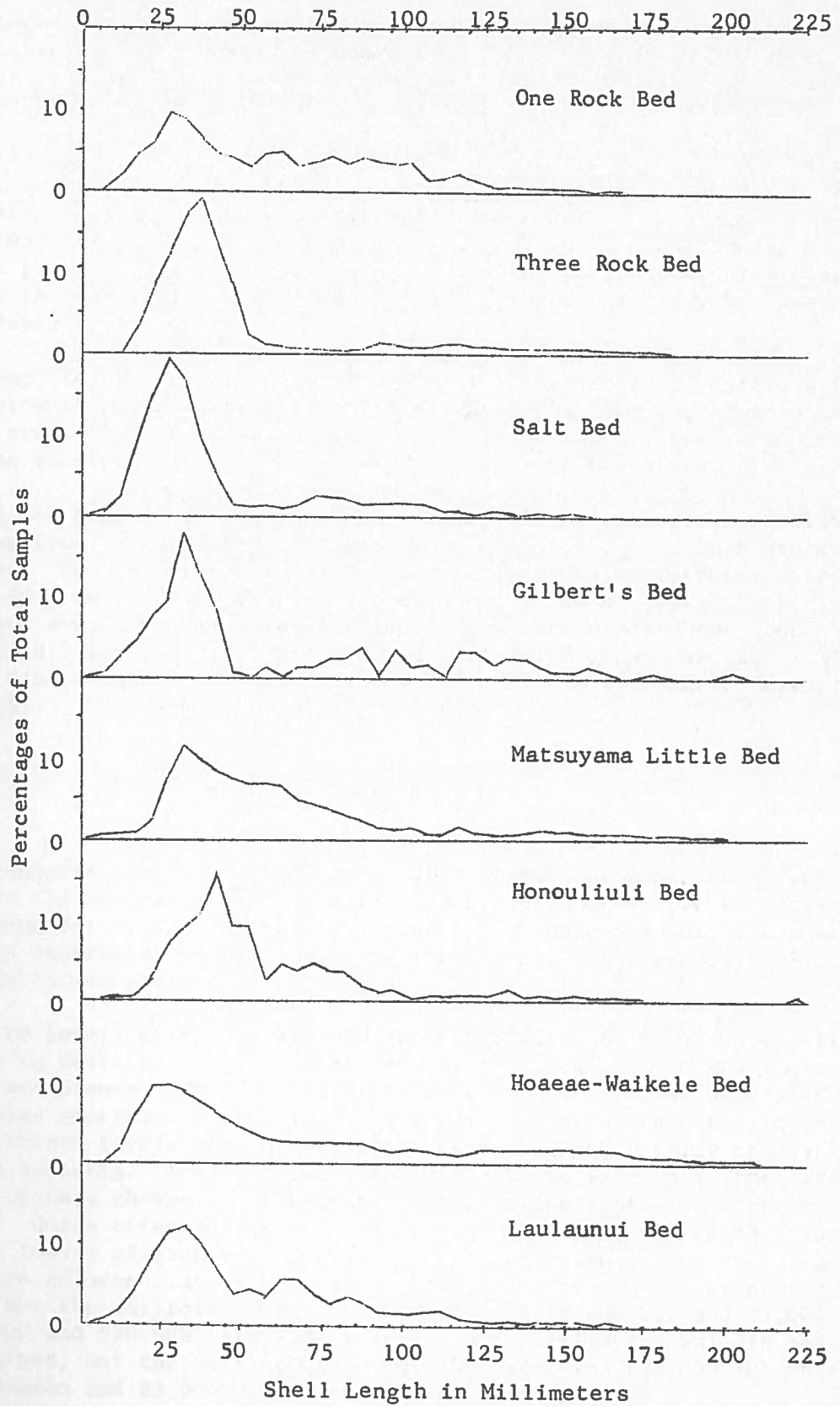


FIGURE 11. Percent Length Composition of Oyster Beds, West Loch, Pearl Harbor

With these figures in mind, study of the histograms of length frequencies are of some value. With the exceptions of Gilbert's Bed and Matsuyama Little Bed, the youngest year class is clearly isolated by a mode from 10 to 55 millimeters, peaking at 30 to 40 millimeters. On most beds there is a question as to whether the second year class occupies the lengths of 65 to 100 millimeters or whether two year classes are represented, and cannot be differentiated. If the former possibility is true, growth of Crassostrea virginica is more rapid in Pearl Harbor than anywhere it has been studied, with the same growth occurring in two years that requires three years in the best previous records. The second possibility assumes the growth in Pearl Harbor to be equivalent to the best previously demonstrated and the separation of the year classes masked, probably because of year round favorable growth conditions.

The complete absence of spat below 5 millimeters and the scarcity of small oysters, below 25 millimeters, strongly indicates that setting does not occur throughout the year, but is seasonal. More will be said of the reproductive cycle in the section on histological study of West Loch oysters.

Beyond the first two or three year classes, it is impossible to distinguish year classes from modes on the histograms and therefore, invalid to speculate on growth rates. However, the long right hand tail of every histogram strongly suggests good growth and survival. It would be unwise to guess at the age of those oysters over 200 millimeters in length present on most beds, but they are almost certainly more than 5 years old. To determine growth and survival rates as well as time of spawning and setting will require a systematic research program in West Loch.

Bacteriological Examination

Water samples were collected over most of the major beds and at selected locations in the approaches and in West Loch proper and oysters were taken from the major beds for coliform level determination. These samples were analyzed by the Hawaiian Department of Health in the latest suggested methods (U.S.P.H.S., 1959) and the results are presented in table 4.

Coliform levels were remarkably high in the water over virtually all the oyster beds in West Loch, with no samples anywhere near the 70 MPN (Most Probable Number) of acceptance. The coliform levels of the oysters, as determined from oyster samples according to the latest interim standards, were considerably higher than the coliform levels of the water, demonstrating the ability of oysters to concentrate bacteria. Study of the data, of both the water over the oyster beds and of the oysters themselves, indicates no consistent pattern in regard to coliform level. Quite often adjacent beds show no relationship from the standpoint of coliform levels of either oysters or water; for example, One Rock and Three Rock Beds are adjacent, about 600 yards apart, and occupy similar physiographic locations, but the coliform levels of both oysters (2,400,000 and 23,000 MPN) and water (23,000 and 620 MPN) are widely divergent. Similarly, Waikele and Hoaeae Beds are joined, but the coliform level of the water was 620,000 MPN on the Waikele Bed portion and 23,000 MPN on the Hoaeae Point portion.

Due to the extremely variable and grossly polluted condition of the water (coliform MPN/100 ml. ranging from 620 to 2,400,000 and mean of 179,913 coliform MPN/100 ml.), it appears unlikely that any oyster bed in West Loch can be certified for direct consumption type commercial harvesting in the foreseeable future.

TABLE 4. Results of Bacteriological Examination of Pearl Harbor Oyster Bed Waters and Oysters.

No.	Collection Date	Time	Location	Water			Oyster			
				S.P.C. per ml.	Coliform MPN per 100 ml.	E. coli MPN per 100 ml.	Sample No.	S.P.C. per ml.	Coliform MPN per 100 ml.	E. coli MPN per 100 ml.
1	3/19/62	0950	Walker Bay Bed, Surface. 100' off west shore	600	620	230	8 - 180	9,100	23,000	620
2	"	1010	West Loch, "One Rock" Bed. Surface. 150' off south shore	500	23,000	6,200	10 - 185	650,000	24,000,000	24,000,000
3	"	1030	West Loch, "Three Rock" Bed. Surface. 200' off south shore	500	620	230	8 - 145	35,000	2,400,000	2,400,000
4	"	1055	West Loch, Matsuyama Fish Pond. 95' from shore	11,000	2,300	620	12 - 185	13,000	23,000	60
5	"	1120	West Loch, Laulaunui Is. Pt. Bed. 50' off shore	1,400	23,000	6,200	9 - 165	30,000	620,000	62,000
6	"	1130	West Loch, Honouliuli Pt. Channel. Surface. 200' off shore	4,600	2,300	2,300	10 - 160	100,000	230,000	23,000
7	"	1145	West Loch, Hoaeae Pt.	21,000	620,000	6,200	9 - 145	43,000	230,000	230,000
8	"	1200	" Waikele Bed. Surface	29,000	23,000	23,000	8 - 210	220,000	230,000	62,000
21	3/20/62	--	Waikele Pt. Bed	75,000	2,400,000	neg.	8 - 200	650,000	7,000,000	2,300
22	"	--	Kekona Bay Bed	12,000	230,000	6,200	7 - 205	91,000	230,000	230
23	"	--	Honouliuli Bed	2,200	620	620	7 - 195	47,000	62,000	neg.
24	"	--	Matsuyama Fish Pond (inside)	1,300	2,300	2,300	6 - 210	46,000	230,000	neg.
25	"	--	Matsuyama Bay, Submerged Bed	1,500	620	neg.	6 - 210	28,000	23,000	neg.
26	3/21/62	0920	Concrete Ramp	400	2,300	neg.	23 - 150	60,000	620,000	neg.
27	"	1035	Yoshida Bed	21,000	230,000	neg.	8 - 195	400,000	24,000,000	neg.
28	"	1100	Laulaunui Cove	2,500	62,000	neg.	6 - 205	200	2,300	neg.
29	"	1115	Honouliuli Channel Parallel	2,300	6,200	neg.	6 - 210	20,000	620,000	230,000
30	"	1135	Salt Bed	900	2,300	60	10 - 230	10,000	2,300,000	neg.
31	"	1220	Three Rock at Laulaunui Pt.	3,700	62,000	neg.				
32	"	--	One Rock Sunken Tower	2,100	62,000	6,200				
33	"	--	Red Buoy	2,200	23,000	neg.				

Neg. = Not detected in initial dilution of 2-1 ml. portions.

Histological Examination

A total of twelve randomly selected oysters from West Loch were fixed in Zenker's fluid, stored in 50 per cent isopropyl alcohol and shipped to the College of Fisheries, University of Washington, where a representative portion from the palp region of each oyster was blocked in paraffin, sectioned, and stained with Harris' Hematoxylin and Eosin. Some extremely interesting information was revealed from the study of these slides.

Gonadal Development

Ten specimens of Crassostrea virginica were fixed and stained, of which six were female and four were male. Proliferation of gonadal epithelium varied from that of beginning proliferation to fairly advanced stages, but no gravid individuals were present in the sample. From examination of the slides, it appears that the oysters in West Loch spawn seasonally during the late spring or summer, rather than throughout the year. It is likely that a few individuals, as is the case in Louisiana (Menzel, 1951), spawn in almost any month, but a peak of spawning occurs at a particular season.

Several investigators (Needler, 1934, Burkenroad, 1931 and Menzel, 1951) have reported unbalanced sex ratios in Crassostrea virginica under crowded conditions, with males predominating. It is interesting to note that in the admittedly small sample the sex ratio was four males to six females, indicating an equal sex ratio under what are obviously crowded conditions on the West Loch beds.

Encysted Helminth

The slides revealed all oysters in the sample to be infected with an encysted larval tapeworm of the genus Tylocephalum. The small fibrous cysts are found in the connective tissue around the stomach and intestine and between the digestive diverticula (fig. 12). Because of difficulty of identification of the organism in tissue sections, a sample of live oysters was obtained from West Loch. Again, all specimens were infected.

This genus is common in the digestive gland of bivalve molluscs, but had not been previously reported from Crassostrea virginica. A description of this phenomenon in C. virginica from Pearl Harbor was submitted to the Journal of Insect Pathology (Sparks, in press). Subsequently, a group of oysters transplanted from Apalachicola Bay, Florida to Chincoteague Bay, Maryland in October and November, 1961 were found to contain the same or a very similar form. (Burton, 1963)

Ostrea sandwichensis

Two specimens of O. sandwichensis were fixed for histological study, largely to ascertain the proper generic designation of the species. Since all edible oysters were originally placed in the genus Ostrea and subsequently those known to be dioecious were transferred to the genus Crassostrea, a number of species whose life cycle and morphology is unknown have erroneously been left in Ostrea. Examination of stained sections of O. sandwichensis reveal the species to be hermaphroditic, with typical sperm balls in the lumen of the gonad and ova forming the walls. Also, the shell exhibits the pseudohinge teeth of Ostrea.

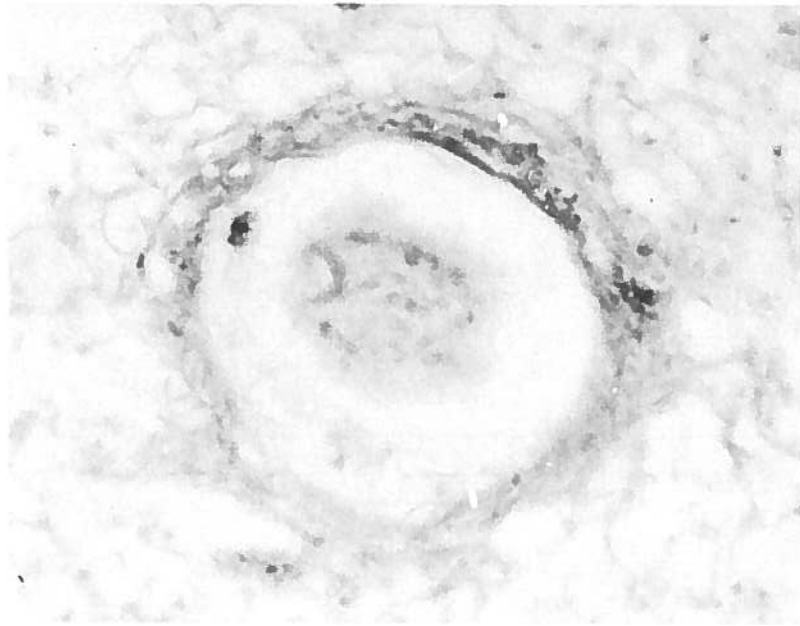


FIGURE 12. Encysted Tylocephalum

Associated Fauna

In the preliminary survey notations were made of all fauna observed on the West Loch oyster beds, and during the search for beds and collection of oyster samples any animals observed on the beds were noted and an attempt made to capture them. During culling of the samples at the Kewalo Laboratory all associated fauna, both free and attached to oysters and shell, was preserved and sent to the College of Fisheries for subsequent identification. The following list is incomplete and incompletely identified; further investigation of the associated fauna on the oyster beds should be a part of any research program.

Phylum Porifera - Sponges are extremely numerous in West Loch to the point of causing discomfort to individuals wading in the water because of siliceous spicules penetrating the skin. The sponge fauna of Hawaii is extensive and varied according to Edmondson (1946). The taxonomy of the group is not well worked out and no attempt was made to identify the sponges to genera or species. In addition to the encrusting sponges, some oyster shells were observed to contain boring sponge, probably Clione brought to Pearl Harbor with the original stock of C. virginica.

Phylum Annelida - Numerous tube worms and nereid worms were collected, but no attempt was made to identify them. Additionally, some oysters were infested with Polydora, a shell drilling annelid oyster pest.

Phylum Mollusca

Class Lamellibranchiata

Family Ostreidae

Ostrea sandwichensis - Small numbers of O. sandwichensis are present on all beds in West Loch. This small species of oyster is native to Hawaii and found throughout the Islands, but never in large concentrations. Only very few specimens were noted in the present survey. Several specimens of this species were fixed for histological study to determine whether O. sandwichensis belongs in the monoecious genus Ostrea or the dioecious genus Crassostrea.

Crassostrea gigas - Although numerous importations of C. gigas to Pearl Harbor are recorded, no adult oysters identifiable as this species were seen in West Loch, but a very few spat typical of C. gigas were observed.

Class Gastropoda

Family Calyptraeidae

Crepidula aculeata Gmelin - In many areas where oysters are grown commercially members of the prosobranch genus Crepidula, particularly C. fornicata, are serious oyster pests. C. aculeata was found to be fairly common on oysters from West Loch beds but is not, it is believed, a potential pest.

Family Littorinidae

A littorinid snail, probably Littorina scabra Linnaeus, is found on the pilings and emergent structures at about the high tide level, particularly in Walker's Bay. It was not seen on the emergent reefs where the heavy concentrations of oysters occur.

Family Anomiidae

Anomia nobilis - This encrusting jingle is found fairly commonly on the oyster beds of West Loch. Although it is a potential competitor for space with oyster spat, it was not found in sufficient numbers to be a pest under present conditions.

No predaceous gastropods were observed on the oyster beds of West Loch. The large population densities of oysters present on the reefs is at least partly due to this absence.

Phylum Arthropoda

Class Crustacea

Sub-class Cirripedia

Two species of barnacles (Balanus amphitrite hawaiiensis and B. eburneus) were common but not present in large numbers on oyster beds of West Loch. Barnacles sometimes compete for space and food with oysters, but are apparently not present in sufficient numbers to be important in the area under consideration.

Sub-class Malacostraca

Order Decapoda

Suborder Natantia

Tribe Caridea

Family Crangonidae

Numerous species, at least 20 according to Edmondson (1946), of snapping shrimp are found in Hawaii. Many specimens of this group are present on the oyster beds of West Loch. They have not been identified to species.

Suborder Reptantia

Tribe Brachyura

Family Xanthidae

Xanthid crabs are fairly common on the oyster beds as they are throughout Hawaii. The specimens collected in the survey have been tentatively identified as Lophozozymus intonsus. A xanthid crab, Menippe mercenaria, is an important oyster predator in the Gulf of Mexico. The species present in Pearl Harbor, though not so large as Menippe, has powerful chelipeds and may be a predator on small oysters.

Family Grapsoidea

Numerous small grapsoid crabs are found in Walker's Bay and West Loch oyster beds and above the tide line along the shorelines, docks, and pilings. These crabs are small, though very active, and could cause no damage to oysters other than spat.

Family Portunidae

Several species of portunid crabs are apparently found commonly in West Loch. The specimens collected during the survey were tentatively identified as Thalamita picta and T. integra, although some of our specimens identified as T. picta exceeds the maximum sizes according to Edmondson (1946). The eastern blue crab, Callinectes sapidus, has been shown to be an important predator on oysters less than one year old in South Carolina and Louisiana so there is a possibility of predation from the swimming crabs in West Loch.

Phylum Chordata

Subphylum Urochordata

A few colonial ascidians were observed among the oysters in Walker's Bay, but were not preserved nor identified.

Subphylum Vertebrata

A few goby-like fishes were found in oyster boxes in the density samples. Additionally, large numbers of Tilapia mossambica were noted on the Loch Point Bed and small numbers of mullet, Mugil cephalus, were occasionally seen over oyster beds throughout the area.

In summary, the fauna associated with the oysters in Pearl Harbor is typical of the groups of animals that associate themselves with oysters on the mainland, though the species are generally different. No obvious important predators or pests were seen, though xanthid and portunid crabs probably prey to some extent on the smaller oysters.

Salinity and Temperature

The temperature and salinity of the water were determined at each station where coliform bacterial samples were taken and are presented in table 5. During the preliminary survey a heavy rainfall occurred in the West Loch area and unquestionably created an unusual hydrographic picture for West Loch, probably representing the lower limit of salinity for the area for this season rather than the normal condition. The effect of the heavy rains on temperature cannot be determined but it is assumed that it was lowered.

Despite the heavy rainfall, salinities did not fall below 12 parts per thousand except in the area just off the Matsuyama Fish Pond, where a salinity of 4.5 parts per thousand was found. In all the other areas in West Loch, temperatures varied from 24° centigrade to 27° centigrade and the salinities from 12.5 parts per thousand to 22 parts per thousand, all well within the most favorable limits for oyster growth, survival and reproduction.

A thorough knowledge of the seasonal hydrography, including currents as well as temperature and salinity, is needed to understand the distribution of oysters in West Loch.

TABLE 5. Water Temperature and Salinity - West Loch

Location	Date	Temperature	Salinity
Walker's Bay	March 19, 1962	24°C.	22 ppt.
One Rock	"	25°C.	17 "
Three Rock	"	24.5°C.	14 "
Matsuyama Fish Pond	"	23.5°C.	4.5 "
Laulaunui Bed (near Pt.)	"	25°C.	15.5 "
Laulaunui Bed (channel)	"	24.5°C.	14.5 "
Hoaeae-Waikele (near Hoaeae Point)	"	25°C.	12.5 "
Waikele Point Bed	March 20, 1962	25.5°C.	--
Loch Point Bed	"	27.0°C.	--
Loch Point	March 21, 1962	26.0°C.	22 "
Waikele Point	"	26°C.	20 "
Yoshida	"	24°C.	18 "
Honouliuli Parallel	"	24.5°C.	17 "
Salt Bed	"	24.5°C.	14 "
Midchannel (between Three Rock and west end of Laulaunui Island)	"	25.5°C.	18 "
Midchannel (between Nichols Point and Loch Point)	"	25°C.	21.5 "
Red Buoy 14 (midchannel off Hanaloa Point)	"	25°C.	20 "

SITE SEARCH

Having learned that extensive stocks of C. virginica were present in West Loch of Pearl Harbor, but could not be harvested for food because of their high coliform levels, inspection of potential sites for transplantation of West Loch oysters was conducted on the Islands of Oahu, Kauai, Hawaii, Maui, and Molokai. Personnel of the Division of Fish and Game, usually from the enforcement branch, provided transportation and valuable knowledge of possible sites for examination.

Oysters to be transplanted from West Loch to other areas could fall into several categories, the value of potential sites varying according to suitability for each type of transplant. The oysters found in West Loch were divided into three categories: (1) those under one inch in length, (2) from one to three inches, and (3) oysters more than three inches in length.

The largest category is composed of market size oysters needing only to be cleared of bacterial contamination and, in most cases, fattened before marketing. This would require only a relatively short time in pollution free water containing sufficient food to improve the condition of the oysters and a salinity sufficiently high to impart a salty taste to the meat. Since these oysters are large, more exposed sites could be utilized than those needed for smaller oysters. Because of the short exposure period involved, it might be economically feasible to maintain oysters in this group in baskets on rafts or racks, which, again, would make possible the utilization of sites not suitable for bottom culture.

Oysters falling in the second size group, from one to three inches in length, must be maintained for a growing period of several months before utilization, during which time the loss of bacteria would also occur. Oysters in this category require placement in locations having adequate protection from wave action, siltation and sanding, and predation. Therefore, suitable sites must have a stable bottom, preferably fairly stiff mud, be well protected from the sea and be relatively free of predators.

The oysters in the smallest size category, less than one inch, would be even more demanding in requirements for a suitable site for transplantation. They would have the same requirements as listed for the second group, but with the importance of each factor intensified. Actually, unless absolutely favorable sites can be obtained for oysters in this category, it might be wise to leave them in West Loch until they have grown into the second category. Possibly the most favorable method of utilizing oysters in this size range would be to use mother-shell strung on wire and floated on rafts for cultch to obtain spat. These strings of cultch could then be transported to other areas and utilized on floats in a hanging culture. The requirements for such a culture are much less restrictive than for bottom culture in regard to protection from the sea, bottom consistency, and predators. The Japanese oyster industry, for example, has increased from approximately 15% raft and 85% bottom culture ten years ago to 90% raft culture and 10% bottom culture.

Oahu

Two possible sites for transplantation of West Loch Oysters were examined on the Island of Oahu. These were Kaneohe Bay and Keehi Lagoon, both of which have had a number of trial oyster importations in the past.

Kaneohe Bay

This area has been discussed previously in the preliminary survey to determine the extent of oyster stocks in the bay. It appears that Crassostrea virginica should survive and grow there and be cleared of coliform bacteria. A number of the oysters collected in the bed surveys of West Loch were transplanted to the hard bottom of the western side of Kaneohe Bay so that their survival, rate of bacterial loss, and condition could be determined. Superficially, much of Kaneohe Bay appears suitable for at least short term transplants of West Loch oysters. However, mortalities of several species of oysters planted in this bay have been recorded.

Keehi Lagoon

Oysters are reported to have been transplanted previously to Kalihi bordering Keehi Lagoon (C. virginica in 1883, C. gigas in 1926, and C. commercialis, 1929), but do not appear to have survived. An inspection of this area revealed an extremely high salinity (38 ppt. - 36 ppt.) and a temperature of 23.5° centigrade. Large numbers of O. sandwichensis, mostly boxes, were observed. It is believed that Keehi Lagoon may have some promise for raft culture of oysters, but has too much sand and too high salinity for bottom culture. Survival and growth studies of oysters in this location would be enlightening.

Kauai

The author arrived at Lihue on Friday evening, March 23, 1962, and was met by Warden James Yamada who had arranged for Warden Tatsuo Nakamura to conduct a tour of possible oyster growing sites on the following day.

The morning of March 24 was spent touring the eastern and northern sides of the island as far as Hanalei Bay and the afternoon in investigating the southern coastline as far as Port Allen. The following morning a discussion of the oyster potential of Kauai and previous attempts to acclimate oysters on the island was held with Warden Yamada. Impressions and opinions of the areas visited follows:

Hanalei Bay

Hanalei Bay is located on the northern side of Kauai and approximately one-half mile wide with a barrier reef across part of the mouth which would afford considerable protection from onshore storms. However, during the winter months the predominant wind is reported to be onshore and the bottom is pure sand which would shift with heavy surf, thus probably precluding successful bottom culture. The Hanalei River and several small streams empty into the bay; a salinity sample on the west side of the bay resulted in a reading of 31 parts per thousand while at the mouth of Hanalei River the water was completely fresh. It is reported that Hanalei Bay is subject to periodic freshets. It is possible that Hanalei Bay would support a small scale raft culture.

Kalihiwai Bay

This is a small bay into which a river empties. There is no reef protecting the mouth of the bay. Since it is on the windward side of the island, Kalihiwai Bay is subjected to heavy wave action and is considered unsuitable for oyster culture.

Wailua Bay

Wailua Bay is a small open bay with heavy surf with no apparent possibilities for oyster culture.

Hanamaulu Bay

The Hanamaulu River empties into this small bay which has a breakwater for protection from offshore storms and surf. The bottom is sandy and probably shifting. The Hanamaulu River, though small, has a strong current and apparently depresses the salinity of the bay. Approximately 50 yards from the mouth of the river, the salinity was found to be 16 parts per thousand. This bay appears to be an excellent site for raft culture, but of doubtful value for bottom culture.

Nawiliwili Bay

This is the largest bay on the Island of Kauai, probably 2,000 yards long and 1,000 yards wide. It is well protected from onshore surf and storms with a double breakwater at the bay mouth. The Nawiliwili River discharges a large volume of water into the bay, which, because of its construction, probably insures an estuarine salinity at all times. A series of salinity determinations made at various locations from the head of the bay to the breakwater with salinities varying from 3 parts per thousand at the head to 12 parts per thousand at the end of the breakwater. Nawiliwili Bay may support a bottom culture of oysters if siltation from the river is not excessive.

A small planting of oysters from West Loch was made along the north shore of Nawiliwili Bay in 1949, but was reported to have been smothered by caving of the north shoreline during a typhoon.

Menehune Fish Pond

This large fish pond located just above Nawiliwili Bay has two entrances; one on the river, the other on the river just above the bay. At the time of inspection Nawiliwili Bay was discolored by silt brought down by heavy rainfall in the mountains; the fish pond was much less turbid than the bay and also had a higher salinity, 9 parts per thousand, compared to 3 parts per thousand, than the lower bay and comparable to the bay's entrance of 12 parts per thousand. The salinity of the fish pond is probably less subject to fluctuation than the bay. The bottom is composed of a fairly firm mud; there are barnacles growing on the walls of the gates and on submerged objects in the fish pond. Numerous grapsoid crabs were seen along the shoreline.

There appears to be possibilities for oyster culture in this fish pond. The bottom seems firm enough to support oysters, there is adequate protection against storm action, and the salinity appears to be high enough to sustain oysters.

Port Allen

Port Allen was the last potential site examined on the Island of Kauai. This harbor, located at the point of discharge of the Hanapepe River, has a sea wall as partial protection. The surf was heavy at the inspection time and is reported to be extremely heaving during the winter. On the side of the bay near the sea wall the salinity was 34 parts per thousand, near the mouth of the Hanapepe River it was five parts per thousand, and 30 parts per thousand in the boat basin. The sand is shifting even in the protected boat basin. Because of the heavy surf and shifting sand, Port Allen is considered unsuitable for oyster culture.

In summary, Menehune Fish Pond, though rather low in salinity, and Nawiliwili Bay are apparently suitable for bottom culture of oysters. Hanamaulu Bay and possibly Hanalei Bay might support limited raft culture.

Hawaii

On Sunday morning, March 25, the author flew to the Island of Hawaii landing at the Kona Airport in the early afternoon. Warden Crisafi, who met the plane, took the author on a tour of the beaches and bays south along the Kona coast, stopping at Kahaluu, Keauhou, Honaunau, Kauhako, and Kiilae Bays. All the bays along the Kona coast are more or less open to the ocean with a heavy surf in most locations. The bottoms are shifting sand, coral, or volcanic rocks. There are a few locations with little or no surf because the water is too deep for surf to form; Honaunau Bay is an example of this condition. Such an area could presumably be used for small scale raft culture, but is too small to support a significant effort. Two other bays, Kahaluu and Keauhou, are fairly well protected, but are too small for oyster culture except for limited scale raft culture.

On the flight to the Kona Airport, two fair-sized fish ponds were observed just back of the shoreline near the airport. At the author's request, on Monday morning Warden Crisafi transported the author to these two sites, which are approximately four miles north of Kailua. To reach the ponds one must drive over an ancient lava flow, which is so rough that it took one hour and fifteen minutes driving time to reach the first pond, the Kaloko Fish Pond. This is a shallow pond between 5 and 10 acres in area with a maximum depth, according to Warden Crisafi, of approximately 7 feet. The bottom is composed of a firm mixture of mud and sand. There is a well constructed rock dam across the mouth of the pond with a tidal inlet at the dam. The salinity was 23 parts per thousand at the dam and is probably lower near the springs which are reported to be present in the upper pond.

The Honokahau Fish Pond is about one mile from Kaloko Pond. It also covers an area of approximately 10 acres and is spring fed as well as receiving salt water from the ocean. The salinity was 9 parts per thousand and large numbers of Awa (Chanos chanos) were present in the pond and a heavy growth of submerged vegetation was observed.

Both these fish ponds are considered good potential sites for oyster culture. The salinity is perhaps slightly lower than desired in Honokahau Pond, but appears to be ideal in Kaloko Pond. The bottom is suitable for bedding oysters, and there is, of course, no possibility of fecal contamination. Research is needed to determine whether fattening of oysters will occur in these ponds. The most detrimental feature of these ponds is their inaccessibility. It would be extremely difficult to transport seed oysters in and market oysters out of the locations by truck or by boat, and it is probable that the bulk of market oysters produced would be shipped to other areas for consumption unless local consumption could utilize the entire production.

On returning to Kailua, we were met by Warden Yap, who conducted a tour of beach areas along the northwest and northeast coast of Hawaii and transported the author to Hilo. Among the locations visited was Kawaihae Bay which has a stone breakwater protecting the harbor and a salinity of 33 parts per thousand. This area was constructed for shipping and as a protected harbor and apparently is a busy port. If oyster culture, particularly raft culture, is possible without interfering with the functioning of the port and coliform levels due to sewage discharge from ships are not high, this is a possible site.

The Puako area was inspected and found to afford some protection, to have a salinity of 31 parts per thousand, and a slight potential for oyster culture. Other areas such as Kaunaoa Bay, Hapuna Beach and Anaehoomalu Beach were visited but were found to be open, sandy beaches with no possibilities for oyster culture. The northeastern coast of Hawaii from Honokaa to Hilo consists mostly of steep cliffs, with no bays even remotely suitable for oysters.

On Tuesday, March 27, the author accompanied Warden Albert Ignacio on a tour of the eastern and southeastern coast of Hawaii as far south as the Black Sand Beach. South of Hilo the only potential oyster growing site seen was Lyman Pond at Kapoko. This is a large area, approximately 40 acres, partly enclosed by coral reefs and lava flows. It seems to be well protected from wave action and had a reduced salinity of 23 parts per thousand at the head of the bay. The bottom is composed of hard lava. This area is certainly worth further investigation as a possible site for oyster culture.

Hilo Bay was also examined as a potential oyster growing site. Oysters were planted, according to Warden Yap, on the seaward side of the large breakwater which protects Hilo Harbor, but were destroyed by a Tsunami. Hilo Bay has several disadvantages for oyster culture, but also has some potential. There is a sugar cane processing plant located on the harbor which discharges unknown amounts of cane pulp and trash into the bay. These discharges might be unfavorable and the possibility of fecal contamination of Hilo Harbor would have to be investigated. There are, however, several fresh water inlets to Hilo Harbor which lower the salinity to estuarine levels. For example, at the head of the harbor just opposite the breakwater, the salinity ranged from 22 to 23 parts per thousand. In the Japanese Garden the salinity was found to be 19 parts per thousand and was 22 parts per thousand in the cove between the Japanese Garden and Coconut Island. On following the lagoon which opens into the Japanese Garden, it was found that the salinity was reduced to 6 parts per thousand about half way along the lagoon and was only 3 to 4 parts per thousand at the back of the lagoon (by the Hilo Hukilau Hotel). The temperature of the water was also decreased from the bay to the head of the lagoon, dropping from about 24° centigrade in the bay to 19° centigrade at the head of the lagoon, indicating a large volume of spring water was being added to the bay. A progressive warming, as well as increase in salinity, was noted along the lagoon.

In summary, on the Island of Hawaii the two fish ponds on the Kona coast, particularly Kaloko Pond, appear suitable for oyster culture and Lyman Pond and Hilo Harbor require further consideration. Few other areas on the big island appear suited to oyster cultivation.

Maui

The Island of Maui was visited on Wednesday, March 28. Mr. Harry Kami, Aquatic Biologist with the Division of Fish and Game, flew in from Honolulu to accompany the author on Maui and Molokai. The western section of Maui was examined by driving from Wailuku to Maalaea Bay and then around the western tip of the island and back to Wailuku. On the trip only three areas showed even the slightest possibilities for oyster culture, since most of the coastline consisted of steep cliffs. Maalaea Bay is a large body of water that appears to be fairly well protected and might support raft culture in the main body of the bay. On the north side of the bay there are several protected tidal inlets emptying from marsh lakes into the Maalaea Bay. One of these, examined in some detail, was approximately 100 yards long and 50 feet wide, had a firm mud-sand bottom and a salinity of 7 to 9 parts per thousand. It connected a shallow marsh lake, which was completely fresh, to the bay. The tidal inlets appear favorable for oyster culture. Kapalua Beach is a very small, well protected cove with a coral bottom and oceanic salinity. It is too small for a significant number of oysters to be grown, but might support small numbers if predators are not present on the coral reefs.

About two miles beyond Kapalua Beach is a deeply-indented, well-protected bay called Honolua Bay. It is fairly large, 25 to 50 acres in size, and has a salinity of 34 parts per thousand. Nothing is known of the depth of this bay or the character of the bottom. It is believed that this bay may hold some promise for oysters, probably in the form of raft culture.

Molokai

The following morning, Thursday, March 29, Mr. Kami and the author flew to the island of Molokai and were met there by Mr. Noah Pekelo, Game Management Assistant, stationed on Molokai. Mr. Pekelo conducted a tour of potential oyster culture sites along the southern coast of the island. A large number of similar fish ponds are found on Molokai, many of them in need of repair. Only a representative number of these could be seen in the limited time available for our visit. Also, several bays not enclosed by walls were examined. Those inspected are included here with notes on each.

Palaau Fish Pond

This is a fairly large mullet pond of some 10 to 20 acres in area, with a soft mud bottom. It is spring fed with a salinity of 0 parts per thousand at the spring, 9.5 parts per thousand at the outlet 50 yards from the spring, and 7.5 parts per thousand at the bank opposite the spring. This fish pond is marginal in potential because the salinity is somewhat below the optimum and the bottom appears softer than desired.

Kaunakakai Harbor

This area, which constitutes the major harbor on Molokai, has a long stone pier running several hundred feet out from shore. There is a long coral reef on each side, beginning near the end of the pier and running parallel to the shore for between three and four miles in both directions. The pier and the coral reefs serve to protect these areas from wave action. Mr. Pekelo said no waves occur on the east side of the pier. Because of runoff and, presumably springs, the salinity in these lagoons is reduced (20 ppt. at the pier), the bottom has large amounts of mud mixed with sand for some distance offshore and the entire lagoon has a depth of less than 18 feet. This area appears to have an excellent potential for oysters, with adequate protection, favorable salinity, suitable bottom and depth. Nothing can be said, of course, of possible predator problems without further study.

Kamalo

This site is located at the old harbor for Molokai, part of the old pier is still present. The bottom is of sandy mud, there are two intermittent streams emptying into the bay which is protected by an offshore fringing reef. The salinity at the old pier was 28.7 parts per thousand.

Keawe Nui Fish Pond or Yuen Fish Pond

Keawe Nui Fish Pond or Yuen Fish Pond is an enclosed, well protected salt water pond of 20 to 30 acres in area. It has a firm bottom and a salinity of 29 parts per thousand at the time of our visit. Numerous Ostrea sandwichensis were observed on the rock walls.

Mystic Spring (Apo) or Ualapue Fish Pond

This is a small pond, approximately 5 acres, belonging to the State of Hawaii. The top of the wall was destroyed by the last Tsunami and has not been replaced. There are numerous springs at the back of the pond, reducing the salinity to 11.5 parts per thousand at that point and to 19.5 parts per thousand at the outlet.

Kaopeahina (or Hustace) Fish Pond

A medium sized pond, newly repaired of 19 acres, according to the owner, Mr. Hustace, with a salinity of 23.4 parts per thousand.

Niaupala (or Jones) Fish Pond

This is a large fish pond with an area of 30 to 50 acres. It has a number of springs emptying into it which reduces the salinity (11.8 ppt.). The bottom is of soft mud, though probably firm enough to support oysters. The walls are in need of repair, with breaks in several places.

Kupeke (Yoshimura) Fish Pond

This pond, owned by the Yoshimura family, is another large (30-50 acres) well protected pond with a lowered salinity (13.5 ppt.). Mr. Yoshimura informed the author that oysters had been planted in the pond previously but had not survived.

Matayoshi Fish Pond

Actually consisting of two ponds bearing the Hawaiian names of Kihaloko and Kulaalamihi Fish Ponds, the total area involved is probably less than ten acres. The last Tsunami washed parts of the wall away so that openings to the sea exist, but a large fringing reef provides some protection. Salinities of 12.9 and 21.4 parts per thousand were recorded from the two ponds.

In summary, all the fish ponds and much of the lagoon-like area behind the fringing reefs appear to possess excellent potentialities for oyster culture. They are well protected from storm damage and have suitable bottom and salinity conditions. Possibilities for fecal contamination are unlikely, except perhaps, in very local areas, and the distance from the Honolulu market is not great. Studies on the growth, fattening and survival of oysters in these areas would be appropriate before initiation of commercial plantings.

RECOMMENDATIONS

Pearl Harbor

As mentioned previously, large stocks of oysters of various sizes are present in West Loch of Pearl Harbor, with a number of extensive reefs established. It is recommended that this area be designated a state seed area and not be opened for utilization for market oysters. Before the area can be properly managed, the areas and density of oysters on the beds must be more accurately determined; the seasonal spawning cycle, and the pattern and intensity of spat fall must be established; the mortality and growth rates of oysters of the various age groups must be determined. Additionally, the seasonal hydrographic characteristics of the bay should be known and the fecal coliform levels of both the water and oysters require regular monitoring. The seasonal variation in Condition Index should be established at each location and on all possible beds.

It is recommended that semi-permanent stations be established at several sites in West Loch, for example, in the western Honouliuli Bay area, the Hoaeae-Waikele bed area, the Laulaunui Island area, and the Nichols Point (One Rock Bed) area. At each of these locations, and more if feasible, oysters of various size groups, probably the size categories used in the present study, should be culled to singles, measured, maintained in enclosed baskets, and checked at frequent intervals to determine growth and mortality rates. All dying and dead oysters should be fixed in Zenker's fixative, sectioned and stained for histological study in an attempt to determine causes of death. Separate trays of oysters should be maintained for removal of oysters for fecal coliform determination, Condition Index, and histological studies from which oyster mortality factors can be studied and the seasonal gonadal cycle established. Bags of clean oyster shell should be placed at each of these stations, and other sites if feasible, at each check to determine the seasonal occurrence, geographic pattern, and rate of spat-fall. Subsequently, it will probably be necessary to study the oyster larvae in the plankton, but it is not considered essential initially.

Transplantation Experiments

There have been a number of haphazard attempts to establish oysters at various locations other than West Loch of Pearl Harbor. Their notable lack of success, it is believed, were more likely due to a lack of proper preparation and care than to unsuitability of other sites. In many instances shipments were too small for any hope of establishment, in others apparently unfavorable sites were selected for planting. In no cases, apparently, were careful records kept of the number planted and their growth and mortality rates. We do not know that the failure of some transplants to become established was not the result of poaching by the local inhabitants. It is recommended that growth, survival and fattening studies of oysters from Pearl Harbor be conducted at each potential site. If it is established that oysters can be transplanted from West Loch to a particular site with subsequent satisfactory survival, growth, fattening, and loss of bacterial contamination, the area can then be utilized by commercial interests through importation of oysters from West Loch.

Of all the potential growing areas surveyed, the Island of Molokai contains the areas appearing most suitable to the author. All the fish ponds along the eastern half of the southern side of the island appear to be excellent potential sites for oyster production and much of the lagoon-like area of the beach which is protected by fringing reefs holds high promise of success. It is the opinion of the author that several research stations should be established, as described for West Loch, on Molokai, including as many fish ponds as possible and Kaunakakai Harbor. If the oysters will survive, grow, and fatten in trays at these sites, then a trial transplantation of commercial quantities will be called for.

The second most likely area for investigation is probably Kaneohe Bay on Oahu. The obvious fact of establishment of C. gigas on pilings indicates that survival of C. virginica is likely, but the absence of C. gigas on the bottom creates some doubt as to the success of large scale plantings. The small plantings of oysters from the present West Loch survey should throw considerable light on the potentialities of this area. It is recommended that a station be established in Kaneohe Bay, with oysters maintained in enclosed baskets as recommended for West Loch and Molokai.

Since the extent of investigation possible for the Division of Fish and Game is not known, the number of stations and the areas to be investigated cannot be recommended by the author. It is felt that the Pearl Harbor, Molokai, and Kaneohe Bay studies deserve the highest priority and probably should be undertaken prior to investigation of other areas. Following these areas, Nawiliwili Harbor and Menehune Fish Pond on Kauai should be investigated as soon as feasible.

The fish ponds on the Kona Coast of Hawaii appear to be suitable for oysters, but due to inaccessibility, investigation should probably be postponed if a choice of areas to be investigated is necessary.

LITERATURE CITED

- Anonymous
Undated Oyster Report. Hawaii Division of Fish and Game.
- Brock, V.E.
1952 A history of the introduction of certain aquatic animals of Hawaii. Rept. of the Bd. of Comm. of Agri. and Forestry of the Terr. of Hawaii for the period ending June 30, 1952.
- Brock, V.E.
1960 The introduction of aquatic animals into Hawaiian waters. Int. Revue. ges. Hydrobiol. 45: 463-480.
- Burkenroad, M.D.
1931 Sex in the Louisiana oyster Ostrea virginica. Sci. 74: 71.
- Burton, R.W.
1963 Report on a cestode microparasite of the oyster, Crassostrea virginica, in Florida. Pres. at Fifth Ann. Shellfish Mort. Workshop. Jan. 29-30.
- Coleman, R.A.
1923 Efforts to acclimatize Atlantic oyster and soft clam in the Hawaiian Islands. Nautilus. Boston, Mass., 36: 138-339.
- Edmondson, C.H. and I.H. Wilson
1940 The shellfishery resources of Hawaii. Proc. 6th Pac. Sci. Cong., 3: 241-243.
- Edmondson, C.H.
1946 Reef and Shore Fauna of Hawaii. Bernice P. Bishop Mus., Spec. Publ. 22, 381 pp.
- Ingle, R.M. and C.E. Dawson, Jr.
1952 Growth of the American oyster, Crassostrea virginica (Gmelin). Bull. Mar. Sci. Gulf and Carrib., 2: 393-404.
- Jensen, E.T.
1959 Manual of recommended practice for sanitary control of the shellfish industry. Part I. Sanitation of shellfish growing areas. U. S. Dept. Health, Education and Welfare, Public Health Service, 36 pp.
- Menzel, R.W.
1950 Report on oyster studies in Lake Felicity and Bayou Bas Bleu, Terrebone Parish, Louisiana. Tex. A & M, Res. Fndn. Proj. 9.
- Menzel, R. W.
1951 Early sexual development and growth of the American oyster in Louisiana Waters. Sci. Vol. 113, No. 2947, 719-721.

Needler, Alfreda B.

1934 Crowding and sex reversal in Ostrea virginica. Ann. Rept. Biol. Bd. Can. 1933. p. 30.

Ostergaard, J.M.

1930 Shellfish of Hawaii and the introduction of edible species.
J. Pan-Pac. Rest. Inst. Honolulu, 54: 8-9.

Sparks, A.K.

In Press. Infection of Crassostrea virginica (Gmelin) from Hawaii with a tapeworm, Tylocephalum. J. Insect Pathol.