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OYSTER ABUNDANCE IN APALACHICOLA BAY, FLORIDA IN RELATION TO BIOTIC ASSOCIATIONS INFLUENCED BY SALINITY AND OTHER FACTORS[1]

by

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Abstract

From June 1955 through May 1957, stations on three oyster reefs were sampled quantitatively at intervals and all oysters and associated macroscopic organisms were recorded per unit area. Station I was a privately leased "natural" reef, consisting of higher places exposed at low water, with a salinity range of 22.7-36.6 o/oo and was fairly productive. Station II, depth ca. two meters, was the least saline, range 1.2-29.3 o/oo, and was considered very productive for natural reef. Station III, depth one meter, salinity range 7.5-35.7 o/oo, was depleted although there was an abundant spatfall.

Depth and bottom types as well as salinity were found to delimit certain species of animals. Analysis of past records showed that the bay had formerly been less saline; there was an extended drought in the watershed before and during the investigation. As a result several species of animals less euryhaline than oysters became established on some of the reefs. At Station III, two serious oyster enemies, Thais haemastoma *Say and* Menippe mercenaria *Conrad were abundant. A field experiment at this station during the second year pointed to these two enemies as the main cause of the depletion of the reef. Near the end of the investigation rainfall became more nearly normal and the lowest salinities were recorded at this time. The reduction in salinity, especially at Station III, eliminated many of the less euryhaline species, including drills and stone crabs, and the reef later regained its former productivity.*

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Introduction

Apalachicola Bay, Franklin County, is the center of oyster production in Florida, producing about 85% of the state's crop. Quantitative samples were made of the oysters and associated biota to determine if such sampling would delineate a non-productive oyster reef from a productive one. The presence or absence of certain organisms, especially known oyster enemies, as well as their abundance, was correlated with salinity and other physical factors. Stations were established on non-productive and productive oyster reefs of high and low salinities and shallow and deep water. The study extended from June 1955 through May 1957.

There have been several studies of the oyster reefs in the region of East Bay, Indian Lagoon, St. Vincent Sound, Apalachicola Bay, St. George Sound, which are known collectively as Apalachicola Bay. Ingersoll (1881) mentioned the oyster fishery of the area and later Swift (1897) made an extensive survey of the region. Moore (1897) discussed the organisms collected by Swift. Danglade (1917) studied all the oyster reefs of the region and attempted to determine the density of oysters on several of the producing reefs. Pearse and Wharton (1938), in their study of the oyster "leech", gave considerable information on the biota and hydrography of the region. Ingle and Dawson (1953) made a recent survey of the oyster reefs and have published on the spawning, setting, growth and conditions of the oysters (Ingle, 1951a; Ingle and Dawson, 1950, 1952).

DESCRIPTIONS OF STATIONS AND METHODS

Three stations (described below) were selected for study because they represented different ecological conditions (Figure 1).

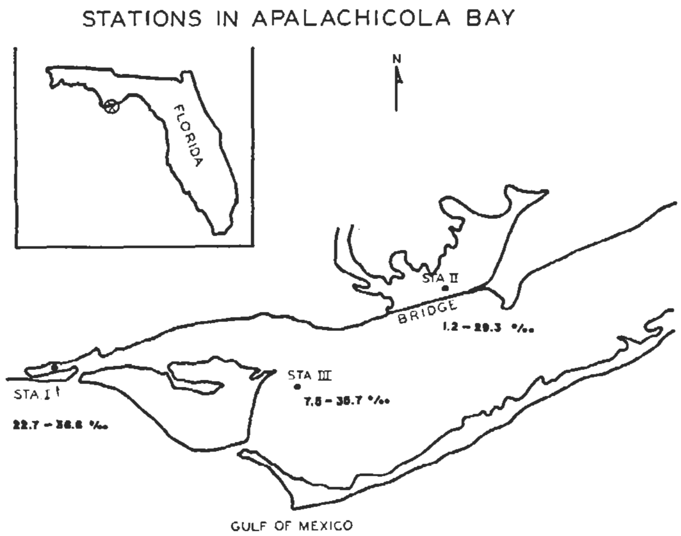

Figure 1. Map of Apalachicola Bay showing locations and bottom salinity ranges of stations.

Station I

Station I was a reef located in the middle of Indian Lagoon on privately leased ground that is harvested sporadically. At mean low water the top of the reef is exposed. The top of the reef is approximately one-half meter higher than the lower edges. The surrounding area has a mud bottom and an average depth of less than one meter at mean low water. The reef is relatively small, about 175 meters long and 20 meters wide in the middle, and tapers gradually at both ends. Bottom salinities during this study ranged from 22.7 o/oo to 36.6 o/oo (Table 1).

Although many single oysters were present, the majority occurred in clusters up to about ten. The oysters were more numerous on the lower edges of the reef than on the higher middle part, which had more shells and smaller oysters and a firmer substrate than the lower edges. Though not large, oysters were thick-shelled, deep-cupped, and rounded.

Station II

Station II was located in polluted water north of Gorrie Bridge where the depth was from 2 to 3 meters. The main reef of oysters is rather narrow and extends about 500 meters northward from the bridge. The bottom is firm on the reef (it was estimated that the shells and oysters were a foot or more thick), but is fairly soft in other areas.

The maximum size of the oysters was greater than at Station I. This reef was opened for commercial exploitation each winter during the investigation, when the pollution cleared. The bottom salinity ranged from 1.2 o/oo to 29.3 o/oo (Table 1).

Station III

Station III was established on St. Vincent Bar. The reef is extensive, and although several small sectors are exposed at low water, most of it is under a meter or more of water. Masses of shell fragments (mainly oyster) cover the reef. The bar is in an exposed position in the bay and is subject to the vagaries of estuarine conditions. The currents are swifter here than at any of the other stations. The general location of the sampling was in a depth of one meter at low tide. The bar is reported to have been productive in former years, and the dense masses of shells support this. During the investigation, however, it produced no market oysters, although spatfall was heavy. The bottom salinity ranged from 7.5 o/oo to 35.7 o/oo (Table 1).

Field Procedures

During the first year of observation (June 1955-May 1956) sampling trips were made to all stations at approximately monthly intervals. During the second year, Station III was sampled at monthly intervals, but Stations I and II only seasonally.

Each station was sampled quantitatively by collecting all the oysters and the associated macroscopic organisms in a measured area. Frames were made with areas of one square meter and one-fourth square meter. In sampling Station I, two transects, ten meters apart, each one meter wide and 20 meters long, were established parallel to the short axis of the reef. Samples were taken from one transect and near (but outside) the

TABLE 1

Monthly bottom salinity reading (o/oo) and surface temperature (°C) at the three stations in Apalachicola Bay

	I		II		III	
Date	o/oo	°C	o/oo	°C	o/oo	°C
1955						
June	36.3	28.5	—	27.5	—	—
July	31.0	33.0	—	29.5	—	—
Aug	29.1	32.0	—	32.1	—	—
Sept	22.9	27.5	—	27.3	28.5	29.5
Oct	29.5	23.0	—	22.9	29.0	23.0
Nov	31.2	23.0	28.6	19.0	18.8	21.0
Dec	29.1	8.1	27.2	10.2	17.3	12.1
1956						
Jan	30.4	13.6	6.6	11.0	22.7	13.7
Feb	23.5	15.0	1.2	14.0	13.7	16.0
Mar	32.9	13.0	7.1	14.1	32.1	14.4
Apr	35.3	19.2	—	—	10.3	19.5
May	36.6	27.1	26.8	23.3	16.2	26.0
June	—	—	29.3	28.0	35.7	29.0
July	—	—	26.5	29.0	34.4	29.0
Aug	32.3	32.9	—	—	27.5	30.0
Sept	—	—	—	—	22.6	28.0
Oct	—	—	—	—	19.7	24.4
Nov	30.7	20.5	—	—	24.3	19.0
1957						
Jan	27.8	16.4	—	—	35.7	14.9
Feb.	—	—	—	—	—	—
Mar	—	—	19.7	17.0	30.6	16.5
Apr	—	—	—	—	10.6	20.0
May	27.0	24.0	—	—	7.5	24.0

other. The second transect was left and treated as a control area. Two one-fourth square meter samples were taken from each edge and two from the middle of the reef. The reef was usually sampled at the low tide when it was either exposed or in very shallow water.

At Station II an attempt was first made to anchor a one-meter square frame to the bottom and to tong all oysters and other organisms within the frame. This was abandoned and SCUBA was used thereafter. After the reef was located, the frame was cast at random from a motor launch. The diver then collected all material by hand from the enclosed area of the frame. Three one-square-meter samples were taken the first year and four one-fourth-square-meter samples were taken the second year at each sampling. At Station III, because of the shallow water SCUBA was not used, but hand collections were made with the aid of a face mask.

Surface water temperatures and bottom salinity samples, were taken and a U.S.C.G. and G.S. hydrometer (Emil Griener and Co.) was used to determine salinity (Table I). On September 7, 1956, surface and bottom samples were taken at 30 minute intervals at Station III, over a 12 hour period.

A field experiment was conducted at Station III during the second period of observation in which an attempt was made to protect oysters from predators. Baskets were constructed of one-half inch mesh hardware cloth and filled with twelve liters of the shelly bottom material, from which all large predators were removed. Twenty-four such baskets were utilized. Two of the baskets were removed for examination concurrently with four one-fourth-square meter bottom samples, during each trip to the station.

One hundred large oysters from Station I and 100 from Station II were transplanted to Station III for mortality studies. These oysters (25 per basket) were placed in baskets similar to those containing the shelly bottom material. These experiments yielded some information but were not completed because the baskets were lost after several months.

Laboratory Procedures

All the samples were analyzed in the laboratory at Florida State University. The oysters were measured to the nearest half-millimeter in length and numbers tabulated in size intervals; Interval "1" - oysters below 10 mm long (not recorded except for Station III); Interval "2" - oysters between 10.0 and 19.5 mm long; . . . ; Interval "14" - oysters between 130.0 and 139.5 mm long. Recent mortality in the various size intervals was estimated by the fouling on the shells. The determination of the species composition of oysters from Station III was made by opening and examining the shells of approximately 100 oysters. The species *Ostrea equestris* Say was abundant at this station along with the commercial oyster *Crassostrea virginica* (Gmelin). A twelve liter sample of culled oysters from Stations I (edges of reef) and II was counted, weighed to the nearest gram in the shell and shucked; the volume of the drained meat was measured to the nearest milliliter.

All of the conspicuous faunal elements were identified and particular attention was given to enemies and possible enemies of oysters. Abundance of each species was estimated during the first year as follows: abundant ("A") - more than 10 per square meter; common ("C") - 4 to 10 per square meter; rare ("R") - 1 to 3 per square meter; present ("P") - no estimate of numbers could be made (e.g., blue crabs, encrusting bryzoans). The number per unit area was determined for some species, mostly during the second year of study. The data have been tabulated as numbers per square meter. Oysters from the several stations were examined for *Dermosystidium marinum* Mackin, Owen and Collier by use of the thioglycolate method.

Although samples were usually taken at monthly intervals, numbers of oysters are given on a seasonal or quarterly basis. The quarters are January-March, April-June, July-September and October-December. Thus the seasonal data will include an average of as many as nine one-square-meter samples for Station II during the first year of observations and as few as four one-fourth-square-meter samples for this station during the second year.

RESULTS AND DISCUSSION

Salinity

The ranges of salinities for the stations are shown in Figure 1 and Table 1. Since these were monthly samples, they can give only a general idea of the hydrographic conditions. The salinity samples taken during the present investigation show wide fluctuations but salinity was generally highest at Station I, slightly less at Station III, and lowest at Station II. This sequence would be expected from the location of the several stations. Previous investigations in the bay have shown rapid and wide fluctuations in salinities, influenced by freshets, tides, currents, and wind direction and velocity (Dawson, 1955a; Ingle and Dawson, 1950, 1953).

The twelve-hour survey at Station III showed that the salinity varied nearly 4 o/oo at the surface and nearly 5 o/oo at the bottom during the period. Concurrent samples taken at the surface and bottom never differed more than 3.4 o/oo; the majority showed top-to-bottom difference of less than 0.5 o/oo. There was little tidal exchange at this date because of a strong easterly wind. Possibly under other conditions, when there would be more in-and-out water movement, the hourly fluctuations as well as the stratification in salinity would be greater. Station III is a shallow water station and stratification was found to be greater in deeper water. Station II, which had the deepest water of all stations (and was also closest to the influence of river runoff), sometimes had top-to-bottom differences of as much as 20 o/oo.

Salinities recorded by previous investigations (Pearse and Wharton, 1938; Ingle and Dawson, 1950; Dawson, 1955a) and those of the present investigation are summarized in Table 2. These data indicate that overall salinity was higher than during the earlier investigations. There had been an extended drought in the watershed of Apalachicola Bay, but beginning in the spring of 1957, precipitation had become more normal, and the lowest salinities during the present study were recorded at this time. The salinity of the area should become more stable due to the construction of the Woodruff Dam on Apalachicola River and the opening of passes to the Gulf through the barrier islands, both of which were completed since the termination of this investigation.

TABLE 2

Comparison of salinities (o/oo) taken in Apalachicola Bay region in 1935-36, 1949-50, 1953-54, and 1955-57.

Investigator		Station I		Station III		Station II	
and Date	Depth	Low	High	Low	High	Low	High
Pearse and	Surface	5.97	32.45	0.00	20.19	0.40	32.46
Wharton	Bottom	5.97	34.41	0.10	28.66	0.60	34.58
1935-36							
Ingle and Dawson 1949-50	Surface	16.1	43.8	—	—	2.6	39.4
Dawson 1953-54	Surface	18.4	37.2	1.2	18.4	4.1	35.1
Present	Surface	—	—	0.0	25.8	7.5	35.1
authors	Bottom	22.7	36.6	1.2	29.3	7.5	35.7
1955-57							

Spatfall

In the following discussion the presence of a large number of oysters in the smaller size intervals is assumed to indicate recent spatfall. *Ostrea equestris,* as well as *Crassostrea virginica,* occurred at Stations I and III (sometimes in equal numbers at Station III) but the discussion and the figures are only of *Crassostrea.*

The heaviest spatfalls at Station I on the edges of the reef occurred during the fall of 1955 and the summer of 1956 (Figure 2). On the middle of the reef the greatest numbers of small oysters were found during the fall in both years (Figure 3).

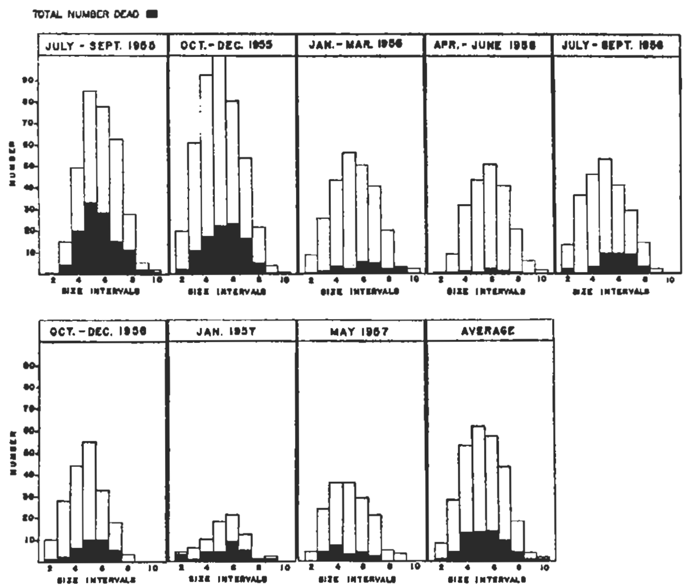

Figure 2. Seasonal average total number of *Crassostrea* and number dead per square meter in each size group during sampling period, STATION I, edge.

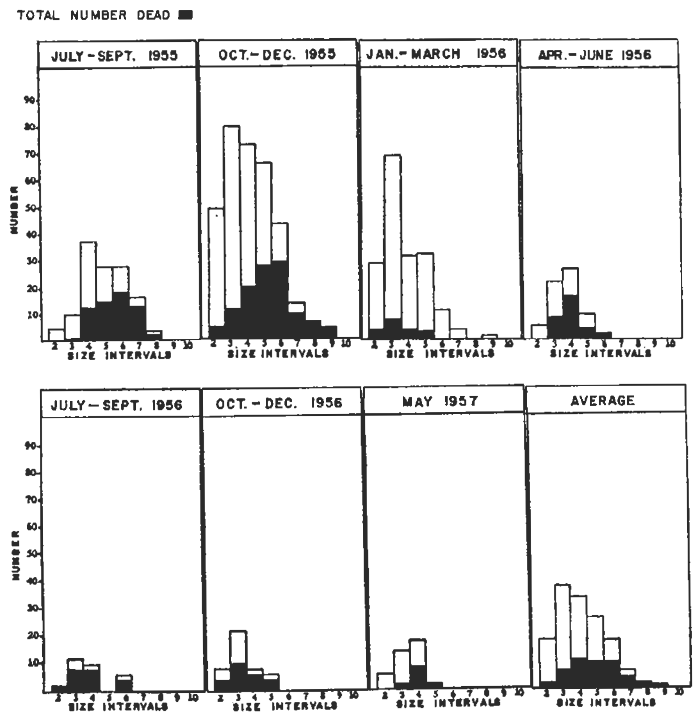

Figure 3. Seasonal average total number of *Crassostrea* and number dead per square meter in each size group during sampling period, STATION I, middle.

Station II never had a heavy spatfall (Figure 4). It is surprising that the oysters in this area maintained such a level of abundance since there was a constant loss from mortality and harvesting. The area has fewer natural enemies than other stations examined and the lack of enemies probably accounts for the sustained production despite the low spatfall. Ingle and Dawson (1953) also found that, generally, the spatfall was lighter on the less saline reefs.

Station III had a heavy spatfall during both years of the investigation. Figure 5 indicates that spatfall on the bottom was greatest in the summer and fall. Spatfall in the baskets (Figure 6) was heavy at all times, but especially in the spring. Monthly data (not shown) indicate heaviest spatfall in late May and June.

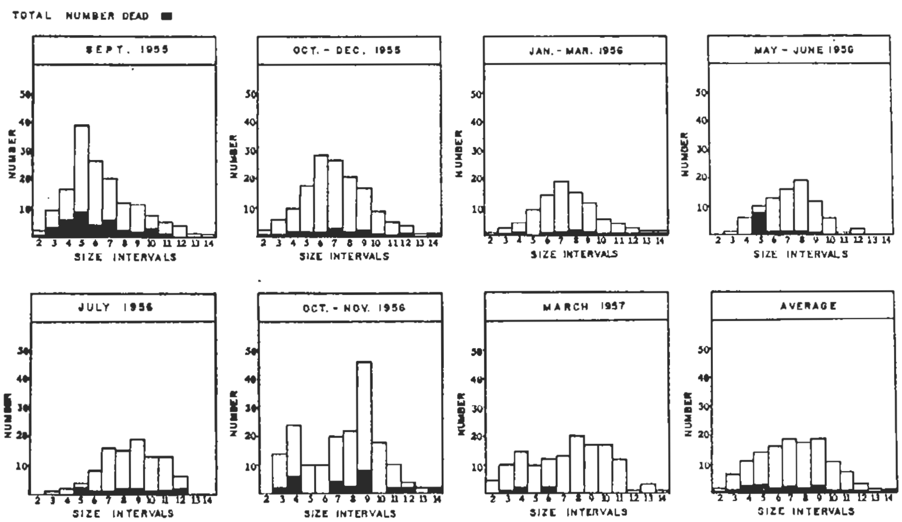

Figure 4. Seasonal average total number of *Crassostrea* and number dead per square meter in each size group during sampling period, STATION II.

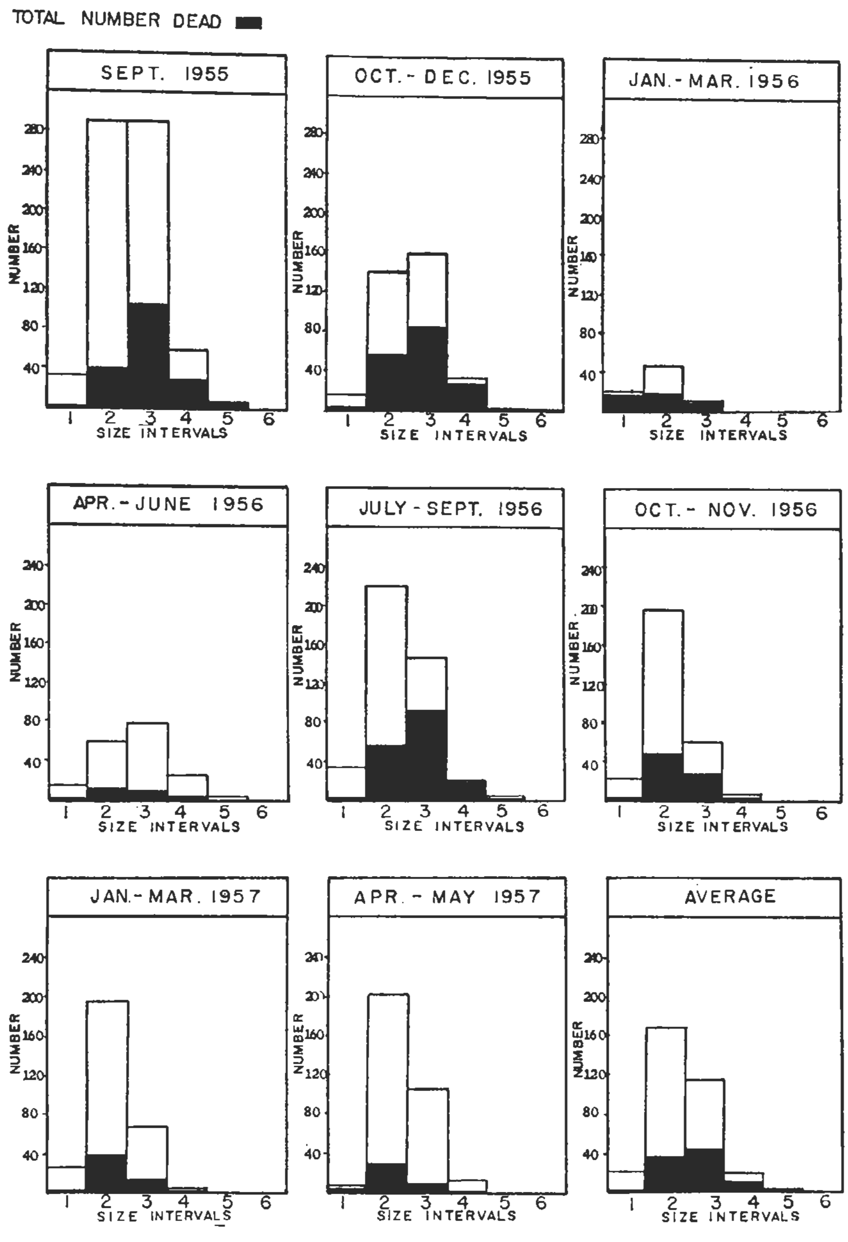

Figure 5. Seasonal average total number of *Crassostrea* and number dead per square meter in each size group during sampling period, STATION III.

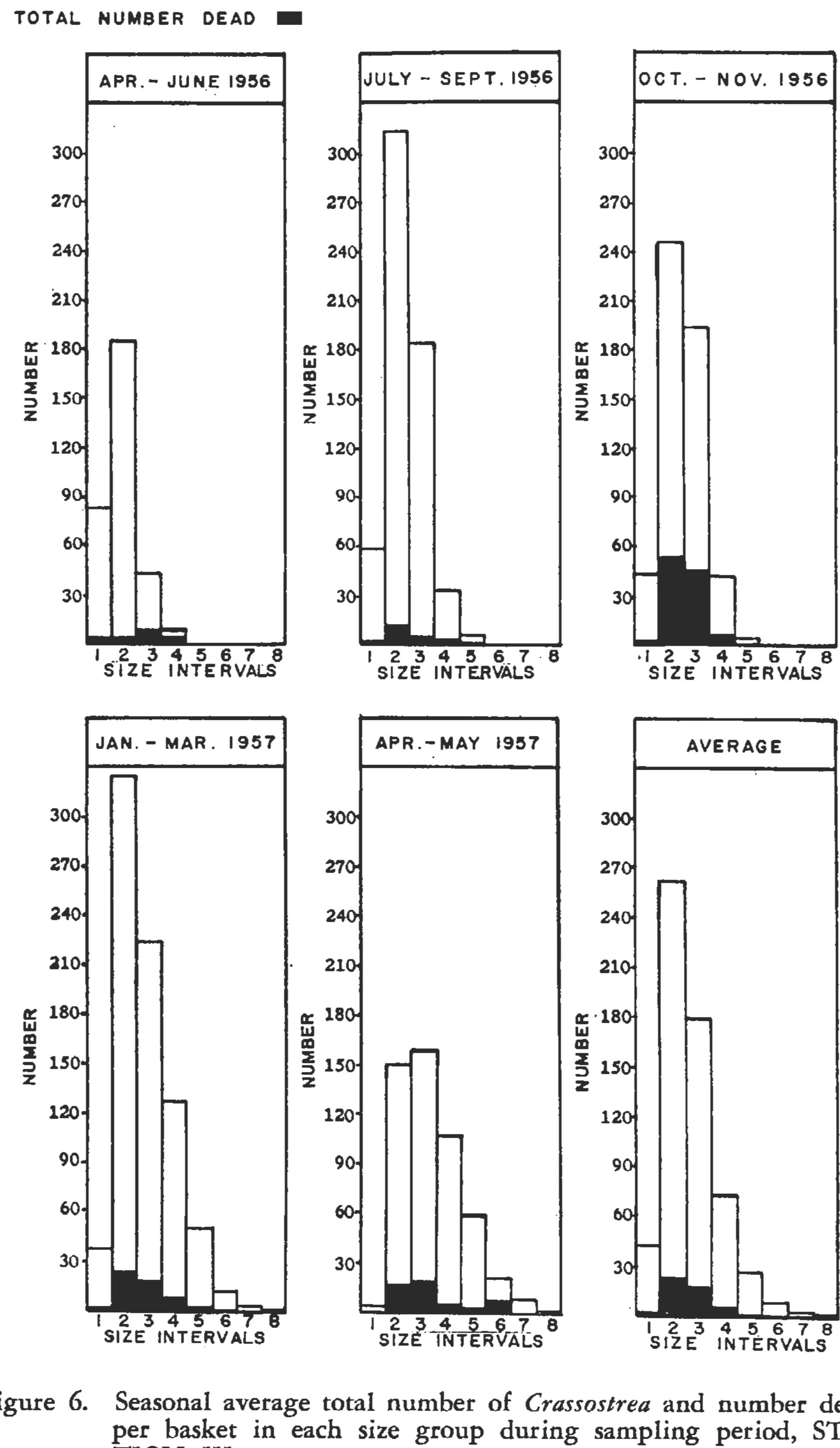

Figure 6. Seasonal average total number of *Crassostrea* and number dead per basket in each size group during sampling period, STATION III.

Mortality

The mortality data, based on a judgment of recent deaths, are very conservative estimates. The difference in growth rates of fouling organisms at various times of the year, the time of separation of the valves of various size oysters and other factors, all make it difficult to determine recent mortality. Gunter, Dawson and Demoran (1956) have discussed problems which apply here in determining oyster mortality.

At Station I the mortality was greater on the middle of the reef than on the edges and was less the first year than the second (Figures 2, 3). Station II had much less mortality than Station I (Figure 4). Mortality was very high at Station III during all periods of the year. The oysters in the baskets had less mortality that those on the bottom (Figures 5, 6).

Mortality was heaviest in summer and fall, especially on the edges of the reef at Station I. The high summer and fall mortality is correlated with the greater activity of predators and incidence of disease during these seasons. A more detailed discussion of the mortality at Station III is given by Menzel, Hulings and Hathaway (1957). On the average the greater proportion of dead oysters at all the stations was found in the larger size groups, but these data are due partly to the method used in determining mortality.

Growth and Size

Oyster growth is very rapid in the Apalachicola Bay area (Ingle and Dawson, 1952). Shell size increases throughout the year. Our data show some evidence of growth in the change in modal length between sampling periods. At some stations, however, the mode remained the same throughout the period because of the mortality and recruitment.

At Station I, few oysters reached 100 mm in length (Figures 2 and 3). The average modal length at the edge of the reef was 40.0-49.5 mm. In the middle of the reef, the modal length was 20.0-29.5 mm.

Samples of oysters collected at Station II showed a progressive increase in length (Figure 4). In September 1955 the mode was at 40.0-49.5 mm, and throughout the year this value increased until July 1956, when a maximum modal length of 80.0-89.5 mm was reached. In the following sampling period (October-November, 1956) a clear bimodal distribution in length was found. It appears, from the length distribution found at the two periods, that a spatfall occurred during the summer. At Station II, number of oyster per square meter, especially larger oysters, decreased during the spring, perhaps because of commercial harvesting as well as mortality.

At Station III, measurements were made of samples from the bottom and from basket culture. No oysters reached a length greater than 50 mm on the bottom and the majority were between 10 and 30 mm long (Figure 5). In samples from the baskets (Figure 6), growth was reflected in increasing numbers of larger oysters during the year, although the modal length remained constant.

Market Oysters

Oyster farming in Apalachicola Bay has not developed commensurately with the potential that exists, despite the abundance of seed oysters and the fast growth. Most of the market oysters are produced from more or less wild stock, despite extensive shell plantings for cultch in certain areas and experimental plantings by the State Board of Conservation to demonstrate the feasibility of oyster culture.

TABLE 3

Weights (gm) in shell and volume (ml) of shucked meat of oysters from a 12-liter sample at Stations I and II

Date	Total No. Oysters I	Total No. Oysters II	Total Weight I	Total Weight II	Meat Volume I	Meat Volume II
1955						
Aug.	120	—	8,530	—	490	—
Sept.	167	100	9,451	8,750	550	420
Oct.	192	142	10,115	7,600	600	675
Nov.	150	77	10,185	7,450	725	510
Dec.	114	—	10,450	—	750	—
1956						
Jan.	111	87	10,200	8,400	750	725
Feb.	113	95	9,560	7,600	750	850
Mar.	108	99	8,800	8,180	650	650
Apr.	131	—	8,590	—	890	—
May	110	126	8,100	8,300	725	550
June	—	116	—	9,550	—	620
July	—	93	—	9,250	—	525
Aug.	108	—	8,175	—	525	—
Nov.	110	88	6,750	8,250	520	675
1957						
Jan.	101	—	9,435	—	950	—
Mar.	—	93	—	9,050	—	690
May	116	—	9,795	—	985	—

TABLE 4

Organisms found at the three stations in Apalachicola Bay, Florida

Organisms	Stations I	II	III
Fungus			
Dermocystidium marinum Mackin, Owen and Collier	X	X	X
Porifera			
Cliona vastifica Hancock	X	O	X
Coelenterata			
Astrangia sp.	O	O	X
Bryozoa			
Membranipora sp.	X	X	X
Platyhelminthes			
Bucephalus cuculus McCrady	X	X	O
Stylochus frontalis Verrill	X	X	X
Annelida			
Neanthus succinea (Frey and Leukart)	X	X	X
Sabella sp.	X	X	O
Polydora websteri Hartman	X	X	X
Arthropoda			
Balanus eburneus Gould	X	X	X
Callinectes sapidus Rathbun	X	X	X
Clibanarius vittatus (Bosc)	O	O	X
Menippe mercenaria Say	X	X	X
Neopanope packardi (Kingsley)	O	O	X
N. texana Stimpson	X	X	X
Panopeus sp.	O	O	X
Petrolisthes armatus (Gibbes)	X	X	X
Synalpheus minus (Say)	X	O	X
Mollusca - Gastropoda			
Anachis obesa (Adams)	O	X	X
Cerithiopsis greeni (Adams)	O	O	X

Crepidula plana Say	X	X	X
Epitonium sp.	O	O	X
Kurtziella sp.	O	O	X
Melongena corona Gmelin	X	O	O
Mitrella lunata (Say)	O	X	X
Odostomia impressa Say	X	X	X
Polinices duplicatus (Say)	O	O	X
Seila adamsi H. C. Lea	O	O	X
Thais haemastoma Conrad	X	O	X
Triphora nigrocincta (Adams)	O	O	X
Mollusca - Pelecypoda			
Abra aequalis Say	O	X	O
Anadara transversa Say	X	X	X
Anomia simplex Orbigny	X	X	X
Brachidontes exustus (L.)	X	O	X
B. recurvus (Rafinesque)	X	X	X
Chione cancellata L.	O	O	X
Crassostrea virginica (Gmelin)	X	X	X
Corbula sp.	O	O	X
Martesia smithi (Tryon)	X	X	X
Mulinia lateralis (Say)	O	X	O
Noetia ponderosa Say	O	O	X
Ostrea equestris Say	X	O	X
Semele bellastriata Conrad	O	O	X
Trachycardium muricatum L.	O	O	X
Fishes			
Hypleurochilus germinatus (Wood)	O	O	X
Hypsoblennius hentz (LeSueur)	O	O	X
H. ianthus (J. and G.)	O	O	X
Opsanus beta (G. and B.)	O	O	X

X — Present

O — Not found

Although the oysters from Station I were of a smaller shell size than those at Station II (Figures 2, 3, 4) they often yielded more meat per unit measure (Table 3). This was especially true during the summer months. Visual inspection at time of shucking showed that the meats from Station I were generally in better condition than those from Station II. The drop in meat yield during the summer and the rise in the period from December through March, is typical of other oysters in the Gulf (Gunter, 1942; Hopkins, Mackin and Menzel, 1953).

A rough estimate can be made of the production of live market oysters for Stations I and II. Figures are calculated from the data of average numbers of live oysters over 70 mm long per square meter and the numbers of oysters of this size needed to fill a 12 liter container. These data may be converted to bushels per acre. For Station I, only the west and east edges of the reef are used, and at this station the estimate was about 225 bushels of live market oysters per acre during the period of the investigation. At Station II, the yield was estimated to be an average of 715 bushels per acre during the period. At times, especially in November 1955 and 1956, before the reef was opened for commercial exploitation, the yield would have been twice as high.

The yield from Station I, though not exceptional, was fairly good, especially when the ease of harvesting from a very shallow reef is taken into consideration. The yield from Station II is considered exceptional for a natural oyster bed, since this reef was subject to intensive harvesting each year. When the reef was open, the oystermen concentrated their efforts in this area. Despite the restricted season (because of pollution) the harvesting of oysters from this area was probably as complete as from other areas that were open for tonging throughout the season. After several weeks many tongers left the area of Station II and returned to areas that had formerly been less productive, but were now comparatively more so.

Association of Organisms on Oyster Reefs

Apalachicola Bay is usually very turbid and probably for this reason macroscopic algae are not conspicuous. Species of green algae were seen on several occasions during the winter months at Station III when the water was less turbid, but no records were kept. Only animals are discussed here, except for the pathogenic fungus *Dermocystidium marinum.*

The organisms found and the stations where they occurred are in Table 4. Table 5 gives quantitative data on selected animals. The discussion that follows is mainly of the oyster enemies.

The pathogenic fungus *Dermocystidium marinum* occurs in Apalachicola Bay (Dawson 1955b) and was found at all the stations during the present investigation. The mortality of the larger oysters at the stations during the summer months suggested *Dermocystidium marinum* disease (Mackin 1951a, 1952; Ray, 1954). In the survivors of one of the growth baskets at Station III, infection ranged from none to heavy (Menzel, Hulings and Hathaway, 1957).

The boring sponge *Cliona vastifera* was present at all stations in the shells of older oysters and in dead shells. This was the only species of *Cliona* found in the bay.

TABLE 5

Occurrence of several animals at the three stations in Apalachicola Bay estimated during period, August 1955-May 1956; numbers given per square meter during period, June 1956-May 1957.

Date	*Neopanope texana*			*Petrolisthes armatus*			*Anachis obesa*			*Brachidontes exustus*			*Brachidontes recurvus*			*Crepidula plana*			*Odostomia impressa*		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Aug. 1955	A	C	—	R	R	—	O	C	—	A	O	—	R	A	—	A	A	—	C	C	A
Sept. 1955	A	C	A	C	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	C	A
Oct 1955	A	C	A	R	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	C	A
Nov. 1955	A	C	A	R	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	C	A
Dec. 1955	A	C	A	R	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	A	A
Jan. 1956	A	C	A	R	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	A	A
Feb. 1956	A	C	A	C	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	A	A
Mar. 1956	A	C	A	C	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	A	A
Apr. 1956	A	C	A	R	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	A	A
May 1956	A	C	A	R	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	A	A
Average	A	C	A	R+	R	A	O	C	C	A	O	A	R	A	R	A	A	A	C	A-	A
June 1956	—	7	62	—	1	12	—	6	5	—	0	—	—	42	1	—	35	A	—	73	84
July 1956	—	3	80	—	0	43	—	0	1	—	0	A	—	136	3	—	41	A	—	44	33
Aug. 1956	35	—	20	12	—	40	0	—	11	23	—	A	3	—	0	A	—	A	8	—	75
Sept. 1956	—	—	100	—	—	52	—	—	16	—	—	168	—	—	4	—	—	40	—	—	83
Oct 1956	—	—	59	—	—	5	—	—	16	—	—	26	—	—	0	—	—	11	—	—	96
Nov. 1956	13	1	106	5	1	4	0	2	60	—	0	16	—	16	6	20	16	6	6	111	21
Jan. 1957	18	—	80	11	—	4	0	—	56	32	—	130	3	—	0	48	—	40	68	—	98
Feb. 1957	—	—	64	—	—	2	—	—	48	16	—	48	—	—	0	—	—	52	—	—	86
Mar. 1957	—	9	15	—	0	4	—	3	28	—	0	A	—	12	7	—	12	78	—	36	62
Apr. 1957	—	—	90	—	—	1	—	—	13	—	—	208	—	—	0	—	—	34	—	—	52
May 1957	29	—	42	0	—	0	0	—	8	35	—	42	1	—	0	55	—	10	10	—	25
Average	23.8	5.0	65.3	7.0	0.5	15.2	0.0	2.8	23.8	26.5	0.0	91.1	1.8	51.5	1.9	41.0	26.0	33.9	23.0	66.0	65.0

The flatworm *Stylochus frontalis,* sometimes called the oyster wafer or leech (=*S. inimicus, vide* Hyman, 1940), was the subject of an extensive study by Pearse and Wharton (1938). They found that damage to oysters may be considerable when the worms occur in large concentrations, but concluded that they never cause extermination of the population in a particular locality. The worm was found in concentrations up to 50 per square meter at Station III on several occasions. The worms were also found at other stations and hence salinity was not a limiting factor in their distribution in the areas under study. The oyster mortality rate did not reflect their presence or absence.

The cercariae of *Bucephalus cuculus* were found at all stations (Table 4). The highest percentage of infection was at Station I. In one sample 20% (20 oysters examined) were infected. Although Hopkins (1956a) has stated that heavy infections effectively castrate oysters and probably cause death, the worm was never found in epidemic numbers in Apalachicola Bay and the overall effect was probably of minor importance.

Several investigators have found that mudworms, *Polydora websteri,* damage oysters (Lunz, 1940, 1941; Mackin and Cauthron, 1952; see also Owen, 1957). Mudworms were fairly abundant at all stations, with the largest numbers at Station II, with as many as 20 *Polydora* blisters per oyster, covering an estimated 50% of the inside surfaces. The infestations found during the present study were not so severe as commonly found by investigators in South Carolina and Louisiana. It is concluded that mudworms did not cause oyster mortality directly.

Stone crabs, *Menippe mercenaria,* are serious predators of oysters (Menzel and Hopkins, 1955). No detailed analysis was made of all the dead oysters, but broken shells, indicative of stone crab predation, were seen at all localities. No satisfactory quantitative sampling method was devised for this burrowing crab, but it is estimated that up to one large crab (carapace over 75 mm wide) was present per square meter at Stations I and III. Sometimes up to a dozen small crabs (carapace under 50 mm wide) were found per square meter at these stations. Up to five small stone crabs (carapace les sthan 20 mm wide) were found in the two baskets examined monthly at Station III. Stone crabs were recorded from Station II up to the January 1956 examination, but were never found after this date. They disappeared after the first recorded salinity drop, even though higher salinities were recorded subsequently in May, June, and July, 1956. This is an indication that stone crabs are not tolerant of low salinities. Past observations by the senior author in Louisiana indicated that the stone crab is limited by salinities below 12-15 o/oo. Stone crabs were probably one of the main enemies of oysters, especially at Station III.

Blue crabs, *Callinectes sapidus,* were usually abundant, except in the coldest months, even though actual numbers were not recorded because of the sampling method. Lunz (1947) found blue crabs to be important oyster predators in pond culture in South Carolina. Menzel and Hopkins (1955) and Menzel and Nichy (1958) showed that they destroy small oysters and sometimes larger ones. Menzel and Nichy found that blue crabs destroyed oyster on intertidal reefs when the oysters were weakened by high temperatures. Blue crabs were probably a factor in the mortality observed in this investigation, especially on the middle of the reef at Station I.

The snail *Odostomia impressa* was present at all stations and was especially common at Stations II and III (high and low salinity stations). Salinity evidently was not a limiting factor in the area under study. Hopkins (1956b) found that *O. impressa* feeds on large oysters and Allen (1958) mentions oysters, other mollusks, worms, and ascidians as food. No detailed examinations were made of the damage caused by the gastropod and it was not possible to relate the oyster mortality to the abundance of the snail.

The crown conch *Melongena corona* at times was a conspicuous element on the oyster reef at Station I and has been observed with the proboscis inserted into oysters. Gunter and Menzel (1957) first recorded the crown conch as an oyster predator. Hathaway (1957) and Menzel and Nichy (1958) concluded, however, that it is an oyster enemy of minor importance in this area. This gastropod has been discussed more recently by Hathaway and Woodburn (1961).

The boring clam *Martesia smithi* does not feed on the oyster, but uses the shell as a habitat as do boring sponges and mudworms. Boring clams were most abundant at Station II in larger oysters. No correlation could be made with mortality or the condition of the oysters, although a more thorough investigation might reveal such association.

The southern oyster drill *Thais haemastoma* has been called the most serious oyster enemy in the Gulf of Mexico region (Butler, 1954). Mackin (1951b) states that where the drill occurs in abundance, along with the fungus parasite, *Dermocystidium marinum,* the drill probably causes a higher proportion of the oyster mortality. The drill was abundant at Station III (Figure 7), but was found at no other station except for one drill at Station I. The importance of the drill as an oyster enemy at Station III has been discussed by Menzel, Hulings and Hathaway (1957). The basket experiments at this station pointed strongly to predation as the cause of depletion of this reef.

At Station III there were numerous *Thais* egg cases during the season of 1956, but none was found in the spring of 1957. Even more noteworthy is the fact that no small snails were collected in any of the samples. It appears from the sizes and the fouled and eroded appearance of the shells that all the snails were more than one year old. Growth rate of drills in this particular area is unknown. Ingle (1951b) found that drills increased 12.2 mm in height in 82 days at Coral Gables, Florida. Butler (1953) found that they can reach a height of 55 mm in five months after hatching; however, he found that some six-month-old drills were larger than those that were thirty-six months old. This would imply that some three-year-old drills are under 60 mm. The maximum age attained by the drill is not known. In the present study the average size as well as the ranges in size were about the same for the first year's observations as for the second (Figure 7). The most likely explanation is that the drills on the reef were adult and were growing only slowly.

It is evident from the lack of small drills that there was no recruitment from the surrounding population during the two years of the study. The reef was re-sampled on October 8, 1957, when the bottom salinity measured 8.5 o/oo, and a search of several square meters revealed one live drill buried under several centimeters of shells. This was an adult snail (ca. 60 mm in height) and the operculum was tightly closed.

It is probable that a population of snails became established on

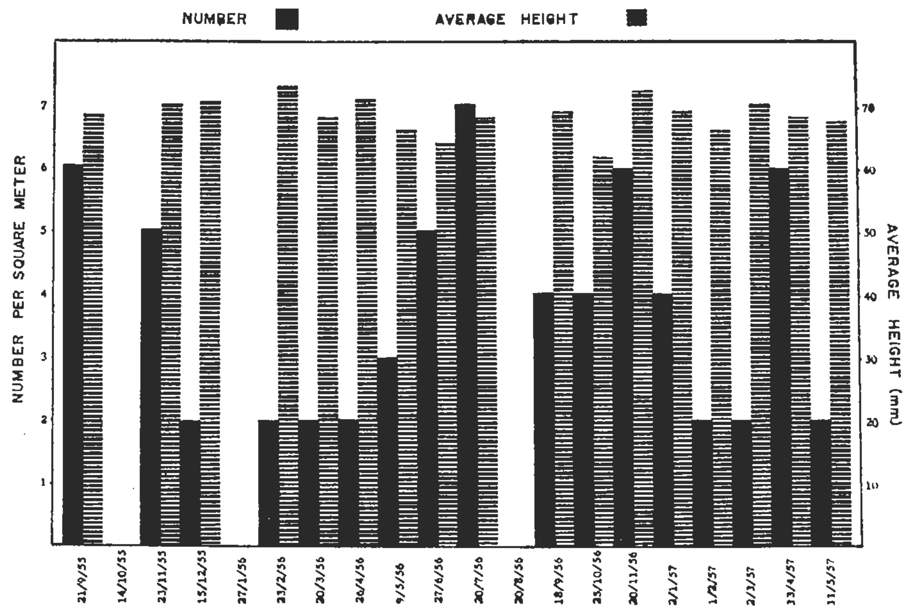

Figure 7. Numbers and average heights (mm) of *Thais haemastoma* per square meter during sampling period. Range in size from 52 to 84 mm.

this station when the salinity was favorable for them. Adult snails probably survived the occasional lowering of salinity by closing the opercula. Butler (1953) found the snail to be limited by an average salinity below 15 o/oo.

In addition many of the sessile animals that occur on an oyster reef probably have an adverse effect on oysters, especially in competition for food and space. For example, Engle and Chapman (1951) found that heavy attachment of mussels adversely affected the conditions of oysters.

At the two high salinity stations, the oyster *Ostrea equestris* occurred. This species was often very abundant at Station III, sometimes making up half of the numbers of oysters. It was found in small numbers on the extreme lower edges of the reef at Station I. Menzel (1955) has shown that *O. equestris* is stenohaline and also that it is subtidal. It is noteworthy that *O. equestris* had disappeared entirely from Station III on the May 11, 1957 examination, nor were any found when the reef was re-sampled in October 1957.

The two species of hooked mussels (*Brachidontes exustus* and *B. recurvus*) are fairly good salinity indicators. *B. exustus* is confined to fairly high salinity, *B. recurvus* is more euryhaline (although it was less abundant at Station III than at Station II, Table 5). The mud crab, *Neopanope texana,* was more abundant at the higher salinity stations and the same was true for the flat crab, *Petrolisthes armatus* (Table 5).

Some of the animals seemed to be limited more by other factors, such as bottom types and depth of water, than by salinity. *Anachis obesa* was more abundant at Station III than II, but it did not occur at Station I, perhaps because of the mud bottom, or the water depth, or both (Table 5). *Mulinia lateralis* was the only animal recorded exclusively from Station II, but its absence from other stations was probably due to factors other than salinity, since Simmons (1957) found this species in the Laguna Madre, Texas where the salinity is greater than normal oceanic waters.

Gunter (1955) has shown that in Texas waters the mortality of oysters increases over a rising salinity gradient from the inner bays towards the sea. Our own studies show that oyster mortality at a given station increases as the salinity rises following dry weather conditions. Both studies lead to the conclusion that the euryhaline Virginia oyster is strongly affected by salinity changes, indirectly through salinity influences on its predators and parasites. Grave (1905) has previously noted that oysters are subject to greater predation and parasitism at higher salinities.

Special Study of Station III

The reef at Station III formerly produced market oysters, but it had become depleted in the five years or so before the present investigation. A detailed report has been given by Menzel, Hulings and Hathaway (1957) of this station. Previous data on hydrographic conditions in the bay indicate generally lower salinities in the past than were found in this study (Table 2). The probable cause of the depletion of oysters at Station III was predation by animals with higher salinity requirements than oysters, notably stone crabs and drills. There was abundant spatfall. Some oysters, which were protected from large predators, reached a length of over 70 mm by the early spring of 1957 in contrast to unprotected oysters that were never larger than 50 mm in length (Figures 5, 6).

Station III was re-sampled on October 8, 1957. At this time one basket was recovered which had been left from the experiment begun in May 1956. In addition a random bottom sample of 24 liters was taken. The maximum size of the oysters found on the bottom and in the basket was no greater than it had been the previous spring. Rainfall had been continuous and rather heavy during the summer of 1957 and the salinity had undoubtedly remained low. The absence of *Ostrea equestris* and the presence of only one live *Thais haemastoma* with tightly closed operculum (12 dead shells found) corroborate the above statement. The salinity at the time of sampling in October 1957 was 8.5 o/oo.

From the evidence, predation during the summer period of 1957 may be largely discounted. The oysters should have reached larger sizes during this period than they had attained the previous spring. Because of growth, this reef should have supported a commercial fishery by the winter of 1957-58. It was predicted by Menzel, Hulings and Hathaway (1957), that with a return to normal rainfall, that the reef would become productive. St. Vincent Reef did become productive again, but no oysters of commercial size were obtained until the fall of 1958, one year later than expected.

SUMMARY

1. A study was made of three oyster reefs of differing ecological conditions in Apalachicola Bay area during the period from June 1955 through May 1957. Periodic quantitative samples of oysters and associated macroscopic organisms were taken, with particular emphasis on known oyster enemies.

2. Samples were taken at approximately monthly intervals during the first year at all stations and during the second year, one station (subtidal with high salinity) was sampled monthly and the other two seasonally.

3. During the second year some oysters were protected from two of the known enemies, drills and stone crabs, by wire baskets at the station (III) with high salinity that was sampled monthly. The protected oysters showed less mortality and reached a greater size than the unprotected oysters at this station.

4. The numbers sizes and mortality of oysters and of the associated animals differed from station to station and could be correlated with salinity, the past salinity regime, type of bottom and depth of water.

5. Salinity seemed to be the most important limiting factor on the oyster populations, but the strongest influence is indirect in that low salinity precludes the presence of important predators. The overall salinity increased shortly before the present study, correlated with an extended drought, and allowed certain oyster enemies less resistant than oysters to euryhaline conditions to become established on reefs. The depletion of a formerly productive reef occurred when the enemies became established. With increased rainfall and lowered salinities, the reef regained its former productivity.

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